UNIT –I

ACOUSTICS & ULTRASONICS

ACOUSTICS

What is acoustics?

Acoustics is a branch of physics that study the sound, acoustics concerned with the production, control, transmission, reception, and effects of sound.

The study of acoustics has been fundamental to many developments in the arts, science, technology, music, biology, etc

ACOUSTICS

- **Deals with the production, propagation and detection of sound waves**

Classification of sound:

(i) Infrasonic < 20Hz (Inaudible)

(ii) Audible 20 to 20,000Hz (Music and Noise)

(iii) Ultrasonic >20,000Hz (Inaudible)

Classification of audible sound

1. Musical sound and

2. Noise

1. Musical sound: A sound which produces a pleasing effect to our ears is called musical sound. The wave form produced by a musical sound has the following features:

   i. They are regular in shape

   ii. They have periodicities

   iii. Change in amplitude is uniform.

2. Noises: A noise produces unpleasant effect in our ears.

   i. They are irregular in shape

   ii. They are not periodic

   iii. Change in amplitude is not uniform

Characteristics of musical sound

(i) Frequency or pitch

(ii) Intensity or loudness

(iii) Timbre or quality

(i) Frequency or pitch

- Pitch:- *a degree of sensation depends on frequency*
- Frequency: *number of vibrations of sound producing object/second.*

(ii) Intensity or loudness

Intensity:

Amount of sound energy flowing per sec per unit area $I = Q/A$ watt/ m^2

Loudness:

- Loudness is the degree of sensation produced in our ears.
- The loudness of the sound varies from person to person.

(iii) Timbre or Quality

- Distinguish b/w any two or more musical sound having same pitch and frequency

Weber-Fechner law

Loudness is directly proportional to the logarithm of intensity

L α log I

L = K log I

where k is a constant

Acoustics of Buildings

The branch of science which deals with the planning of a building or a hall with a view to provide best audible sound to the audience is called acoustics of building.

Reverberation :

Persistence or prolongation of sound in a hall even after the sound source is stopped

Reverberation Time :

Time taken by the sound wave to fall below the minimum audibility level.

i.e., to fall to one millionth of its initial intensity, after the source is stopped

$$E = \frac{E_m}{10^6}$$

Where, E is the energy of the sound at any time t and E_m is the maximum sound energy produced before the source is cut off.

- According to Sabine, the reverberation time is given by

$$T = \frac{0.165V}{A} \text{ seconds}$$

Where, V is the volume of the hall and A is the total observation.

- Total absorption of any hall is given as

$$A = \sum as$$

Where, s is the area of sound absorbing surface and a, the coefficient of absorption.

- The optimum value of reverberation time of a hall is different for different sounds.

  It is 0.6 to 0.75 seconds for speech and 1 to 2seconds for music.

Factors Affecting Acoustics of Building and their Remedies

i. Reverberation and reverberation time

ii. Loudness

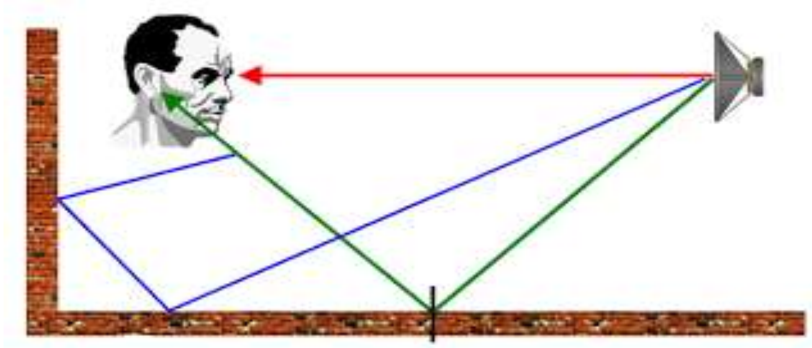
iii. Echo

iv. Echelon Effect

v. Resonance

vi. Noise

(i) <u>Reverberation</u>



The persistence or prolongation of sound in a hall even though the sound source is stop

<u>If Reverberation time is too low:</u>

Sound disappear quickly and become inaudible.

<u>If Reverberation time is too high:</u>

Sound exist for a long period of time-an overlapping of successive sounds-cannot hear the information clearly

<u>For the good audibility</u>

The reverberation time should be kept at an optimum value

Remedies

-reduced by installing sound absorbing materials like

- ❖ *Windows and openings*
- ❖ *Arranging full capacity of audience*
- ❖ *Completely covering the floor with carpets*
- ❖ *False ceilings*
- ❖ *Heavy curtains with folds and*
- ❖ *Decorating the walls with drawing boards, picture boards*

(ii) Loudness

Loudness is the degree of sensation produced on the ear. It varies observer to observer.

