Principles of Electronics

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Course Code: EIE219

UNIT - I **10 Periods**

Basics of Semiconductors: Energy band theory, Fermi levels - Conductors, Semiconductors & Insulators: electrical properties, band diagrams. Semiconductors: intrinsic & extrinsic (P&N-type), Energy band diagram, drift & diffusion currents.

Diodes and Diode Circuits: Formation of P-N junction, energy band diagram, built-in-potential, forward and reverse biased P-N junction, V-I characteristics, Zener Diode & its Characteristics. Rectifier circuits: half wave, full wave, Peak Inverse Voltage, DC voltage and current, ripple factor, efficiency, idea of regulation.

UNIT - II **12 Periods**

Bipolar Junction Transistors: Formation of PNP / NPN junctions, Working principle of CE, CB, CC configuration, transistor characteristics: cut-off, active and saturation mode, transistor action and current amplification factors for CB and CE modes. Biasing: Fixed, Emitter feedback and Voltage divider bias.

Field Effect Transistors: Concept of Field Effect Transistors (channel width modulation), JFET Structure and characteristics, MOSFET Structure and characteristics, depletion and enhancement type - CS, CG, CD configurations - CMOS: Basic Principles

UNIT - III **11 Periods**

Feed Back Concepts: Concept (Block diagram), positive and negative feedback, loop gain, open loop gain, feedback factors.

Operational Amplifiers: Introduction to integrated circuits, operational amplifier and its ideal characteristics - Application of operational amplifier - inverting and non-inverting mode of operation, Adders, Subtractors, Constant-gain multiplier, Voltage follower, Comparator, Integrator, Differentiator.

UNIT - IV **12 Periods**

Digital Electronics Fundamentals: Difference between analog and digital signals, Boolean algebra, Basic and Universal Gates, Symbols, Truth tables, logic expressions, Logic simplification using K- map.

Implementation of Digital Circuits: Half and full adder / subtractor, Basics of multiplexers, demultiplexers and flip-flops.

TEXTBOOKS

- M. Morris Mano and Michael D. Ciletti. *Digital Design: With an Introduction to the Verilog HDL, VHDL and System Verilog*, Pearson education, Sixth Edition, 2018.
- Jacob Millman, Christos C. Halkias, Satyabrata Jit, *Electronic Devices and Circuits*, McGraw Hill Education, Fourth Edition, 2015.
- Robert L. Boylestad and Lousis Nashelsky. *Electronic Devices and Circuit Theory*, Pearson Education, Eleventh Edition, 2015.
- Mehta, V.K. & Rohith Mehta. Principles of Electronics. 3rd Edition, S Chand and Company. 2005.

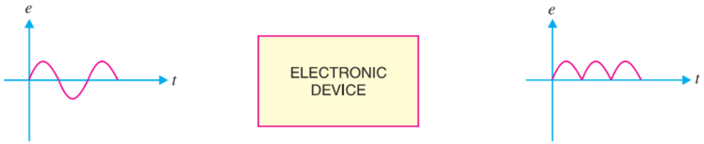
Principles of Electronics Lab

LIST OF EXPERIMENTS

1. Analyse V-I characteristics of PN junction diode
2. Analyse V-I characteristics of Zener diode
3. Design of half-wave and full-wave rectifier circuit using PN junction diode
4. Analysis of BJT characteristics in CE configuration
5. Voltage divider biasing of BJT
6. Analysis of drain and transfer characteristics of FET
7. Design of adder and subtractor using operational amplifiers
8. Design of integrator and differentiator using operational amplifiers
9. Implementation of Boolean expressions using combinational logic circuit
10. Implementation of half and full adder using logic gates
11. Implementation of half and full subtractor using logic gates
12. Construct and check using universal gates the operations of various flip flops

Introduction

- *Electronics* The branch of engineering which deals with current conduction through a vacuum or gas or semiconductor is known as electronics.
- The electronic devices are capable of performing the following functions :
  - Rectification.



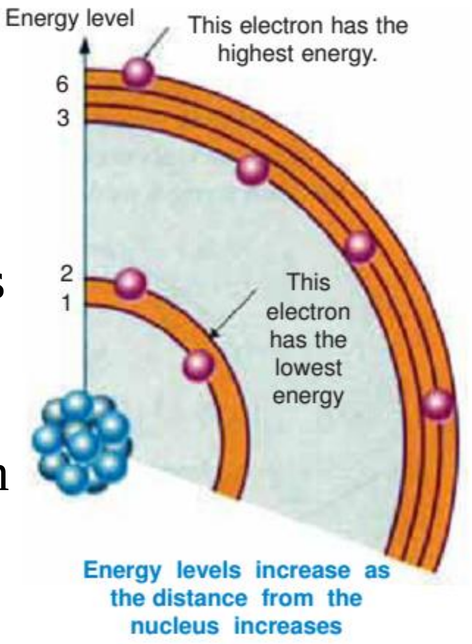
  - Amplification
  - Control.
  - Generation.
  - Conversion of light into electricity.
  - Conversion of electricity into light.

Atomic Structure

- All the materials are composed of very small particles called atoms.
- *Nucleus*. It is the central part of an atom and contains protons and neutrons.
  - atomic weight = no. of protons + no. of neutrons
- *Extra nucleus*. It is the outer part of an atom and contains electrons only.
  - atomic number = no. of protons or electrons in an atom
- The number of electrons in any orbit is given by $2n^2$ where n is the number of the orbit.
- Structure of Elements. The difference between various types of elements is due to the different number and arrangement of these particles within their atoms.

- The Electron
  - Charge on an electron, $e = 1.602 \times 10^{-19}$ coulomb
  - Mass of an electron, $m = 9.0 \times 10^{-31}$ kg
  - Radius of an electron, $r = 1.9 \times 10^{-15}$ metre

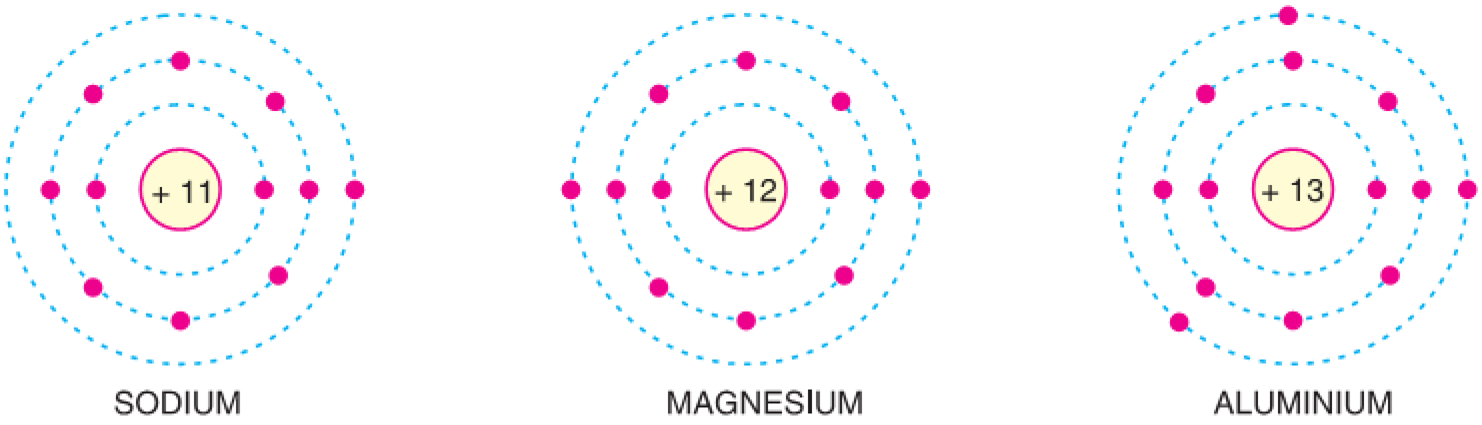
- Energy of an Electron
  - An electron moving around the nucleus possesses two types of energies viz. kinetic energy due to its motion and potential energy due to the charge on the nucleus.
  - These last orbit electrons play an important role in determining the physical, chemical and electrical properties of a material.

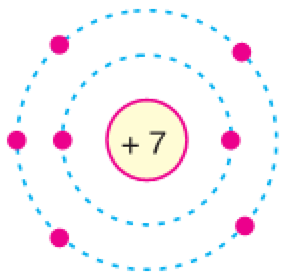


- Valence Electrons
  - The electrons in the outermost orbit of an atom are known as valence electrons.

Valence Electrons

- On the basis of electrical conductivity, materials are generally classified into conductors, insulators and semi-conductors.
- When the number of valence electrons of an atom is less than 4 (i.e. half of the maximum eight electrons), the material is usually a metal and a conductor.
- When the number of valence electrons of an atom is more than 4, the material is usually a non-metal and an insulator. Examples are nitrogen, sulphur and neon which have 5, 6 and 8 valence electrons respectively.
- When the number of valence electrons of an atom is 4 (i.e. exactly one-half of the maximum 8 electrons), the material has both metal and non-metal properties and is usually a semiconductor. Examples are carbon, silicon and germanium





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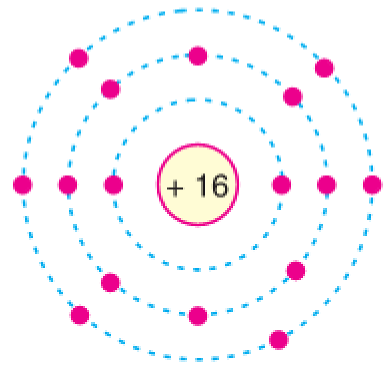
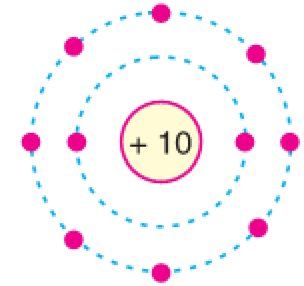
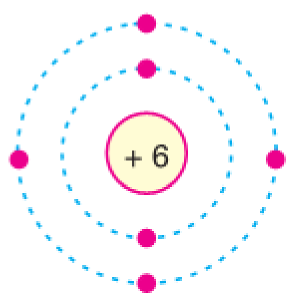