Remedies

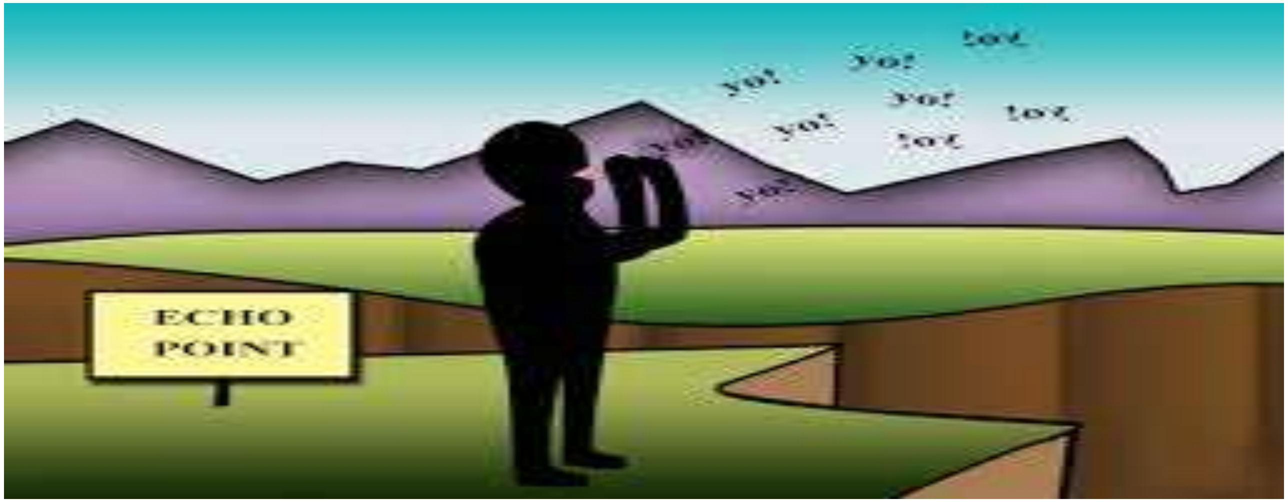
If loudness is low:

- Speakers may be placed at regular distances
- Properly focused sound boards behind speakers
- Lowering the ceiling and placing reflecting surfaces at necessary places.

<u>If loudness is high:</u>

- sound absorbents can be placed at noisy places.

(iii)Echo

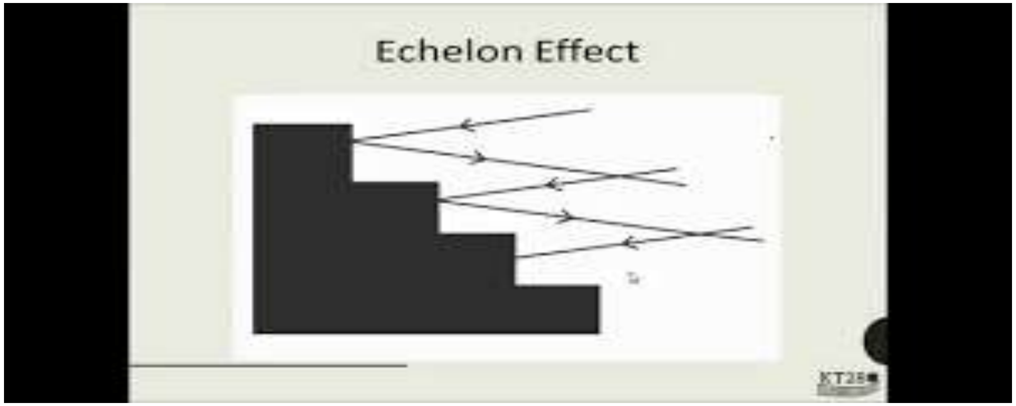


❖ If the time interval between the direct sound and the reflected sound is less than 1/15 of a second, the reflected sound reaches the audience later.

Remedies

❖ Properly covering the long distance walls, high ceilings with Suitable sound absorbing materials.

(iv) Echelon effect



- A set of railings or any regular spacing inside the hall.
- The sound produced inside the hall falls over these surfaces and reflected back. While the incident and reflected sound waves falls on such regular spacing, the original sound is confused. This effect is called as **Echelon effect.**

Remedy:

This effect should be avoided by providing sound absorbing materials on its surface.

(v) Resonance

If window panels or any other wooden sections are not covered properly, the original sound may vibrate with the natural frequency of them.

Remedies

- Vibrating materials should be mounted on non-vibrating and sound absorbing materials.
- Panels must be fitted properly.
- Eliminated through proper ventilation or by Air-conditioning.

(vi) Noise

❖ Unwanted sound produced externally/internally gives an irritating experience to the ears.

Different types of noises are:

(i) Air-borne noise,

(ii) Structure-borne noise and

(iii) Inside noise

Air-Borne Noise

Outside noise which reaches the audience through window, door and ventilator.

Remedies:

(i) The hall should be away from thickly populated area, factories and railway tracks.

(ii) With sound insulating materials, by air conditioning and by double door system it can be reduced.

Structure-Borne Noise

- Noise reaches the audience through the structural defect of the building.
- It is due to the movement of furniture, footsteps and the operation of heavy machinery like generators is created.

Remedy:

Use double walled doors, anti-vibration mounts, carpets etc.,

Inside Noise

Noise produced inside the hall like crying kids, the sound generated by type writers, fan, A/C, refrigerators, etc.,

Remedies:

- Equipments must be serviced properly.
- Equipment should be placed on sound absorbing mount.
- Floor, wall and ceiling must be covered with suitable sound absorbing materials.

Coefficient Of Absorption
(OR)
Absorption Coefficient

- The coefficient of absorption (a) of a material is defined as the ratio of sound energy absorbed by the surface to that of total sound energy incident on the surface.

- Since the open window is fully transmitting the sound incident on it, it is considered as an ideal sound absorber.

- Thus the unit of absorption is the open window unit (OWU) and is named as 'sabine' after the scientist who established the unit.