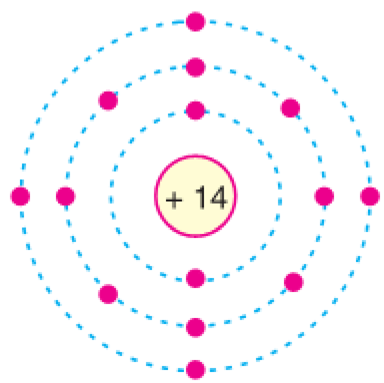
SULPHUR



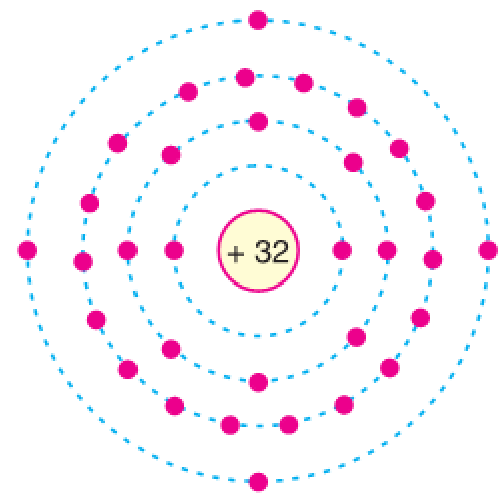
NEON



CARBON



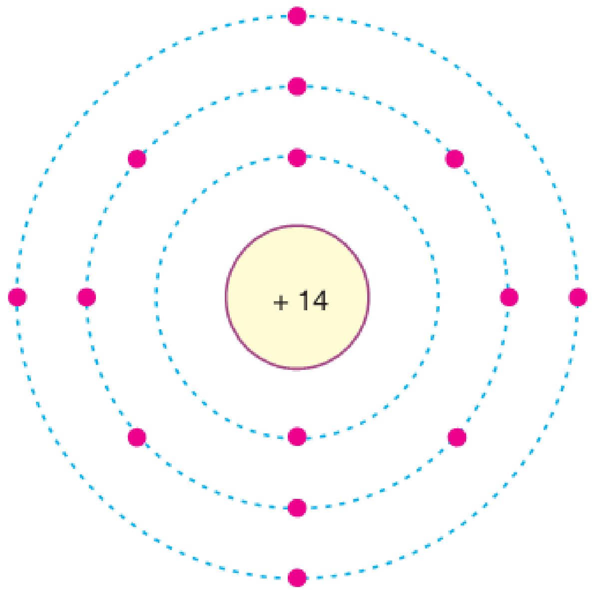
SILICON

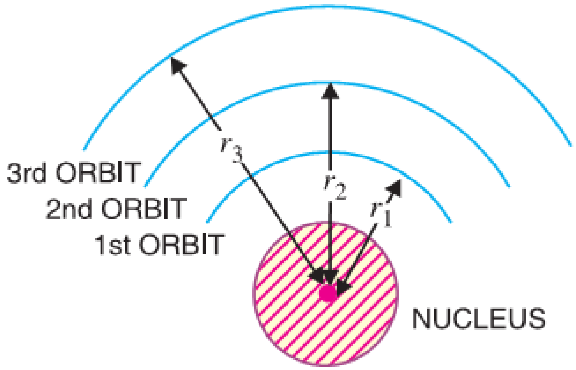


GERMANIUM

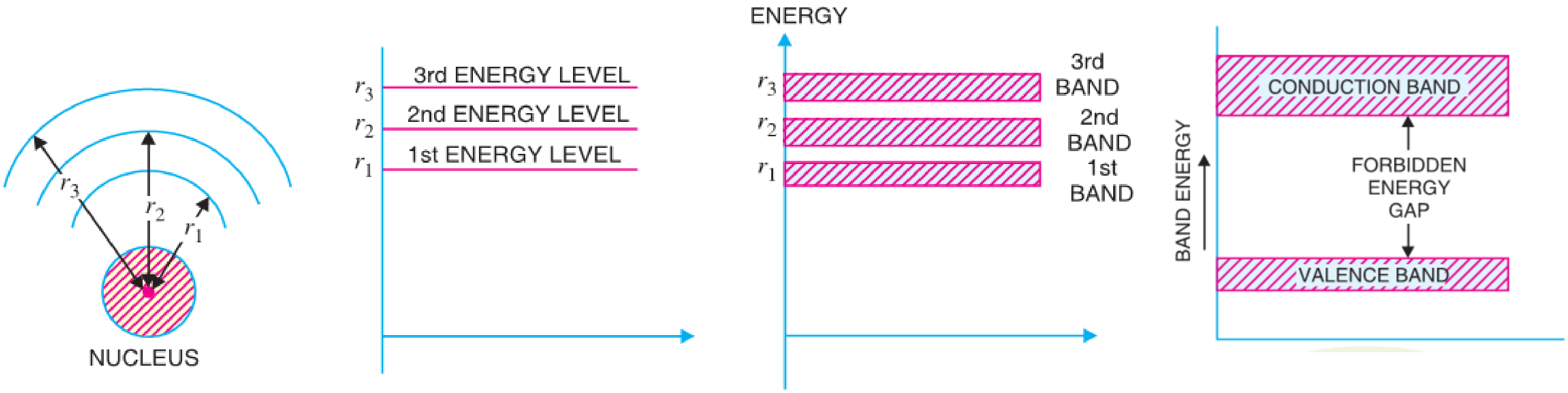
Bohr's Atomic Model

- An atom consists of a positively charged nucleus around which negatively charged electrons revolve in different *circular orbits*.
- The electrons can revolve around the nucleus only in certain permitted orbits i.e. orbits of certain radii are allowed.
- The electrons in each permitted orbit have a certain fixed amount of energy. The larger the orbit (i.e. larger radius), the greater is the energy of electrons.
- If an electron is given additional energy (e.g. heat, light etc.), it is lifted to the higher orbit. The atom is said to be in a state of excitation.



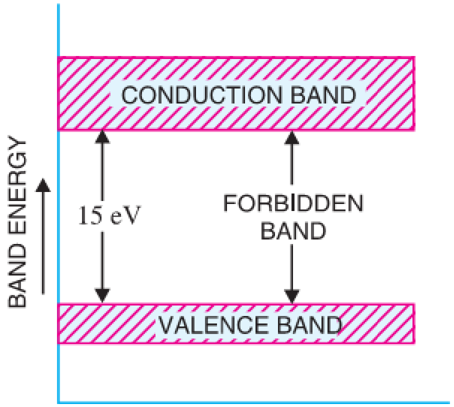


- Energy Levels and Band
  - A convenient way of representing the energy of electron in different orbits called energy level. The range of energies possessed by an electron in a solid is known as energy band.

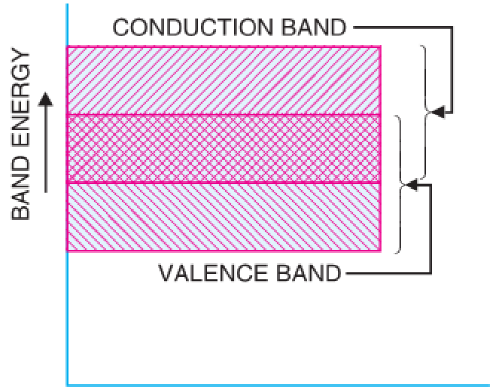


- **Valence band.** The range of energies (i.e. band) possessed by valence electrons is known as valence band.
- **Conduction band.** The range of energies (i.e. band) possessed by conduction band electrons is known as conduction band.
- **Forbidden energy gap.** The separation between conduction band and valence band on the energy level diagram is known as forbidden energy gap.

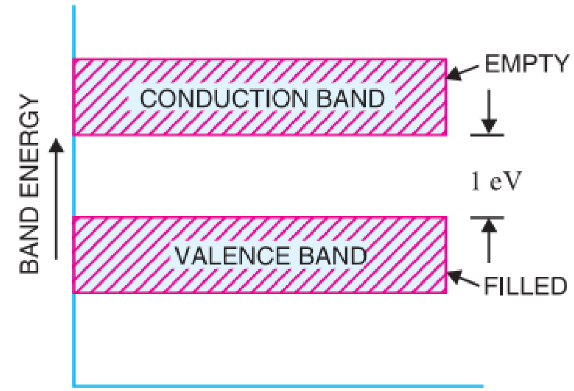
- **Classification of Solids and Energy Bands**



Insulator



Conductor



Semiconductor

- **Insulators.** Insulators (e.g. wood, glass etc.) are those substances which do not allow the passage of electric current through them. In terms of energy band, the valence band is full while the conduction band is empty. Further, the energy gap between valence and conduction bands is very large (≈ 15 eV).
- **Conductors.** Conductors (e.g. copper, aluminium) are those substances which easily allow the passage of electric current through them. It is because there are a large number of free electrons available in a conductor.

Semicondutors.

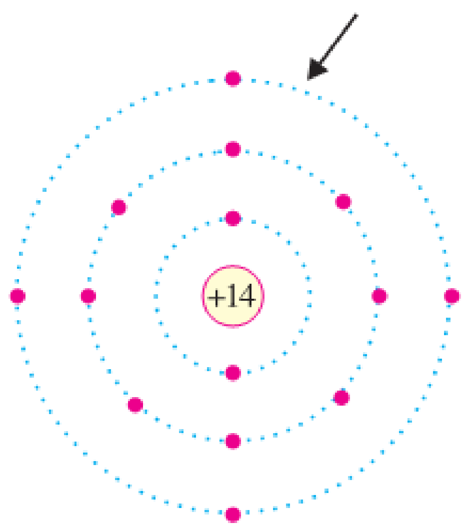
- Semiconductors (e.g. germanium, silicon etc.) are those substances whose electrical conductivity lies in between conductors and insulators. In terms of energy band, the valence band is almost filled and conduction band is almost empty.

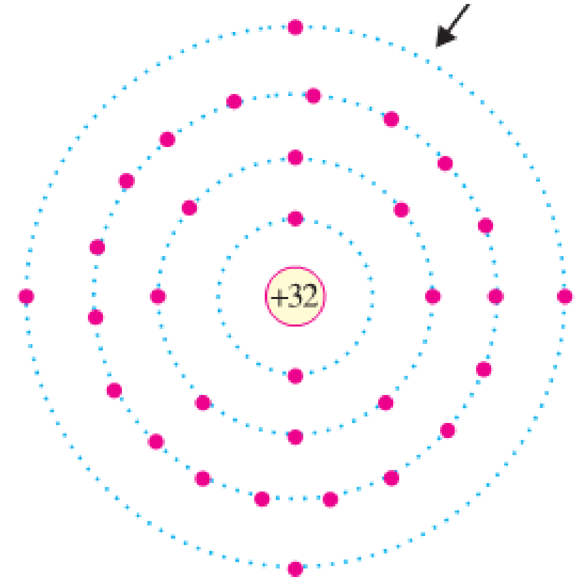
Properties of Semiconductors

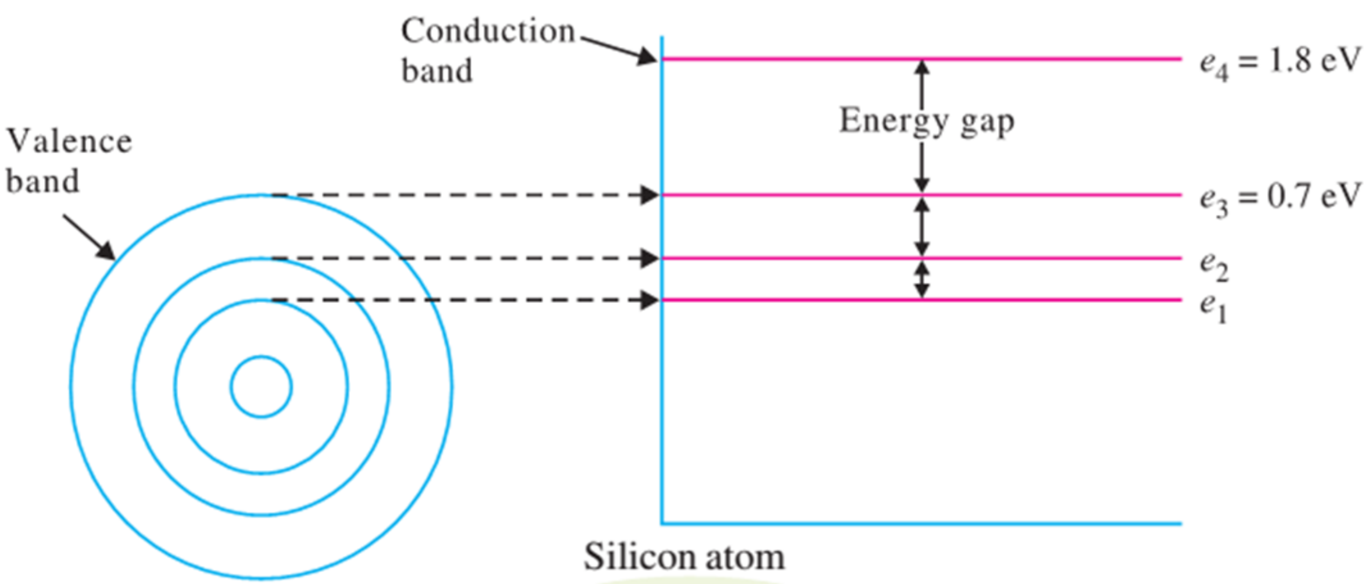
- The resistivity of a semiconductor is less than an insulator but more than a conductor.
- Semiconductors have *negative temperature co-efficient of resistance* i.e. the resistance of a semiconductor decreases with the increase in temperature and vice-versa.
- (iii) When a suitable metallic impurity (e.g. arsenic, gallium etc.) is added to a semiconductor, its current conducting properties change appreciably. This property is most important
- The germanium valence electrons are at higher energy level than those in silicon. Hence, germanium is more unstable at high temperatures. This is the basic reason why silicon is widely used as semiconductor material.

S.No.	Substance	Nature	Resistivity
1	Copper	good conductor	$1.7 \times 10^{-8}\ \Omega\ m$
2	Germanium	semiconductor	$0.6\ \Omega\ m$
3	Glass	insulator	$9 \times 10^{11}\ \Omega\ m$
4	Nichrome	resistance material	$10^{-4}\ \Omega\ m$

- It is interesting to note that it is not the resistivity alone that decides whether a substance is semiconductor or not. For example, it is just possible to prepare an alloy whose resistivity falls within the range of semiconductors but the alloy cannot be regarded as a semiconductor. In fact, semiconductors have a number of peculiar properties which distinguish them from conductors, insulators and resistance materials.



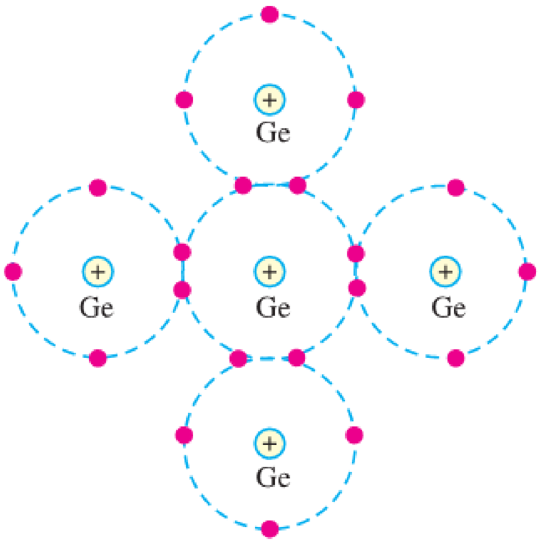




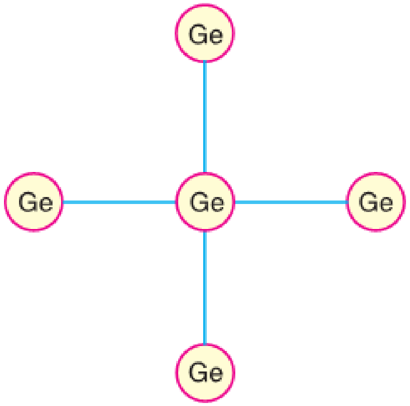
Silicon atom

Bonds in Semiconductors

- The atoms of every element are held together by the bonding action of valence electrons.
- In most of the substances, the last orbit is incomplete i.e. the last orbit does not have 8 electrons. This makes the atom active to enter into bargain with other atoms to acquire 8 electrons in the last orbit.
- In semiconductors, bonds are formed by sharing of valence electrons. Such bonds are called *co-valent* bonds.



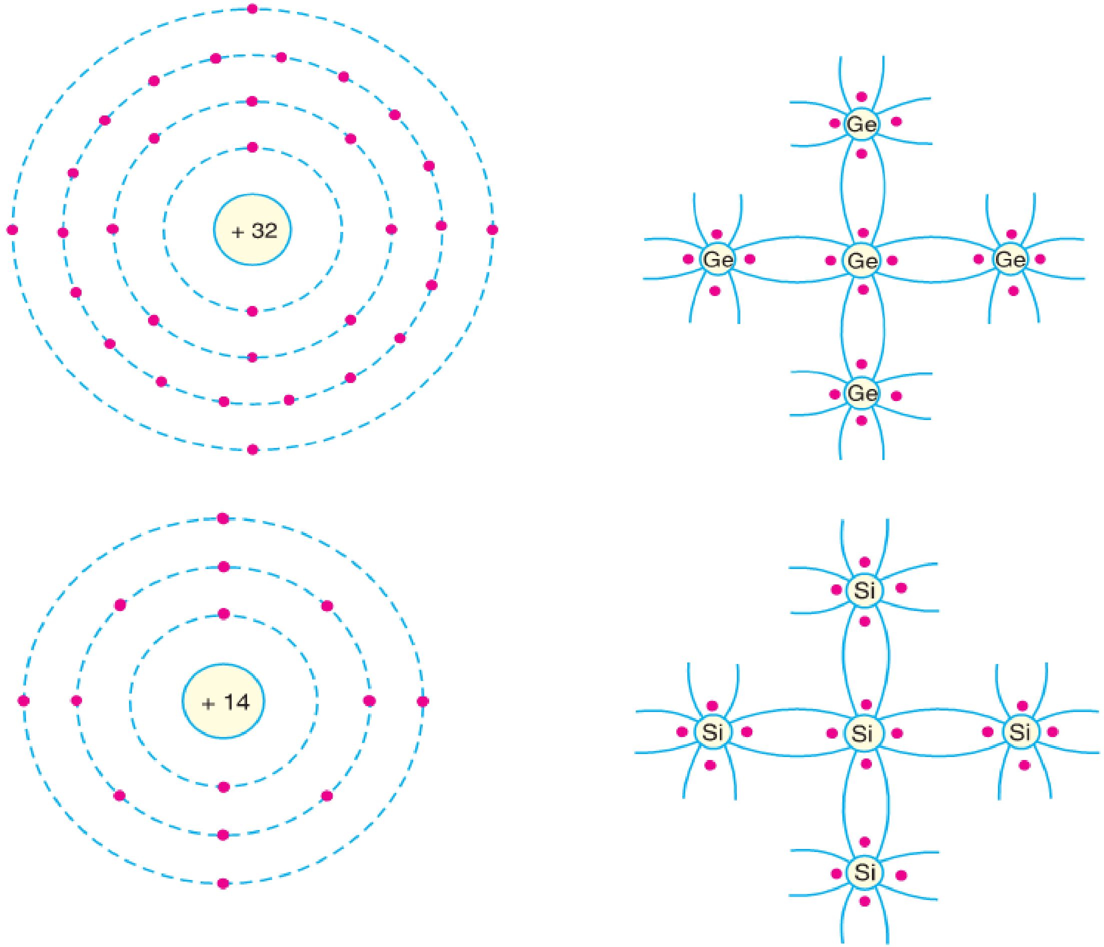
COVALENT BONDS AMONG Ge ATOMS



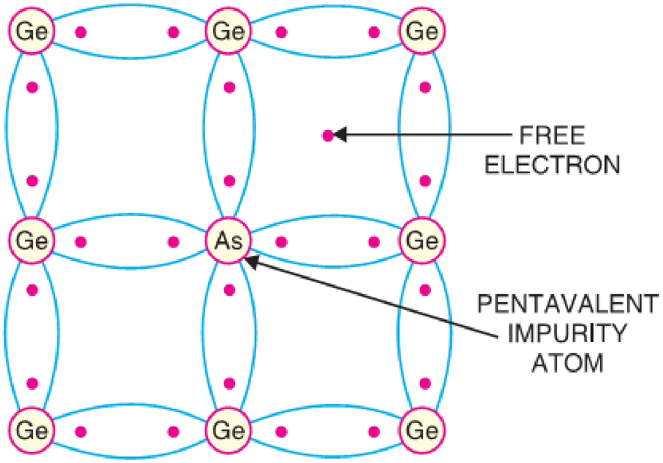
BONDING DIAGRAM

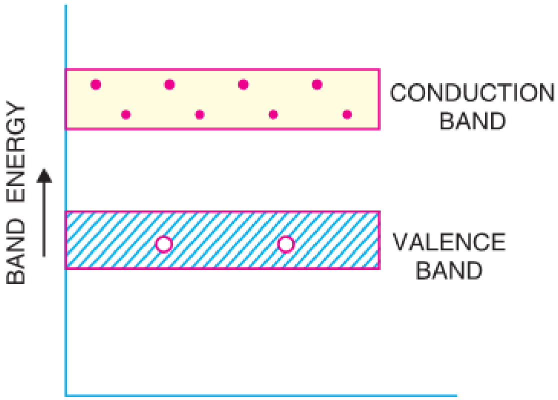
Commonly Used Semiconductors

- The energy required to break their co-valent bonds (i.e. energy required to release an electron from their valence bands) is very small; being about 0.7 eV for germanium and about 1.1 eV for silicon.

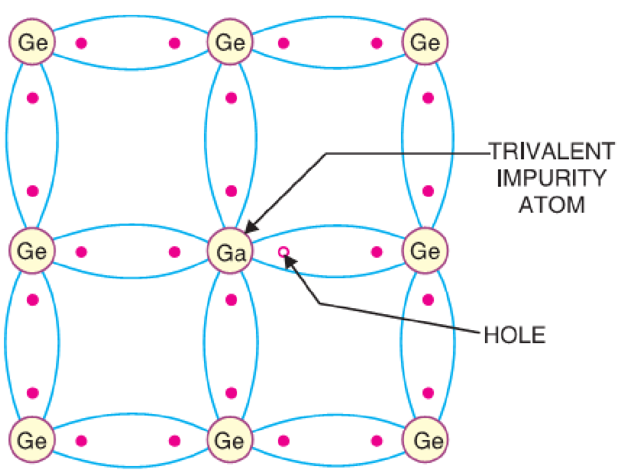


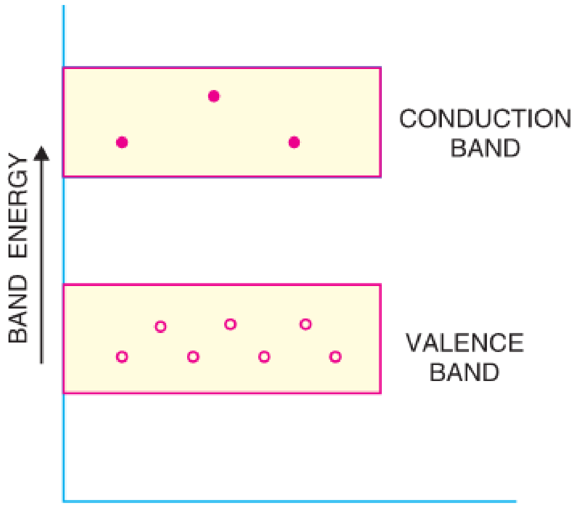
- Intrinsic Semiconductor : A semiconductor in an extremely pure form is known as an *intrinsic semiconductor*.
- The intrinsic semiconductor has little current conduction capability at room temperature.
- The current conduction is improved by adding a small amount of suitable impurity to a semiconductor. It is then called *impurity or extrinsic semiconductor.*
- The process of adding impurities to a semiconductor is known as *doping*.
- Generally, for 10^8 atoms of semiconductor, one impurity atom is added.
- Depending upon the type of impurity added, extrinsic semiconductors are classified into: *(i) n-type semiconductor (ii) p-type semiconductor.*
- When a small amount of pentavalent impurity is added to a pure semiconductor, it is known as *n-type semiconductor*.
- Typical examples of pentavalent impurities are *arsenic (At. No. 33)* and *antimony (At. No. 51)*.
- Such impurities which produce n-type semiconductor are known as *donor impurities.*





- When a small amount of trivalent impurity is added to a pure semiconductor, it is called *p-type semiconductor.*
- The addition of trivalent impurities like *gallium (At. No. 31)* and *indium (At. No. 49)* produce p-type semiconductor.
- *acceptor impurities*



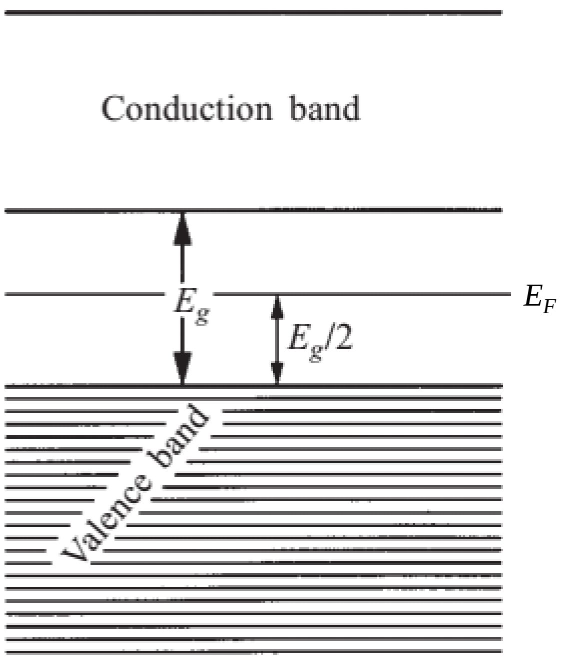


Fermi Energy level

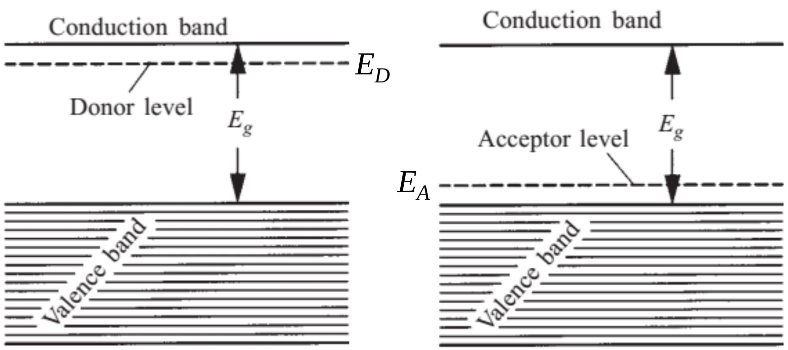
- It is the highest energy state occupied by an electron at absolute zero temperature (0 K)
- without the influence of impurities, the number of electrons excited across the gap can be calculated from the Fermi–Dirac probability distribution:

$$P(E) = \frac{1}{1 + \exp\left[(E - E_F)/kT\right]} = \exp\left[\frac{-E_g}{2\,kT}\right]$$

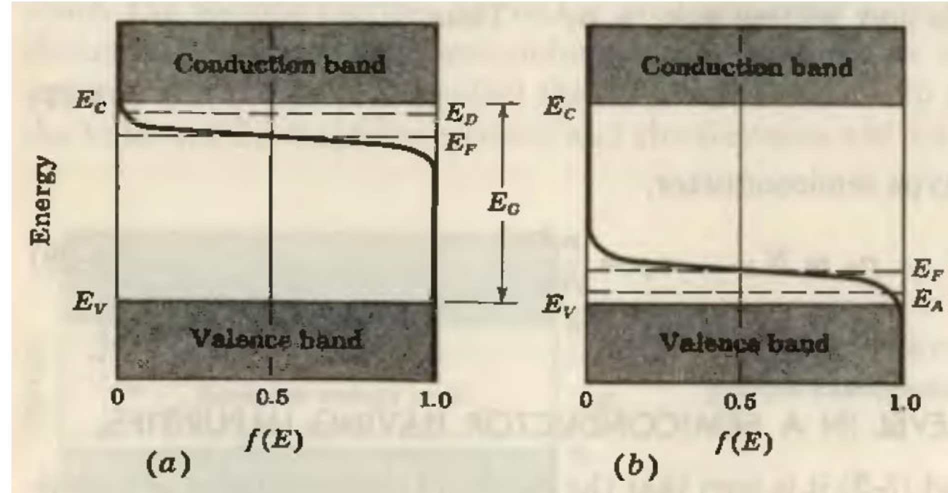
- The Fermi level E_F for an intrinsic semiconductor lies midway in the forbidden gap
- The probability of finding an electron here is 50%, even though energy levels at this point are forbidden.