Determination of Absorption Coefficient

- Absorption coefficient of any material can be by placing the material inside the room.
- Initially the room is kept empty and its reverberation time is assumed to be T_1.

$$T_1 = \frac{0.165V}{A} \quad \text{-------- (1)}$$

- Then the sound absorbing material of area S and absorption coefficient α' is placed inside the room and again the reverberation time (T_2) is measured using the equation (2)

$$T_2 = \frac{0.165V}{A + \alpha' S} \quad \text{------ (2)}$$

Subtracting equation (1) from Equation (2), we get

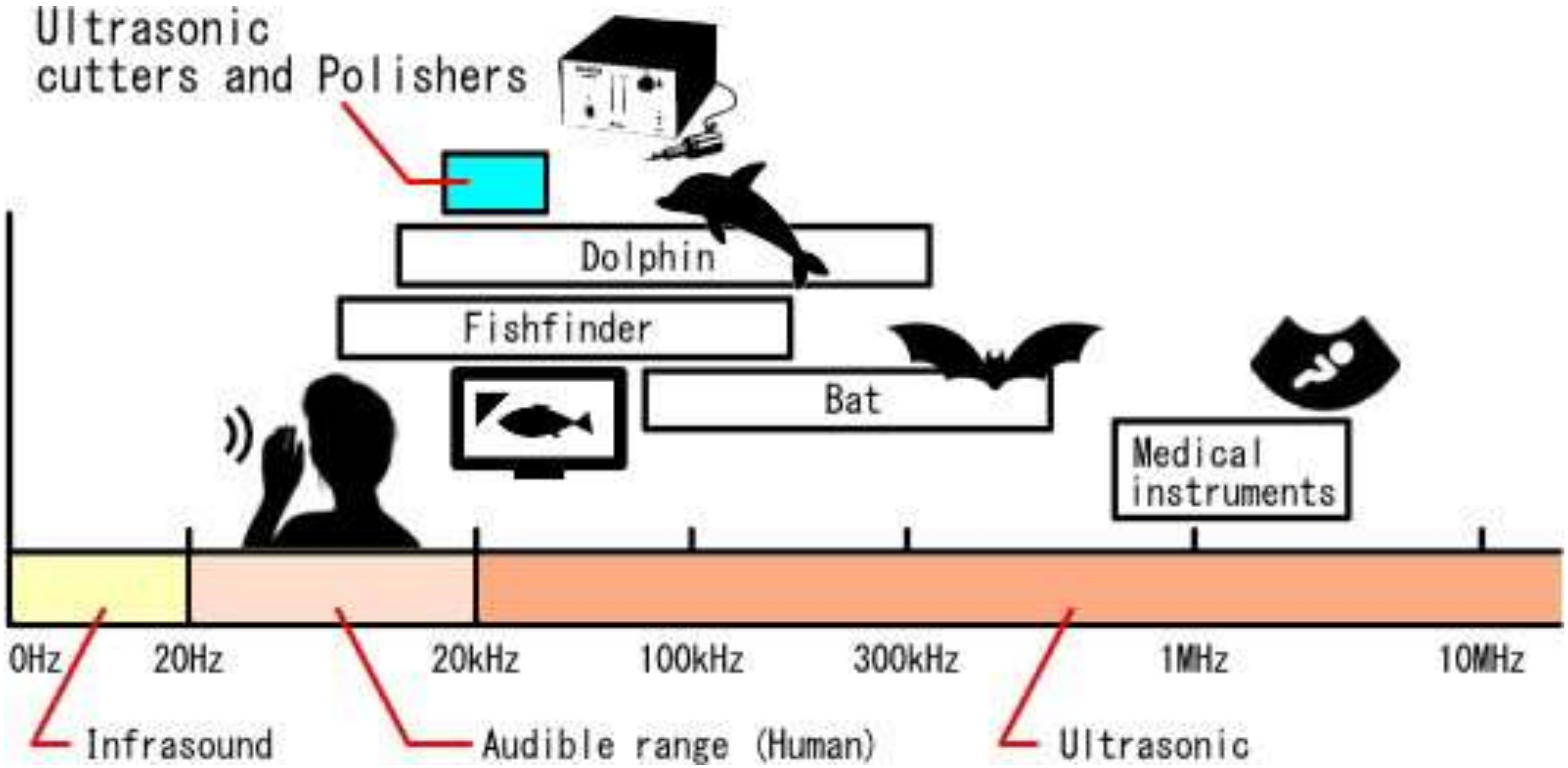
$$T_2 - T_1 = \frac{0.165V}{A + \alpha' S} - \frac{0.165V}{A}$$

$$= \frac{0.165V}{\alpha' S} \qquad \text{-------} \ (3)$$

or $$\alpha' = \frac{0.165V}{S(T_2 - T1)}$$

- Knowing the values on R.H.S of equation (3), the absorption coefficient of the material under test can be calculated.

ULTRASONICS



Properties of Ultrasonic Waves

(1) They have a high energy content.

(2) Just like ordinary sound waves, ultrasonic waves get reflected, refracted and absorbed.

(3) They can be transmitted over long distances with no appreciable loss of energy.

(4) If an arrangement is made to form stationary waves of ultrasonic in a liquid, it serves as a diffraction grating. It is called an ***acoustic grating***.

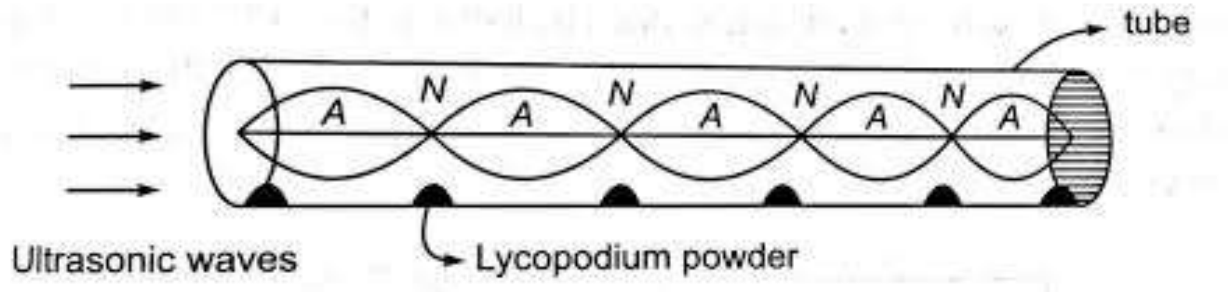
(5) They produce intense heating effect when passed through a substance.

Detection Of Ultrasonic Waves

- The presence of ultrasonic waves in a medium can be detected by the following methods.

- ❖ Kundt's tube method
- ❖ Sensitive flame method
- ❖ Thermal method
- ❖ Piezo-electric method

Kundt's Tube Method



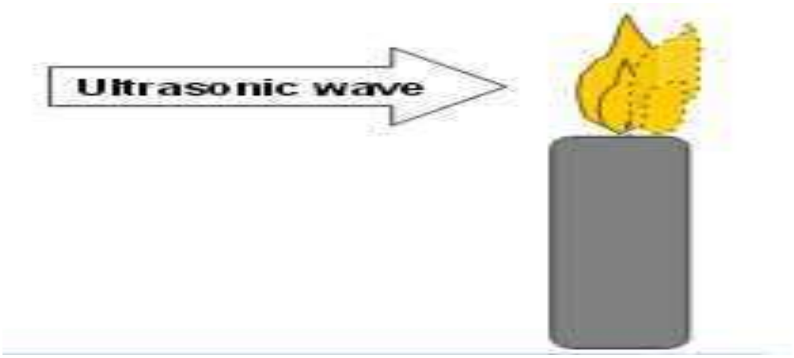
- Lycopodium powder is spread uniformly inside the tube.

- The ultrasonic wave is passed inside the Kundt's tube which is placed horizontally.

- When the ultrasonic wave is traveling inside the tube, the lycopodium powder gets collected in the form of heaps at nodes and is blown off at antinodes.

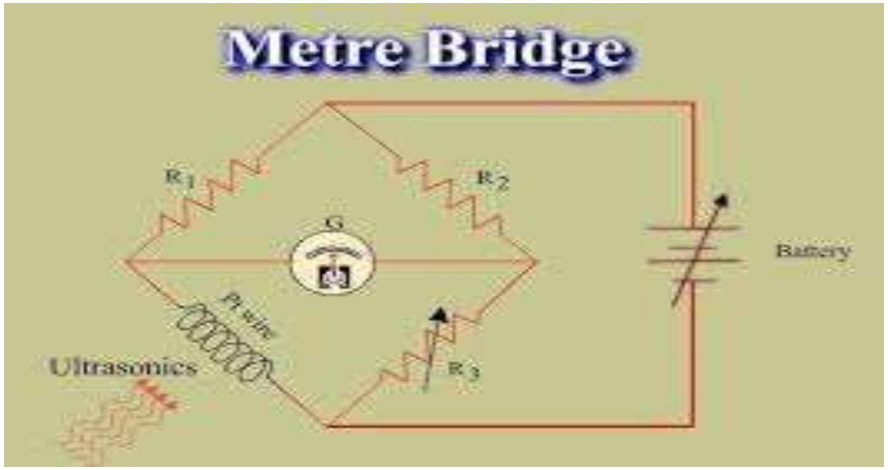
- The formation of heaps shows the existence of ultrasonic waves.

Sensitive Flame Method



- When a narrow sensitive flame is moved in an ultrasonic medium, the change in intensity of the flame is observed.
- The change in intensity is due to high frequency of ultrasonic waves.
- The change in intensity is observed only at nodes and remains unchanged at antinodes.
- Thus the ultrasonic waves are detected.

Thermal Method

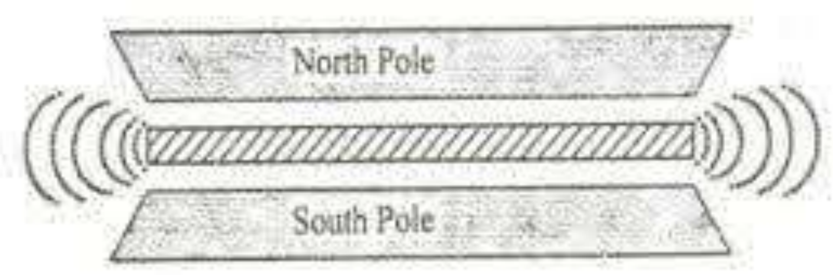


- If the platinum wire is moved in the region of ultrasonic waves, the temperature of the medium changes due to alternate compression and rarefactions.
- There is a change in temperature at nodes and it remains constant at antinodes.
- The change in temperature causes change in resistance of the wire.
- Thus by measuring the change in resistance by meter bridge set up, the ultrasonic waves can be detected

Piezo-electric Method

- Piezo-electric method can also be used for the detection of ultrasonic waves.
- When the faces perpendicular to the optic axis of a crystal is placed in the path of ultrasonic waves, equal and opposite charges are produced on the faces parallel to the optic axis.