Fermi Level in Extrinsic Semiconductors



n-type semiconductor *p*-type semiconductor



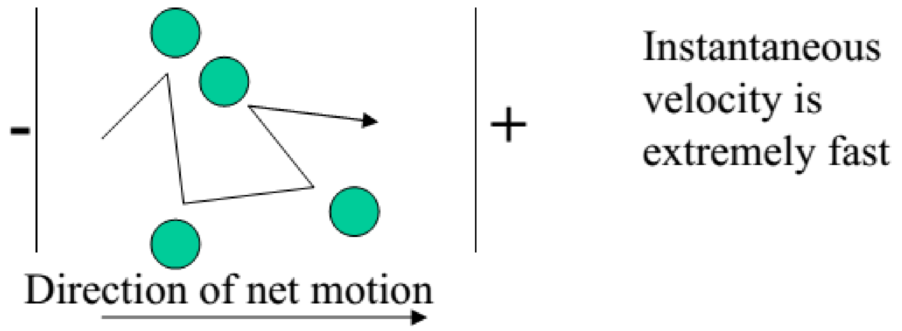
- For n-type semiconductor, E_F must move closer to the conduction band to indicate that many of the energy states in that band are filled by the electrons, and fewer holes exist in the valence band in.
- Similarly, for p-type semiconductor, E_F must move from middle of the forbidden gap closer to the valence band

Current Flow

- Drift: charged particle motion in response to an electric field.
- Diffusion: Particles tend to spread out or redistribute from areas of high concentration to areas of lower concentration.

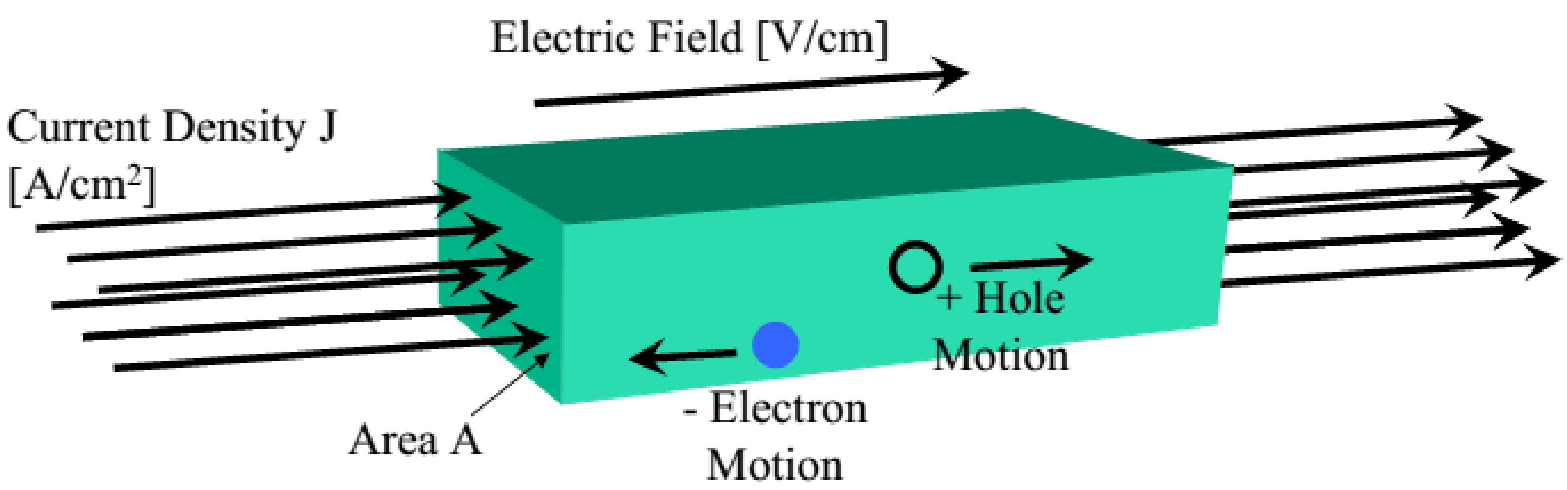
Direction of motion in Drift current

- Holes move in the direction of the electric field (from + to -)
- Electrons move in the opposite direction of the electric field (from - to +)
- Motion is highly non-directional on a local scale, but has a net direction on a macroscopic scale



- Average net motion is described by the drift velocity, v_d with units cm/second

Drift



Given current density J (I=J x Area) flowing in a semiconductor block with face area A under the influence of electric field E, the component of J due to drift of carriers is:

$$J_p|_{Drift} = q\, p\, v_d \quad \text{and} \quad J_n|_{Drift} = q\, n\, v_d$$

Hole Drift current density

Electron Drift current density

Diffusion

Nature attempts to reduce concentration gradients to zero.

Example: a bad odor in a room.

In semiconductors, this "flow of carriers" from one region of higher concentration to lower concentration results in a "diffusion current".

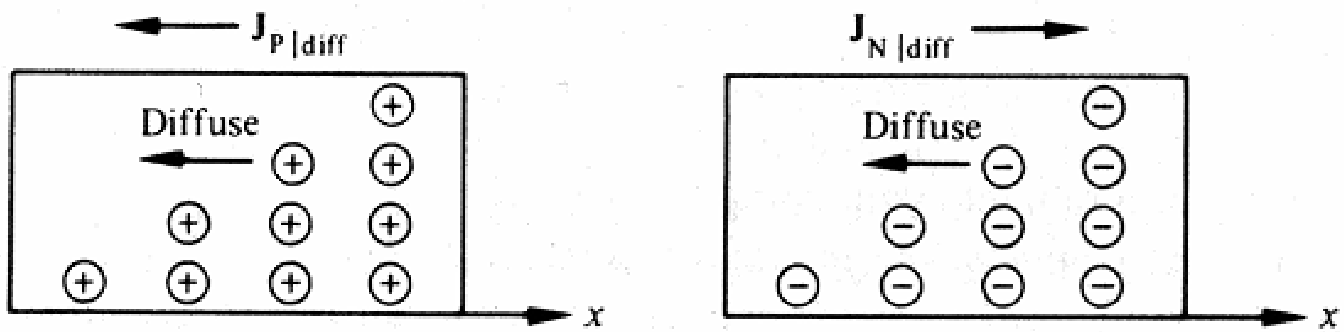
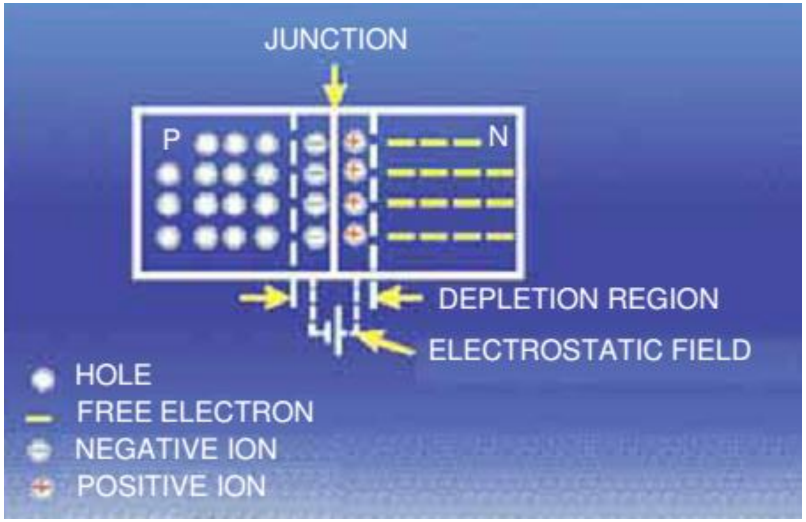


Figure 3.12 Visualization of electron and hole diffusion on a macroscopic scale.

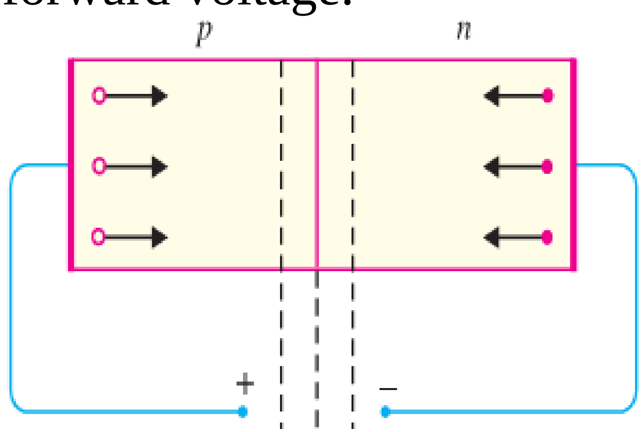
PN Junction

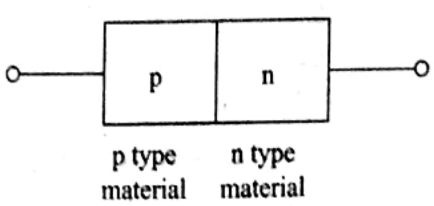
- When a p-type semiconductor is suitably joined to n-type semiconductor, the contact surface is called *pn junction*.
- The depletion region acts as a barrier to the further movement of free electrons across the junction.
- The typical barrier potential is approximately:
- For silicon, $V_0 = 0.7$ V ; For germanium, $V_0 = 0.3$ V

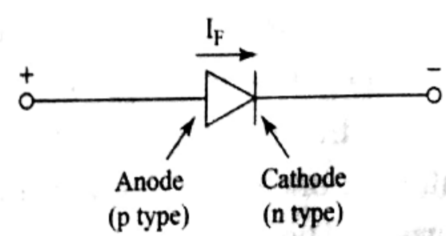


Biasing a pn Junction

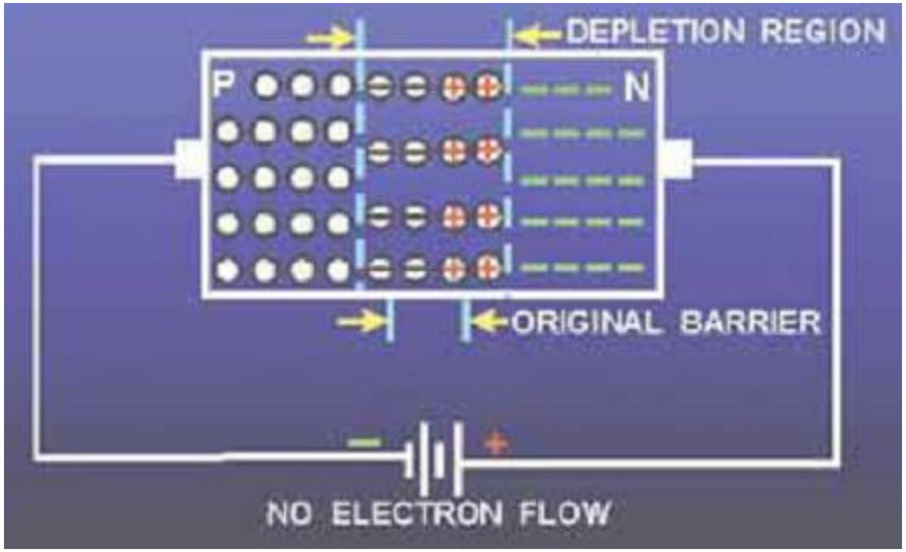
- 1. Forward biasing 2. Reverse biasing
- 1. **Forward biasing.** When external d.c. voltage applied to the junction is in such a direction that it cancels the potential barrier, thus permitting current flow, it is called forward biasing.
- With forward bias to pn junction, the following points are worth noting :
- (i) The potential barrier is reduced and at some forward voltage (0.1 to 0.3 V), it is eliminated altogether.
- (ii) The junction offers low resistance (called forward resistance, R_f) to current flow.
- (iii) Current flows in the circuit due to the establishment of low resistance path. The magnitude of current depends upon the applied forward voltage.



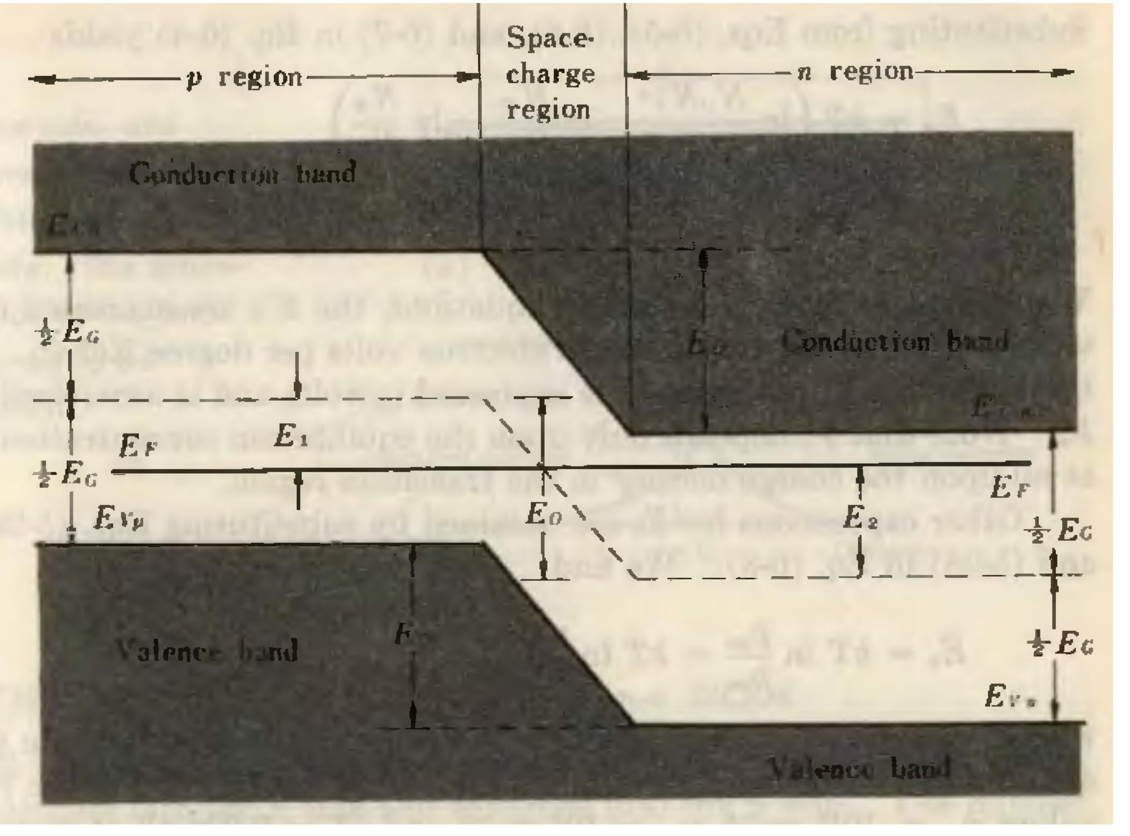




- Reverse biasing. When the external d.c. voltage applied to the junction is in such a direction that potential barrier is increased, it is called reverse biasing.
- (i) The potential barrier is increased.
- (ii) The junction offers very high resistance (called reverse resistance, R_r) to current flow.
- (iii) No current flows in the circuit due to the establishment of high resistance path.



Band Diagram

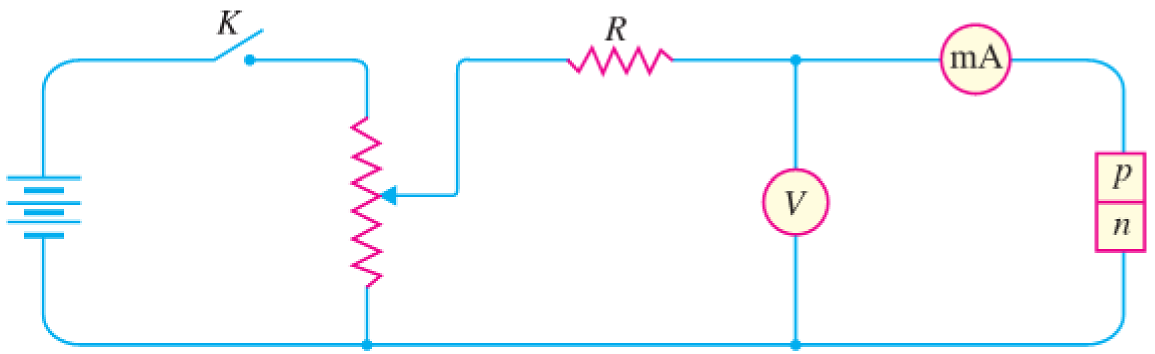


- In *pn*-junction diode, the Fermi level must be constant throughout the specimen at equilibrium.
- If this were not so, electrons on one side of the junction would have an average energy higher than those on the other side, end there would be a transfer of electrons and energy the Fermi kevels in the two sides did line up.

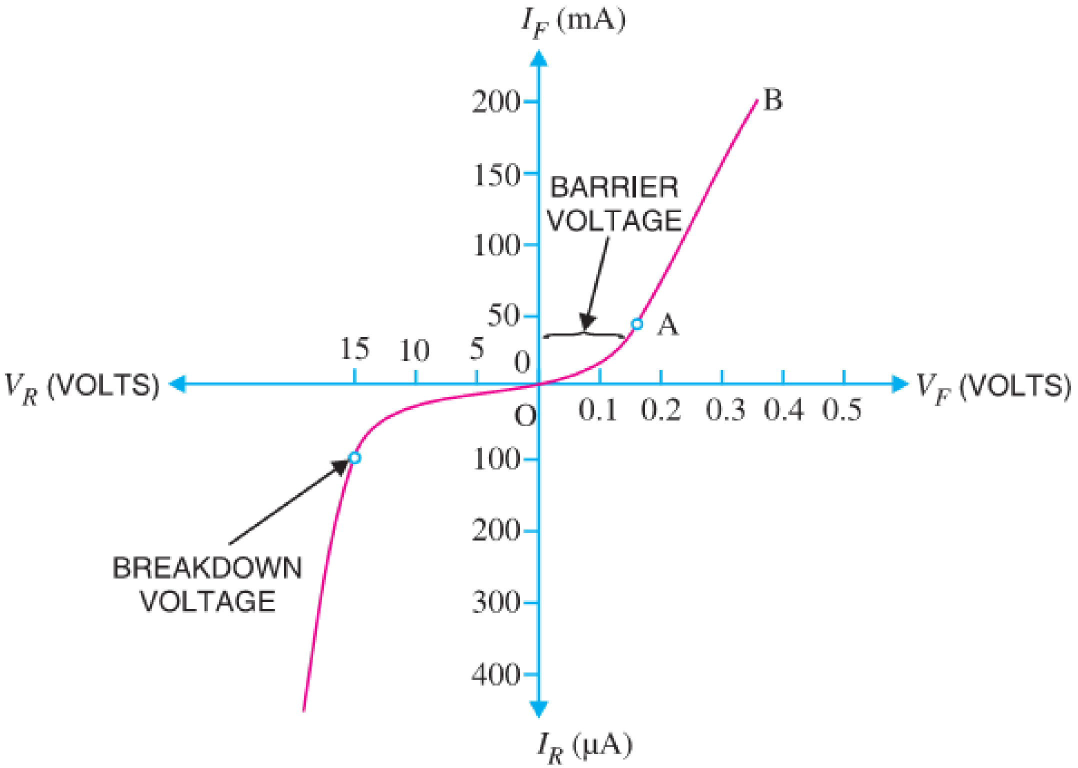
Current Flow in a Forward Biased pn Junction

- The free electrons from the negative terminal continue to pour into the n-region while the free electrons in the n-region move towards the junction.
- The electrons travel through the n-region as free-electrons i.e. current in n-region is by free electrons.
- When these electrons reach the junction, they combine with holes and become valence electrons.
- The electrons travel through p-region as valence electrons i.e. current in the p-region is by holes.
- When these valence electrons reach the left end of crystal, they flow into the positive terminal of the battery.

Volt-Ampere Characteristics of pn Junction



- The characteristics can be studied under three heads, namely; zero external voltage, forward bias and reverse bias.



- The characteristics can be studied under three heads, namely; zero external voltage, forward bias and reverse bias.

Zero external voltage.

- When the external voltage is zero, i.e. circuit is open at K, the potential barrier at the junction does not permit current flow. Therefore, the circuit current is zero as indicated by point O.

Forward bias.

- p-type connected to positive terminal and n-type connected to negative terminal, the potential barrier is reduced.
- At some forward voltage (0.7 V for Si and 0.3 V for Ge), the potential barrier is altogether eliminated and current starts flowing in the circuit.
- Once the external voltage exceeds the potential barrier voltage, the pn junction behaves like an ordinary conductor.

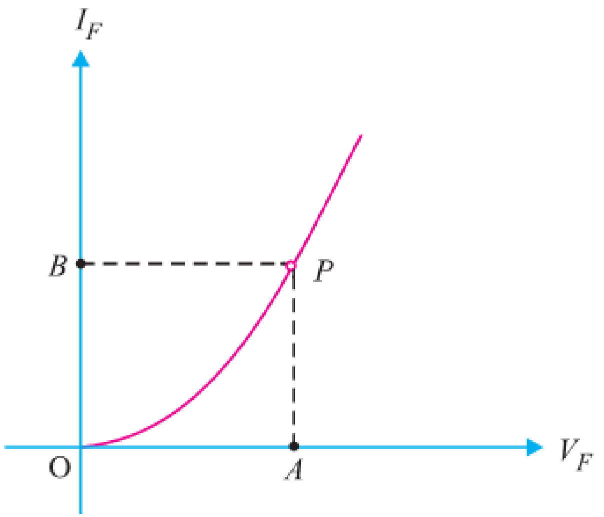
Reverse bias.

- p-type connected to negative terminal and n-type connected to positive terminal.
- potential barrier at the junction is increased.
- a very small current (of the order of μA) flows in the circuit with reverse is called reverse saturation current (I_s) and is due to the minority carriers.

- If reverse voltage is increased continuously, the kinetic energy of electrons (minority carriers) may become high enough to knock out electrons from the semiconductor atoms.
- At this stage breakdown of the junction occurs, characterized by a sudden rise of reverse current and a sudden fall of the resistance of barrier region.
- Breakdown voltage. It is the minimum reverse voltage at which pn junction breaks down with sudden rise in reverse current.
- Knee voltage. It is the forward voltage at which the current through the junction starts to increase rapidly.
- Maximum forward current. It is the highest instantaneous forward current that a pn junction can conduct without damage to the junction.
- Peak inverse voltage (PIV). It is the maximum reverse voltage that can be applied to the pn junction without damage to the junction.
- Maximum power rating. It is the maximum power that can be dissipated at the junction without damaging it.

Resistance of a Diode

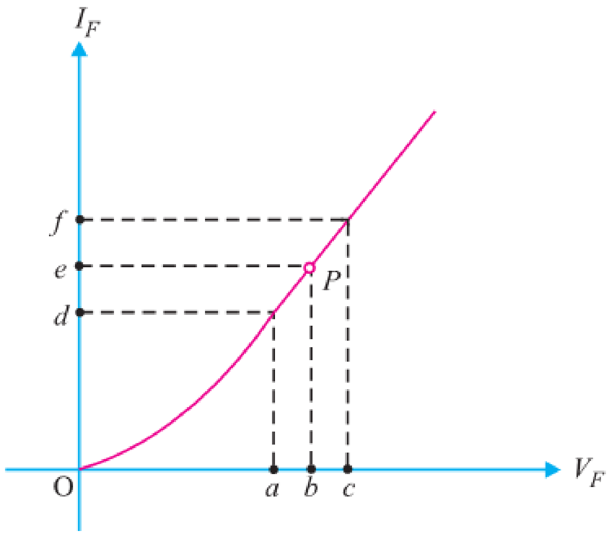
Forward resistance. The resistance offered by the diode to forward bias is known as forward resistance. This resistance is of two types, namely; d.c. forward resistance and a.c. forward resistance.



- d.c. forward resistance. It is the opposition offered by the diode to the direct current. It is measured by the ratio of d.c. voltage across the diode to the resulting d.c. current through it.

$$\text{d.c. forward resistance, } R_f = \frac{OA}{OB}$$

- a.c. forward resistance. It is the opposition offered by the diode to the changing forward current. It is measured by the ratio of change in voltage across diode to the resulting change in current through it.



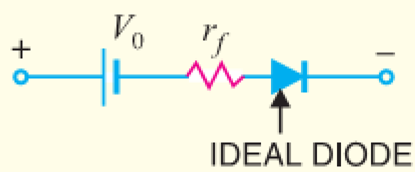
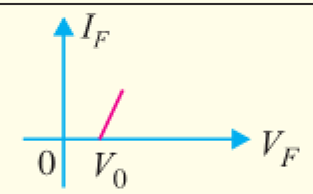
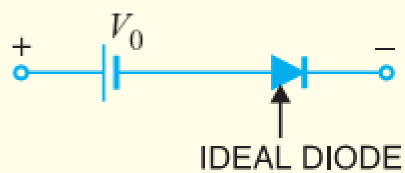
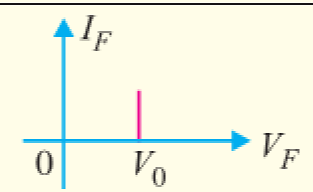
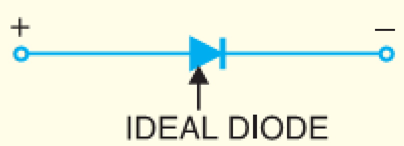
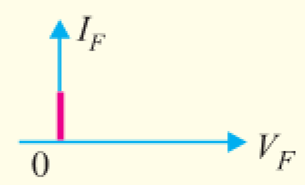
$$\text{a.c. forward resistance, } r_f = \frac{\text{Change in forward voltage}}{\text{Change in forward current}}$$

$$= \frac{oc - oa}{of - od} = \frac{ac}{df}$$

- ranging from 1 to 25 Ω.