Magnetostriction Effect



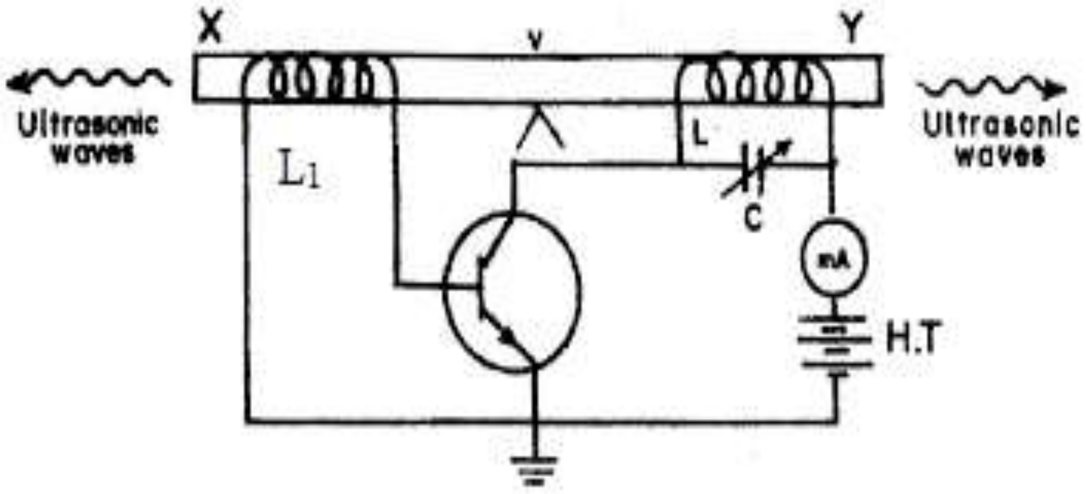
- When a bar of ferromagnetic material, like nickel, cobalt etc. is placed in an alternating magnetic field parallel to its length, it undergoes slight change in dimension.
- This change in length is independent of the field and may be decreased or increased depending on the materials.
- With high frequency alternating magnetic field, the bar contracts and expands alternatively and begins to vibrate to and fro and producing ultrasonic waves at its ends.

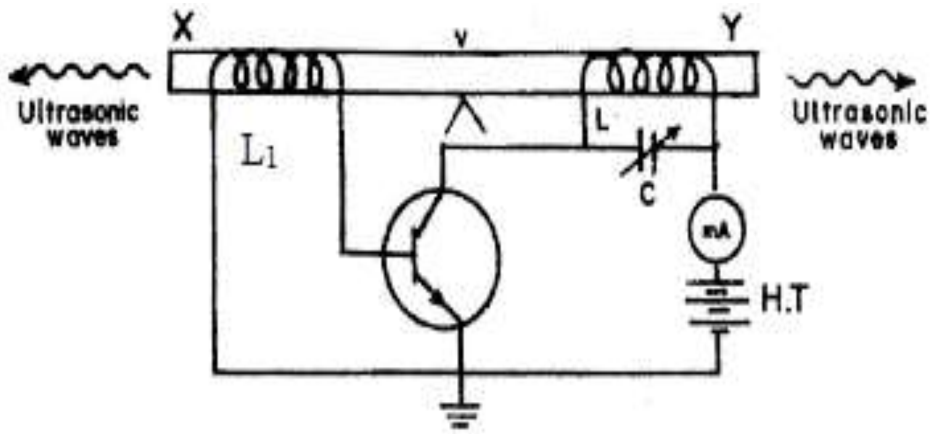
Magnetostriction Generator

Principle

- When an alternating magnetic field is applied to a bar of ferromagnetic materials, it undergoes a change in dimension there by producing ultrasonic waves at resonance is called magnetostriction principle.

Description





- The magnetostriction generator consists of a ferromagnetic rod XY, clamped at its centre.
- Two coils L and L_1 are wound at the ends of the rod as shown in Fig.
- The coil L_1 is connected to the base of the transistor and is used as a. feed back loop
- The coil L is connected to the collector of the transistor and C is the variable capacitor connected parallel at the two ends of the coil L which forms a tank circuit.
- The frequency of the oscillatory circuit (LC) can be adjusted by the capacitor C. The battery is connected in the circuit to provide necessary biasing.

Working

- The battery is switched on and hence current is produced by the transistor.
- This current is passing through the coil L which in turn causes magnetic effect over the rod.
- Because of the magnetic effect, the rod starts vibrating due to magnetostriction effect.
- When the rod is vibrating, an e.m.f is induced in the coil L_1. The induced e.m.f. is fed into the base of the transistor which acts as a feed back for the circuit.
- In this way, the current in the transistor is built up and the vibration of the rod is maintained.
- The frequency of the oscillatory circuit is adjusted by the variable capacitor C.
- When the frequency of the oscillatory circuit becomes equal to the natural frequency of the rod, resonance effect occurs.
- At the resonance condition, the rod vibrates with larger amplitude, producing high frequency ultrasonic waves at both the ends of the rod.

- The frequency of the oscillatory circuit is given as

$$f = \frac{1}{2\pi\sqrt{LC}}$$

- The natural frequency of the ferromagnetic rod is given as

$$f = \frac{1}{2l}\sqrt{\frac{E}{\rho}}$$

Where l is the length of the rod, E is the Young's modulus of the rod and ρ is the density of material of the rod.

At the resonance condition

❖ The frequency of the oscillatory circuit = The natural frequency of the rod

$$\frac{1}{2l}\sqrt{\frac{E}{\rho}} = \frac{1}{2\pi\sqrt{LC}}$$

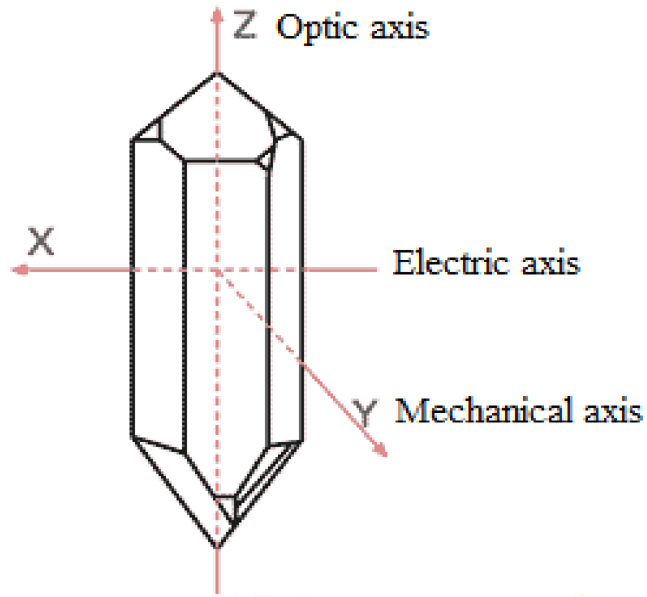
Advantages

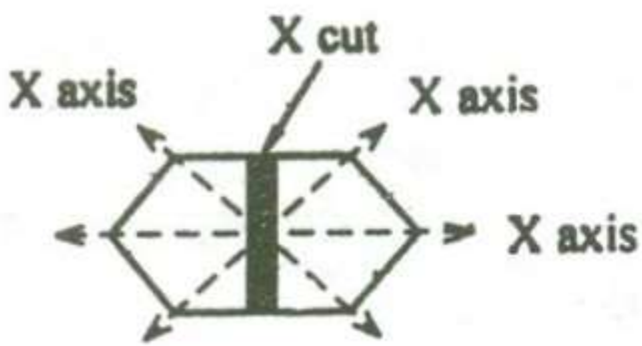
- The design of the oscillatory circuit is very simple and its production cost is low.
- At low frequencies, large power output is possible without causing any damage to the oscillatory circuit.

Disadvantages

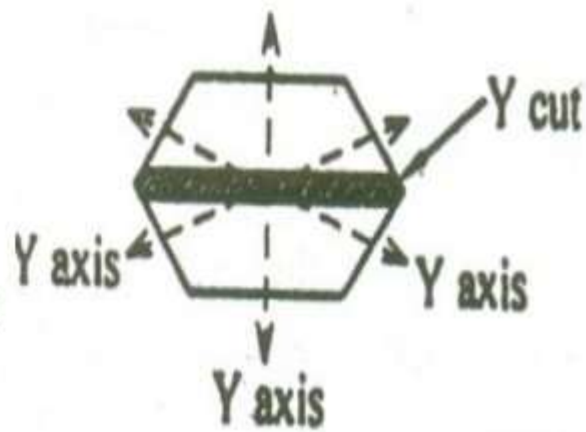
- It can produce frequencies up to 3MHz only.
- The frequency of oscillations depends on the temperature.
- As the frequency is inversely proportional to the length of the rod, the length of the rod should be decreased to increase the frequency which is practically impossible.