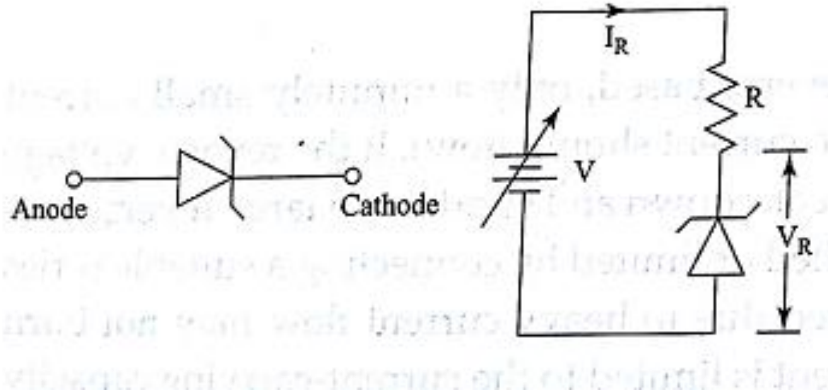
- Reverse resistance. The resistance offered by the diode to the reverse bias is known as reverse resistance. Ideally, the reverse resistance of a diode is infinite.

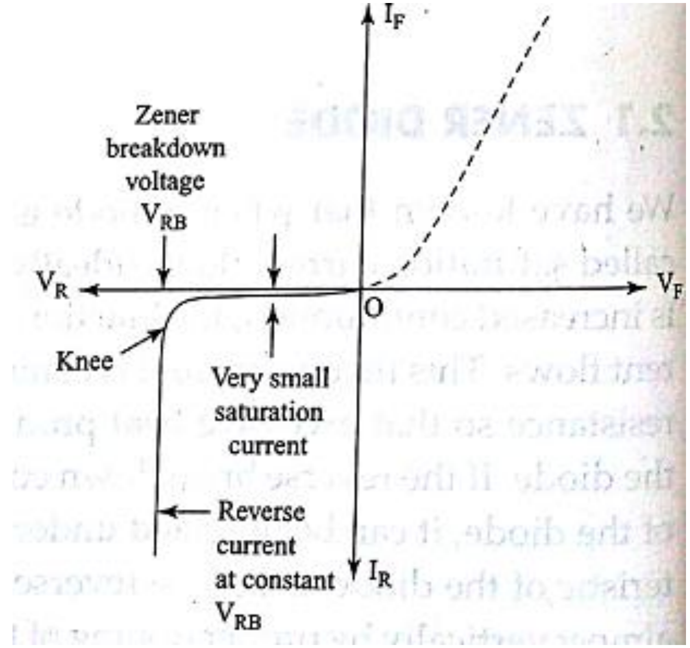
Crystal Diode Equivalent Circuits

S.No.	Type	Model	Characteristic
1.	Approximate model		
2.	Simplified model		
3.	Ideal Model		

Zener Diode

- A Zener diode is a special type of diode that is designed to operate in the reverse breakdown region.
- An ordinary diode operated in this region will usually be destroyed due to excessive current.
- A Zener diode is heavily doped to reduce the reverse breakdown voltage. This causes a very thin depletion layer. As a result, a Zener diode has a sharp reverse breakdown voltage V_Z.
- There are two ways that breakdown of a Zener diode may occur. One is called Zener breakdown and the other is called avalanche breakdown.
- If the depletion layer of a diode is narrow and we apply a reverse voltage, the voltage per unit of width of the depletion layer becomes high. This establishes a strong electric field intensity which causes electrons to break away from their parent atoms.
- This kind of breakdown due to the creation of a strong electric field intensity, i.e., V/pm is called Zener breakdown.
- If the width of the depletion layer is wide for a Zener breakdown, a sufficient reverse voltage may provide the free electrons (minority carriers causing saturation current) to gain sufficient energy to knockout electrons from the atoms of the semiconductor in the depletion region. This is called *ionization by collision*. The breakdown occurring this way is called avalanche breakdown.





- **Zener resistance**: It is the dynamic resistance of the Zener diode somewhat below the knee point on the reverse V-I characteristic.
- It is similar to the dynamic resistance of a forward-biased diode. Zener resistance, R_z is given by

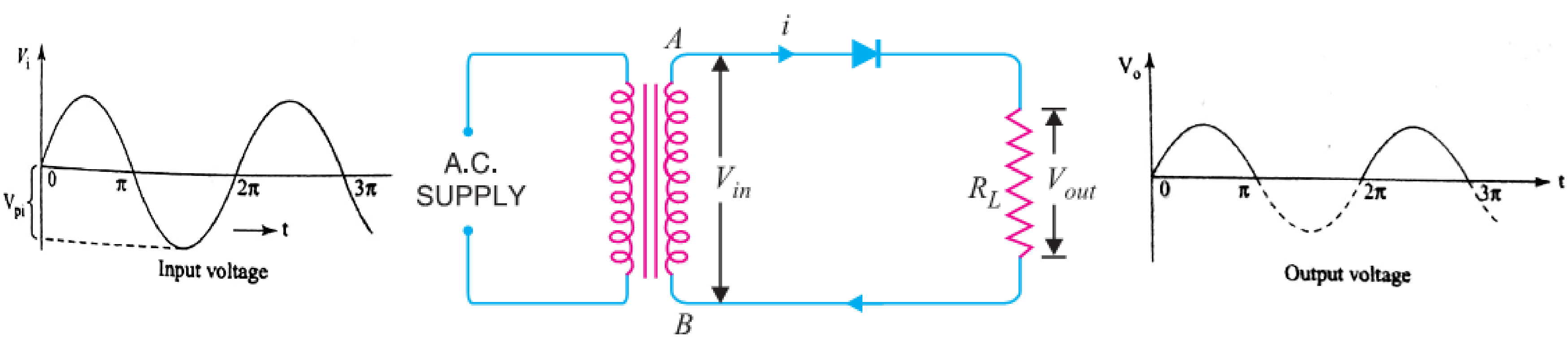
$$R_z = \frac{\Delta V_z}{\Delta I_z}$$

Diode Applications: Rectifier

- A rectifier is a device that converts *ac* supply into *dc* using diodes. Rectification can be done by half-wave or full-wave rectification circuits.

Half wave rectifier

- In half-wave rectification, the rectifier conducts current only during the positive half-cycles of input a.c. supply.
- The negative half-cycles of a.c. supply are suppressed i.e. during negative half-cycles, no current is conducted and hence no voltage appears across the load.
- Therefore, current always flows in one direction (i.e. d.c.) through the load though after every half-cycle.



- It is seen that a diode works as a closed switch during the positive half cycle of the input voltage and works as an open switch during the negative half cycle.
- The load voltage and load current although positive all the time (i.e., unidirectional) are fluctuating dc as its magnitudes changing.
- Our aim will be to obtain steady dc at the output.
- The performance parameters of a half-wave rectifier output are calculated in terms of the dc current (i.e. the average value of the rectified wave), the RMS of the output current, output voltage, ripple factor, peak inverse voltage, etc.

Analysis

- The equation for sinusoidal voltage and current can be written as

$$v = V_m \sin\theta \text{ and } i = I_m \sin\theta$$

- The average value is calculated by integrating the current for a period $\theta = 0$ to π and averaging it for the entire cycle
- I_{dc} is the average value of the rectified current.

$$I_{dc} = I_{av} = \frac{1}{2\pi}\int_0^{\pi} i\,d\theta = \frac{1}{2\pi}\int_0^{\pi} I_m \sin\theta\, d\theta$$

$$= \frac{I_m}{2\pi}\left[-\cos\theta\right]_0^{\pi}$$

$$= \frac{I_m}{2\pi}\left[-(-1)-(-1)\right]$$

$$= \frac{I_m}{\pi} = 0.318\, I_m$$

- The RMS value, I is calculated by first squaring the current, then taking its mean, fid then taking its root as

$$I = \sqrt{\frac{1}{2\pi}\int_0^{\pi} i^2 d\theta} \quad \text{or,} \quad I^2 = \frac{1}{2\pi}\int_0^{\pi} i^2 d\theta$$

$$I^2 = \frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2\theta\, d\theta$$

$$I^2 = \frac{I_m^2}{2\pi}\int_0^{\pi}\left[\frac{1-\cos 2\theta}{2}\right]d\theta = \frac{I_m^2}{4\pi}\left[\theta - \frac{\sin 2\theta}{2}\right]_0^{\pi}$$

$$= \frac{I_m^2}{4\pi}\left[\pi - \frac{\sin 2\pi}{2} - \left(0 - \frac{\sin 2\times 0}{2}\right)\right]$$

$$= \frac{I_m^2}{4\pi}\times\pi$$

$$= \frac{I_m^2}{4}$$

$$I_{rms} = \frac{I_m}{2}$$

- **Ripple Factor:** The output of a half-wave rectifier is a pulsating dc.
- Ripple factor is defined as the ratio of the RMS value of ac component to the value of dc component.
- The ripple factor indicates the level of fluctuation of the output voltage from its steady value. Ripple is an undesired effect and should be minimized.
- The ripple factor, *r* for a half-wave rectifier is calculated as

$$\text{Ripple Factor, } r = \frac{\text{RMS value of ac component}}{\text{value of dc component}}$$

$$= \frac{I_{ac}}{I_{dc}}$$

$$\text{Again, } I_{rms}^2 = I_{dc}^2 + I_1^2 + I_2^2 + I_{44}^{22} + \cdots = I_{dc}^2 + I_{ac}^2$$

- where I_1 , I_2,1_3, etc., are the fundamental and harmonics of the ac component

$$I_{rms} = \sqrt{I_{dc}^2 + I_{ac}^2}$$

$$I_{ac} = \sqrt{I_{rms}^2 - I_{dc}^2}$$

- where I_{ac} is the RMS value of the ac component of the output

$$r = \frac{\sqrt{I_{rms}^2 - I_{dc}^2}}{I_{dc}} = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

- Substituting I_{rms} and I_{dc}
- The ripple factor is

$$r = \sqrt{\left[\frac{I_m/2}{I_m/\pi}\right]^2 - 1} = \sqrt{\frac{\pi^2}{4} - 1} = 1.21$$

- Output voltage, V_{dc} across the load

$$V_{dc} = I_{dc} R_L = \frac{I_m}{\pi} R_L = \frac{V_m}{\pi} = 0.318\ V_m$$

- **Rectifier Efficiency:** It is calculated as the ratio of output to input power

$$DC\ output\ power,\ P_{dc} = I_{dc}^2 R_L = \left(\frac{I_m}{\pi}\right)^2 R_L$$

- AC input power, P_{ac} = Power dissipated in diode junction + Power dissipated in the load

$$= I_{rms}^2 R_f + I_{rms}^2 R_L$$

- The forward resistance, R_f of the diode is very small, and hence $I^2_{rms}R_f$ can neglected

$$\text{Therefore, rectifier efficiency } = \frac{P_{dc}}{P_{ac}} = \frac{I_m^2}{\pi^2} RL \div I_{rms}^2 R_L$$

$$= \frac{I_m^2\, RL}{\pi^2 I_{rms}^2 RL} = \frac{I_m^2}{\pi^2 \cdot \left(\frac{I_m}{2}\right)^2}$$

$$= \frac{4}{\pi^2} = 0.406 = 40.6 \text{ per cent}$$

- This value of efficiency is considered low and ripple factor is considered very high.
- Voltage Regulation of the rectifier is calculated using the relation,

$$\text{Voltage regulation} = \frac{V_{dc} \text{ at no load} - V_{dc} \text{ on full load}}{V_{dc} \text{ on full load}}$$

Disadvantages of half wave rectifier:

(i) The pulsating current in the load contains alternating component whose basic frequency is equal to the supply frequency. Therefore, an elaborate filtering is required to produce steady direct current.

(ii) The a.c. supply delivers power only half the time. Therefore, the output is low.

(iii) The ripple factor of half wave rectifier circuit is 1.21, which is quite high.

(iv) The maximum theoretical efficiency is 40%. The practical value will be less than this. This indicates that half wave rectifier is inefficient.

Problem. The applied input a.c. power to a half-wave rectifier is 100 watts. The d.c. output power obtained is 40 watts.

(i) What is the rectification efficiency ?

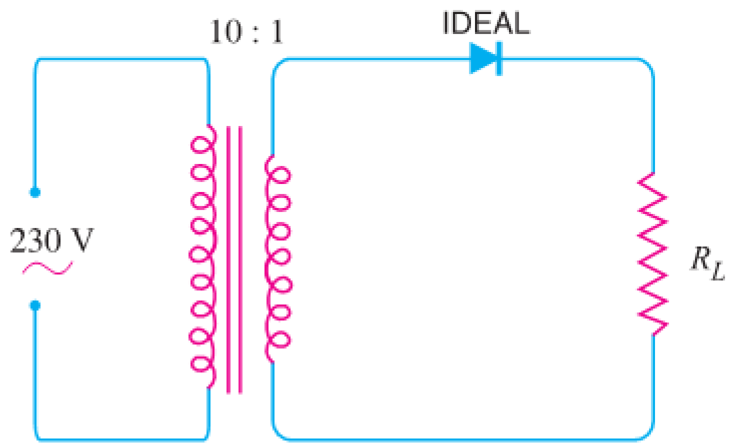
(ii) What happens to remaining 60 watts ?

Solution:

(*i*) $$\text{Rectification efficiency} = \frac{\text{d.c. output power}}{\text{a.c. input power}} = \frac{40}{100} = 0.4 = \mathbf{40\%}$$

(ii) 40% efficiency of rectification does not mean that 60% of power is lost in the rectifier circuit. In fact, a crystal diode consumes little power due to its small internal resistance. The 50 watts in the negative half-cycles are not supplied at all. Only 50 watts in the positive half-cycles are converted into 40 watts.

- An a.c. supply of 230 V is applied to a half-wave rectifier circuit through a transformer of turn ratio 10 : 1. Find (i) the output d.c. voltage and (ii) the peak inverse voltage. Assume the diode to be ideal.



Primary to secondary turns is

$$\frac{N_1}{N_2} = 10$$

R.M.S. primary voltage

$$= 230 \text{ V}$$

∴ Max. primary voltage is

$$V_{pm} = (\sqrt{2}) \times \text{r.m.s. primary voltage}$$

$$= (\sqrt{2}) \times 230 = 325.3 \text{ V}$$

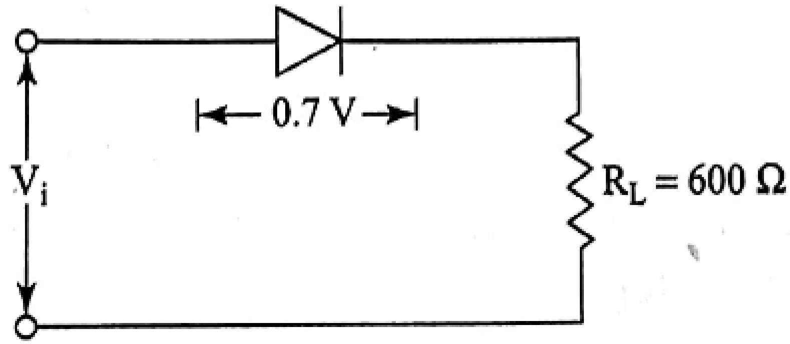
$$V_{sm} = V_{pm} \times \frac{N_2}{N_1} = 325.3 \times \frac{1}{10} = 32.53 \text{ V}$$

$$I_{d.c.} = \frac{I_m}{\pi}$$

$$V_{dc} = \frac{I_m}{\pi} \times R_L = \frac{V_{sm}}{\pi} = \frac{32.53}{\pi} = \mathbf{10.36 \text{ V}}$$

Peak inverse voltage = 32.53 V

A half-wave diode rectifier has a forward voltage drop, i.e., voltage drop across the diode when conducting is 0.7 V. The load resistance is 600 Ω. The RMS value of the ac input is 28.87 V. Calculate I_{dc}, I_{rms}, PIV, and form factor.



$$V_i(\text{RMS}) = 28.27\ \text{V}$$

$$V_i(\text{max}) = \sqrt{2}\, V_i(\text{RMS})$$

$$= 1.414 \times 28.27$$

$$\text{i.e., } V_m = 40\ \text{V}$$

$$\text{PIV} = V_m = 40\ \text{V}$$

$$I_{dc} = \frac{I_m}{\pi}; \qquad I_m = \frac{V_m - 0.7}{R_L} = \frac{40 - 0.7}{600} = \frac{39.3}{600}\ \text{A}$$

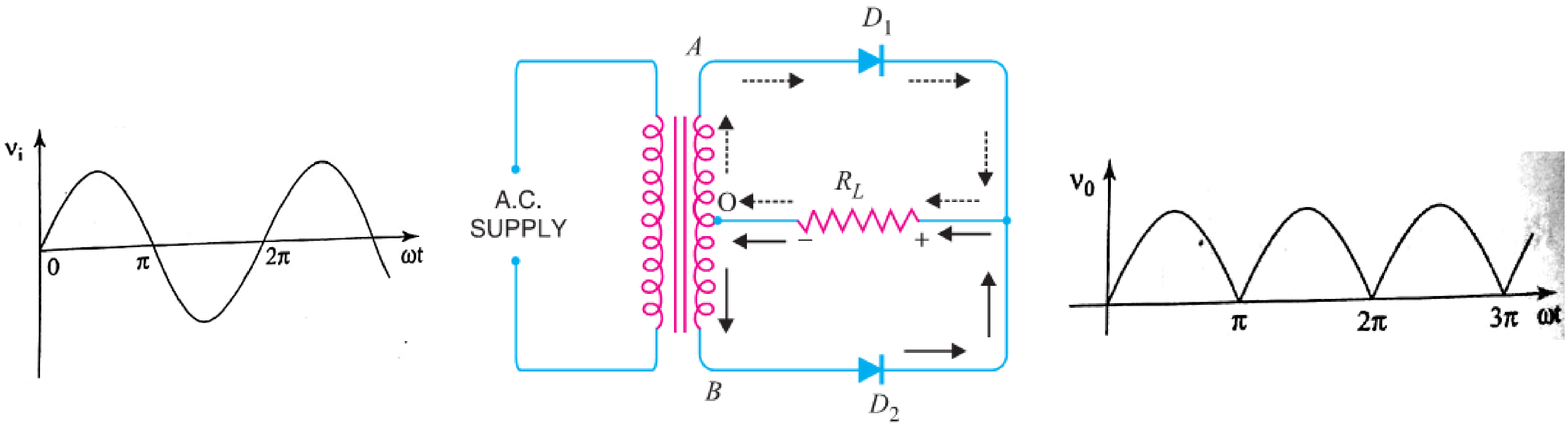
$$I_{dc} = \frac{39.3}{600 \times \pi} = 0.0208\ \text{A} = 20.8\ \text{mA}$$

$$I_{rms} = \frac{I_m}{2}\ \frac{39.3}{600 \times 2} = 0.0327\ \text{A} = 32.7\ \text{mA}$$

$$\text{Form factor} = \frac{\text{RMS value}}{\text{Average value}} = \frac{I_{rms}}{I_{dc}} = \frac{32.7}{20.8} = 1.57$$

Full-wave Rectifier

- Full-wave rectifiers can be made using two diodes and a centre-tapped transformer.
- Full-wave rectifiers are also made using a two-winding transformer and four diodes Such rectifiers are called bridge rectifiers.



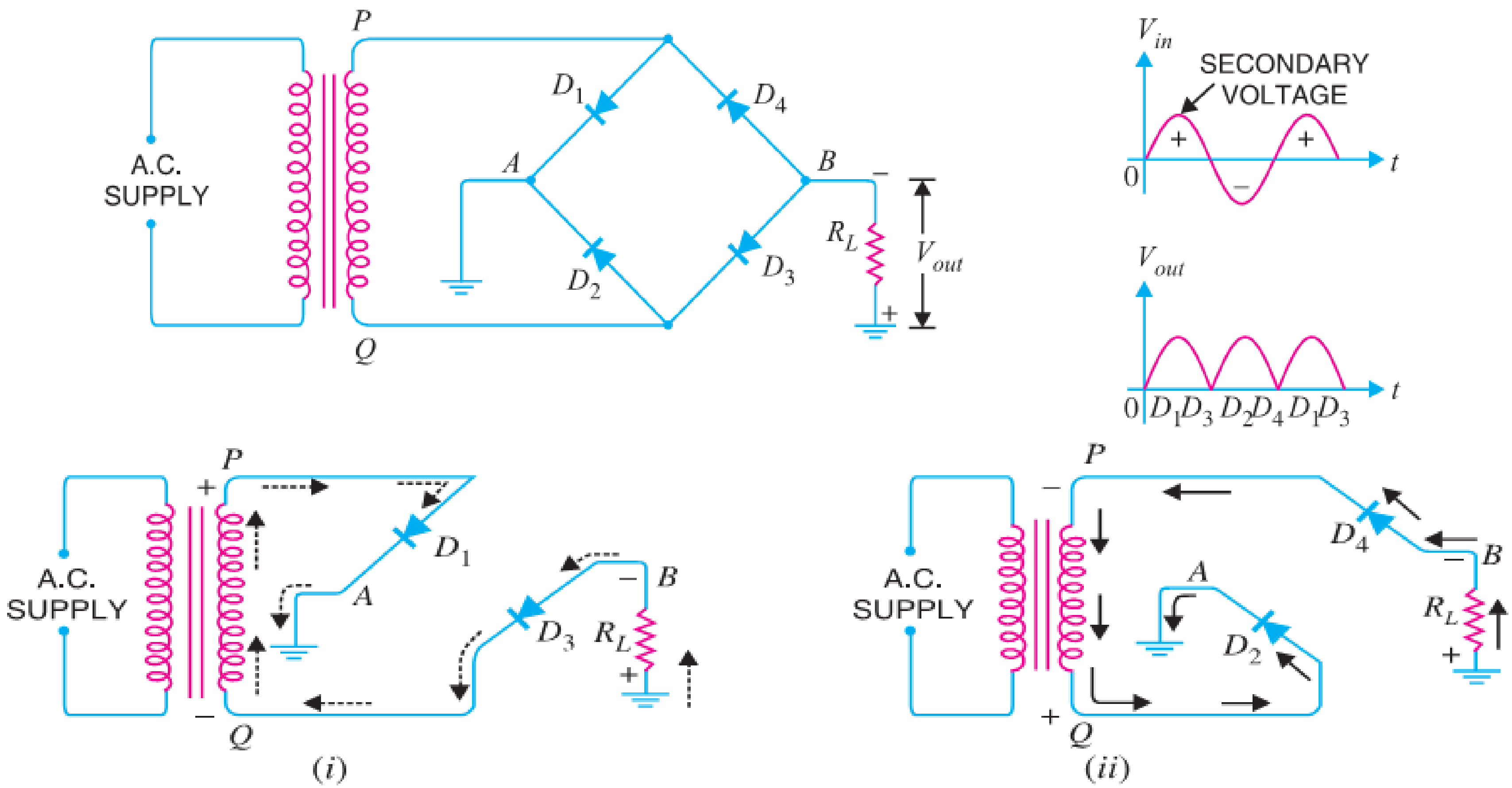
- For the positive half cycle of the input voltage, diode D_1 will conduct. This because terminal A is positive and the diode D_1 is forward biased.
- In the negative half cycle, terminal B is positive and terminal A is negative. Hence, diode D_2 will conduct and diode D_1 will be reverse biased.
- The output current and the output voltage across the load will be a full-wave rectified current and voltage, respectively.

- The current through the load resistance is unidirectional but its magnitude is fluctuating.
- When D_1 is conducting, the voltage that would appear across D_2 is the sum of the voltage across the lower half of the transformer secondary voltage appearing across the load. PIV of the diode is equal to 2 V_m.

- **Disadvantages**
(*i*) It is difficult to locate the centre tap on the secondary winding.
(*ii*) The d.c. output is small as each diode utilises only one-half of the transformer secondary voltage.
(*iii*) The diodes used must have high peak inverse voltage.

Full-Wave Bridge Rectifier

- The need for a centre tapped power transformer is eliminated in the bridge rectifier. It contains four diodes *D*1, *D*2, *D*3 and *D*4 connected to form bridge
- The a.c. supply to be rectified is applied to the diagonally opposite ends of the bridge through the transformer.



Advantages

(*i*) The need for centre-tapped transformer is eliminated.
(*ii*) The output is twice that of the centre-tap circuit for the same secondary voltage.
(*iii*) The PIV is one-half that of the centre-tap circuit (for same d.c. output).

Disadvantages

(*i*) It requires four diodes.

(ii) As during each half-cycle of a.c. input two diodes that conduct are in series, therefore, voltage drop in the internal resistance of the rectifying unit will be twice as great as in the centre tap circuit. This is objectionable when secondary voltage is small.