Piezo-electric Crystal



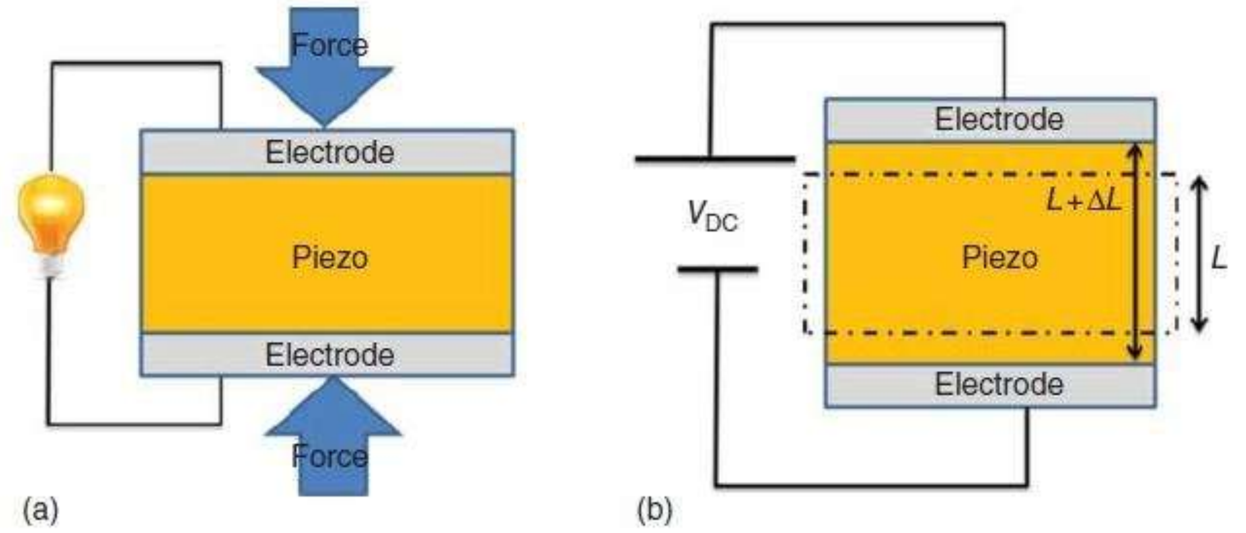


X-cut crystal



Y-cut crystal

Piezo-electric Effect



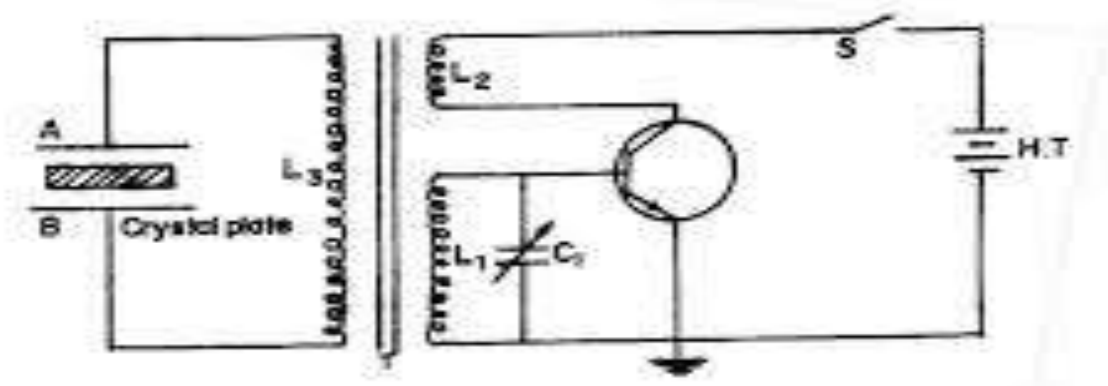
- When a mechanical force is applied along certain axis called mechanical axis with respect to optic axis of the crystal, equal and opposite charges are produced along the perpendicular axis called electric axis. This effect is called piezo-electric effect Fig. (a).
- The inverse of piezo-electric effect is also possible. When the potential difference is applied along the electric axis of the piezo-electric crystal, the crystal starts vibrating along the mechanical axis. This effect is called inverse piezo-electric effect Fig.(b).

Piezo-electric Generator

Principle

- When the potential difference is applied along the electric axis of the piezo-electric crystal, the crystal starts vibrating along the mechanical axis. This in turn produces ultrasonic waves of higher frequencies. This effect is called inverse piezo-electric effect.

Description



Description

- This is based on the principle of inverse piezo-electric effect.
- The piezo-electric generator consists of primary and secondary circuits.
- The coils L_1, L_2 and L_3 are inductively coupled.
- The primary circuit is arranged with coils L_1 and L_2.
- One end of the coil L_1 is connected to the base of the transistor and the other end is connected to the negative of the battery.
- One end of the coil L_2 is connected to the collector of the transistor and the other end to the positive of the battery.
- The capacitor C_1 is connected in parallel with the ends of L_1 forms a tank circuit.
- The coil L_2 is coupled to the secondary circuit, which comprises of coil L_3.

Working

- The battery is switched ON and the current is produced by the transistor.
- The current is passed through the coils L_1 and L_2.
- Due to the transformer action an e.m.f is induced in the coil L_3 and is fed into the plates A and B.
- With the induced e.m.f. across A and B, the crystal starts vibrating along the axis called mechanical axis.
- The frequency of the oscillatory circuit is adjusted by the variable capacitor C_1.
- When the frequency of the oscillatory circuit becomes equal to the frequency of the crystal, the resonance occurs.
- At the resonance condition the crystal vibrates with maximum amplitude and the ultrasonic waves are generated at both the ends of the crystal.

- The frequency of the oscillatory circuit is given as

$$f = \frac{1}{2\pi\sqrt{L_1 C_1}}$$

- The fundamental frequency of longitudinal vibrations of crystal is given as

$$\frac{P}{2l}\sqrt{\frac{E}{\rho}}$$

- Where l is the length of the crystal is E Young's modulus of the crystal, ρ is the density of the crystal and P is the number of overtones, say 1, 2, 3 …