Analysis of Full-wave Rectifiers:

Average value or dc value of load current I_{dc}, The average value or dc value will be the same if calculated for a period 0 to π or 0 to 2π

$$I_{dc} = \frac{1}{\pi}\int_0^{\pi} I_m \sin\theta \, d\theta$$

$$= \frac{I_m}{\pi}\int_0^{\pi} \sin\theta \, d\theta$$

$$= \frac{I_m}{\pi}\left[-\cos\theta\right]_0^{\pi}$$

$$= \frac{I_m}{\pi}\left[-(-1)-(-1)\right]$$

$$= \frac{2I_m}{\pi}$$

RMS value of the load current, I_{rms}

$$I_{rms}^2 = \frac{1}{\pi}\int_0^{\pi} I_m^2 \sin^2\theta \, d\theta$$

$$= \frac{I_m^2}{2\pi}\int_0^{\pi}(1-\cos 2\theta)\, d\theta$$

$$= \frac{I_m^2}{2\pi}\left[\theta - \frac{\sin 2\theta}{2}\right]_0^{\pi}$$

$$= \frac{I_m^2}{2\pi} \times \pi = \frac{I_m^2}{2}$$

$$I_{rms} = \frac{I_m}{\sqrt{2}}$$

Output voltage, V_{dc}

$$V_{dc} = I_{dc} R_L$$

$$= \frac{2\, I_m}{\pi} R_L$$

$$= \frac{2\, R_L}{\pi} \frac{V_m}{(R_L + 2R_F + R_2)}$$

- where R_L is the load resistance, R_F is the forward resistance of the diode, and R_2 is the secondary winding resistance of the transformer.

- Rectifier efficiency, η

$$\eta = \frac{\text{dc power output, } P_{dc}}{\text{ac power input, } P_{ac}}$$

$$= \frac{I_{dc}^2 R_L}{I_{rms}^2 (R_L + 2R_F + R_2)} \qquad \text{(Two diodes being in series)}$$

$$= \frac{(2I_m)^2 R_L}{\pi^{22} I_{rms}^2 (R_L + 2R_F + R_2)}$$

$$= \frac{(2\sqrt{2}\ I_{rms})^2 R_L}{\pi^2 I_{rms}^2 (R_L + 2R_F + R_2)}$$

$$= \frac{8\ I_{rms}^2}{\pi^2 I_{rms}^2 \left(1 + \frac{2R_F + R_2}{R_L}\right)}$$

$$= \frac{8}{\pi^2} = 0.812 \text{ since } (2R_F + R_2) << R_L$$

$$= 81.2 \text{ per cent}$$

Ripple Factor

$$\text{Ripple factor, } r = \frac{\text{RMS value of ac component}}{\text{dc component}}$$

$$= \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

$$\text{Substituting,} \quad I_{rms} = \frac{I_m}{\sqrt{2}} = \quad \text{and} \quad I_{dc} = \frac{2I_m}{\pi}$$

$$r = \sqrt{\left(\frac{I_m \pi}{\sqrt{2}\, 2\, I_m}\right)^2 - 1}$$

$$= \sqrt{\frac{\pi^2}{8} - 1}$$

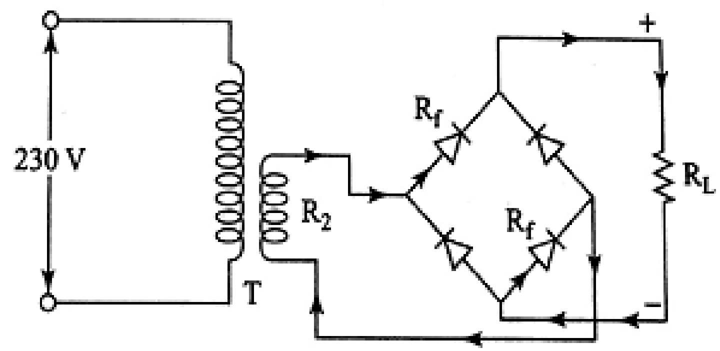
$$= 0.48$$

- We had earlier calculated the ripple factor for a half-wave rectifier as 1.21. For a full-wave rectifier, the ripple factor is reduced to 0.48.
- PIV for a bridge rectifier: V .

S. No.	Particulars	Half-wave	Centre-tap	Bridge type
1	No. of diodes	1	2	4
2	Transformer necessary	no	yes	no
3	Max. efficiency	40.6%	81.2%	81.2%
4	Ripple factor	1.21	0.48	0.48
5	Output frequency	f_{in}	$2\,f_{in}$	$2\,f_{in}$
6	Peak inverse voltage	V_m	$2\,V_m$	V_m

Parameters	Half-wave rectifier	Full-wave rectifier with centre-tapped transformer	Bridge rectifier
AC input, P_{ac}	$I^2_{rms}(R_L + R_F + R_2)$ $= \frac{I^2_m}{4}(R_L + R_F + R_2)$	$I^2_{rms}(R_L + 2R_F + R_2)$ $= \frac{I^2_m}{2}(R_L + 2R_F + R_2)$	$I^2_{rms}(R_L + 2R_F + R_2)$ $= \frac{I^2_m}{2}(R_L + 2R_F + R_2)$
Maximum rectification efficiency	40%	81.2%	81.2%
Ripple factor	1.21	0.48	0.48
PIV	V_m	$2\,V_m$	V_m
Ripple frequency	Fr = f	Fr = 2f	Fr = 2f
Centre tap transformer	Not required	Required	Not required

The input to a bridge rectifier is through a step-down transformer of turn ratio 10:1. The supply voltage is 230 V at 50 Hz. The load resistance is 1.2 kΩ secondary winding resistance of the transformer is 4 Ω diode forward resistance is 2 Ω. Calculate the efficiency of the bridge rectifier.



The RMS value of the emf in transformer secondary

$$V_s\,(\text{RMS}) = 230\left(\frac{N_2}{N_1}\right)$$

$$= 230\left(\frac{1}{10}\right)$$

$$= 23\ \text{V}$$

Peak secondary voltage, V_m is

$$V_m = \sqrt{2}\,V_s(\text{RMS})$$

$$= \sqrt{2} \times 23$$

$$= 32.5\ \text{V}$$

$$I_m = \frac{V_m}{R_L + 2\,R_F + R_2} = \frac{32.5}{1200 + 4 + 4} = 26.8 \text{ mA}$$

For a bridge rectifier,

$$I_{dc} = \frac{2I_m}{\pi} = \frac{2 \times 26.8}{3.14} = 17 \text{ mA}$$

DC power output, $P_{dc} = I_{dc}^2 R_L = (17 \times 10^{-3})^2 \times 1200$

$$= 346.8 \text{ mW}$$

AC power input, $P_{ac} = (I_{rms})^2 (R_L + 2R_F + R_S)$

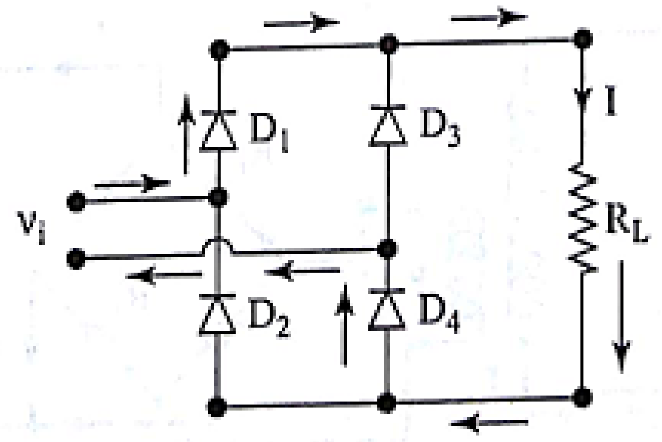
$$= \left(\frac{I_m}{\sqrt{2}}\right)^2 (R_L + 2R_F + R_S)$$

$$= \left(\frac{26.8 \times 10^{-3}}{2}\right)^2 \times (1200 + 2 \times 2 + 4)$$

$$= 432 \text{ mW}$$

Rectifier efficiency, $\eta = \frac{P_{dc}}{P_{ac}} \times 100 = \frac{346.8 \times 100}{432} = 80$ per cent.

Determine for the bridge circuit the peak value of load current where V_i=15 V, R_L = 600 Ω and the forward voltage drop of the diode is 0.7 V. Also calculate the average value of the output current.



$$V_i = 15\text{ V}$$

$$V_i(\text{max}) = \sqrt{2}\times 15 = 21.21\text{ V}$$

$$V_0(\text{max}) = V_i(\text{max}) - 2\,V_F$$

$$= 21.21 - 2\times 0.7$$

$$= 19.81\text{V}$$

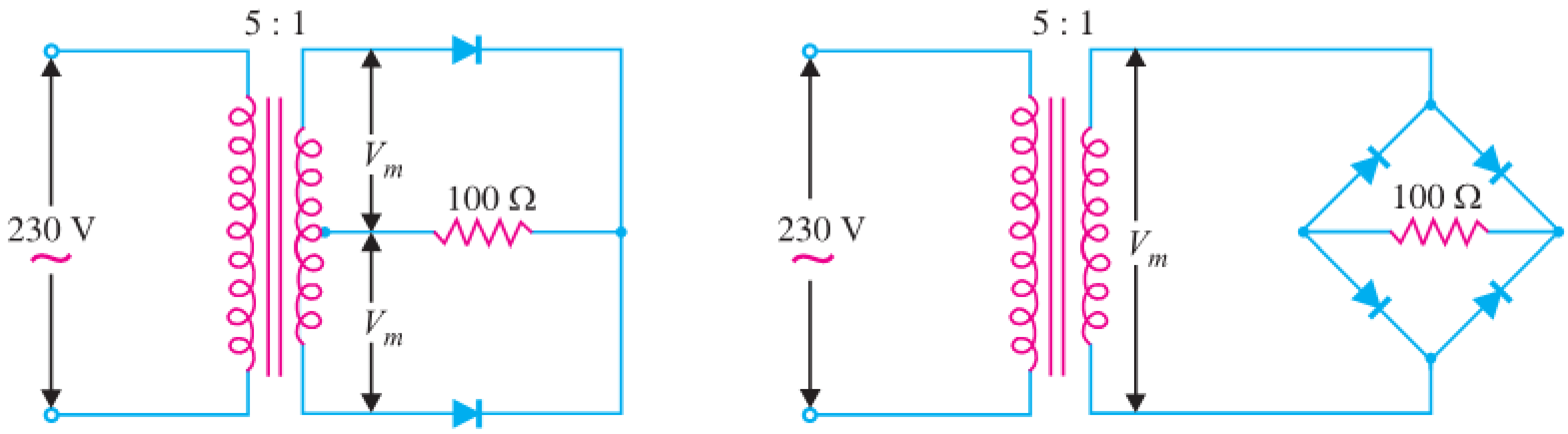
$$I_0(\text{max}) = \frac{V_0(\text{max})}{R_L} = \frac{19.81}{600} = 36\text{ mA}$$

$$I_0(\text{average}) = I_{dc} = \frac{2\,I_m}{\pi} = \frac{2\times 36}{3.14} = 22.93\text{ mA}$$

Below figures show the centre-tap and bridge type circuits having the same load resistance and transformer turn ratio. The primary of each is connected to 230V, 50 Hz supply.

(i) Find the d.c. voltage in each case.

(ii) PIV for each case for the same d.c. output. Assume the diodes to be ideal.



(*i*) (*ii*)

(*i*) D.C. output voltage

Centre-tap circuit

$$\text{R.M.S. secondary voltage} = 230 \times 1/5 = 46 \text{ V}$$

$$\text{Max. voltage across secondary} = 46 \times \sqrt{2} = 65 \text{ V}$$

Max. voltage appearing across half secondary winding is

$$V_m = 65/2 = 32.5 \text{ V}$$

$$\text{Average current, } I_{dc} = \frac{2V_m}{\pi R_L}$$

$$\text{D.C. output voltage, } V_{dc} = I_{dc} \times R_L = \frac{2V_m}{\pi R_L} \times R_L$$

$$= \frac{2V_m}{\pi} = \frac{2 \times 32.5}{\pi} = \mathbf{20.7\ V}$$

Bridge Circuit

$$\text{Max. voltage across secondary, } V_m = 65\text{ V}$$

$$\text{D.C. output voltage, } V_{dc} = I_{dc} R_L = \frac{2V_m}{\pi R_L} \times R_L = \frac{2V_m}{\pi} = \frac{2 \times 65}{\pi} = \mathbf{41.4\ V}$$

(ii) PIV for same d.c. output voltage

Centre-tap circuit

$$\text{R.M.S. secondary voltage} = 230 \times 1/5 = 46\text{ V}$$

$$\text{Max. voltage across secondary} = 46 \times \sqrt{2} = 65\text{ V}$$

Max. voltage across half secondary winding is

$$V_m = 65/2 = 32.5\text{ V}$$

$$PIV = 2V_m = 2 \times 32.5 = \mathbf{65\ V}$$

Bridge type circuit

$$\text{R.M.S. secondary voltage} = 230 \times 1/10 = 23\text{ V}$$

$$\text{Max. voltage across secondary, } V_m = 23 \times \sqrt{2} = 32.5\text{ V}$$

$$\therefore \quad PIV = V_m = \mathbf{32.5\ V}$$