❖ At the resonance condition

The frequency of the oscillatory circuit = The frequency of the crystal

$$\frac{1}{2\pi\sqrt{L_1 C_1}} = \frac{P}{2l}\sqrt{\frac{E}{\rho}}$$

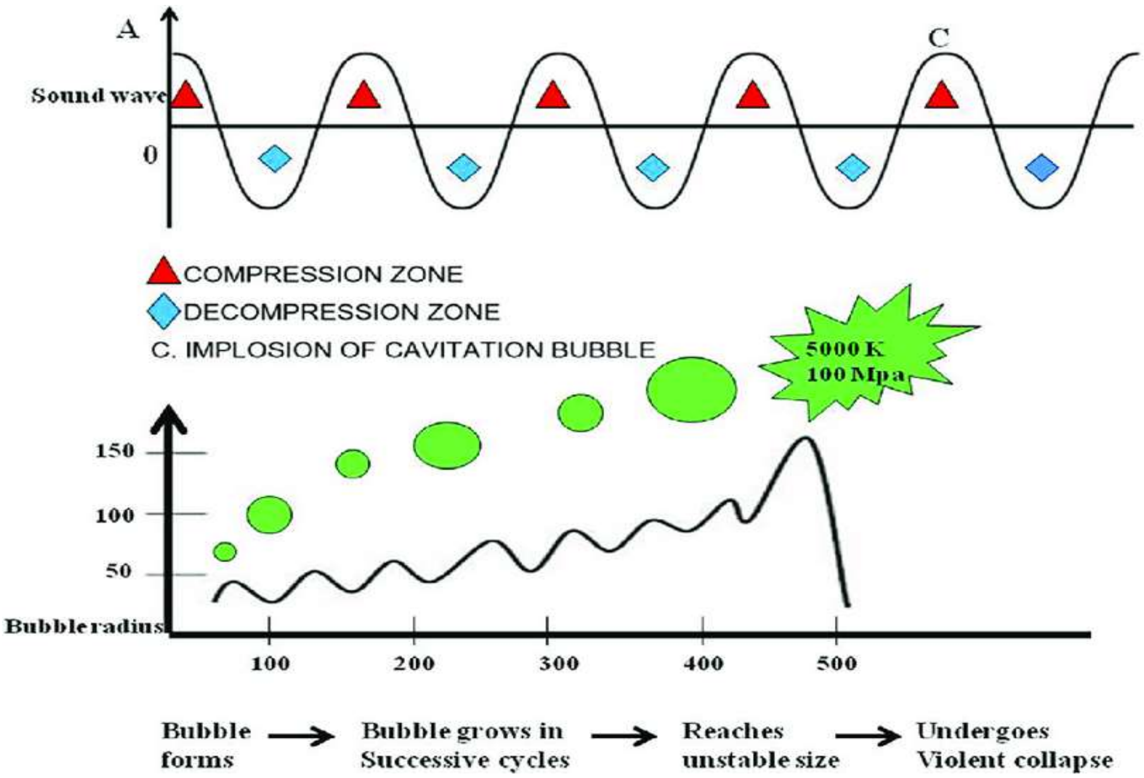
Advantages

- High frequency ultrasonic waves in the order of 500MHz can be produced.
- The production of ultrasonic waves is independent of temperature and hence the output power is high.
- It is more efficient than magnetostriction generator.

Disadvantages

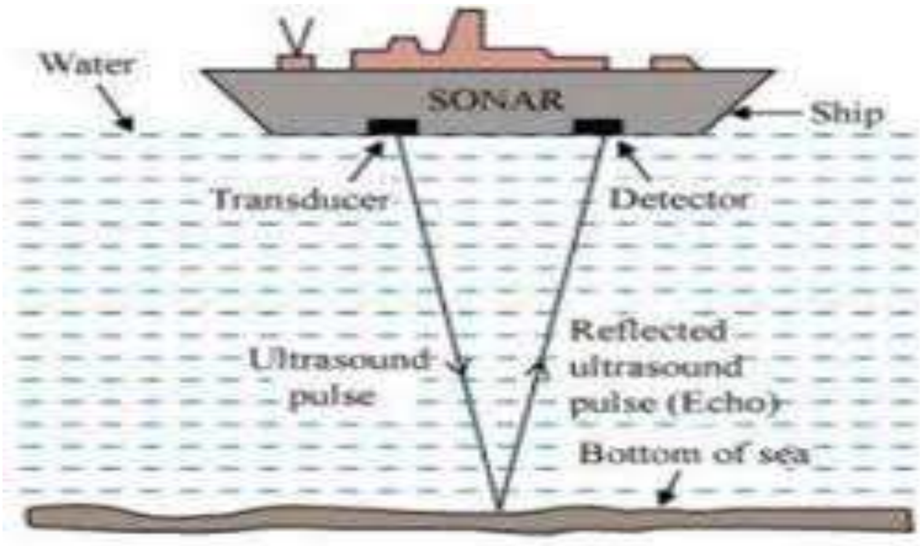
- The cost of quartz crystal is high.
- Cutting and shaping the crystal is more complex.

CAVITATION



- Cavitation is the process of creation and collapse of bubbles due to negative local pressure created inside the bubble.
- Ultrasonic waves while passing through the liquid medium induce compression and rarefaction and create millions of microscopic low pressure bubble
- A negative local pressure at the rarefaction causes local boiling of the liquid accompanied by the bubble growth and it gets collapse. This phenomenon is known as cavitation.

SONAR



- Sonar (**so**und **na**vigation and **r**anging) is a technique that uses sound propagation to navigate, communicate with or detect objects on or under the surface of the water.
- A sonar device sends pulses of sound waves down through the water. When these pulses hit objects like fish, vegetation or the bottom, they are reflected back
- Sonar uses sound propagation to help ships and submarines navigate the oceans and seas.
- Sonar can also be used to explore the depths of the ocean and the various objects found under the sea.
- Another type of application is in medicine and is called ultrasound medical imagining.

Non-Destructive Testing

- Non-destructive testing defines and locates flaws within a material without destroying or defacing the product.
- Ultrasonic non-destructive testing is one of the major tests to find out the defects, cracks and discontinuities in a medium.
- Ultrasonic energy striking at an interface of two different materials is partially reflected and partially transmitted.
- The transmitted energy in the medium is utilized for the inspection purpose.

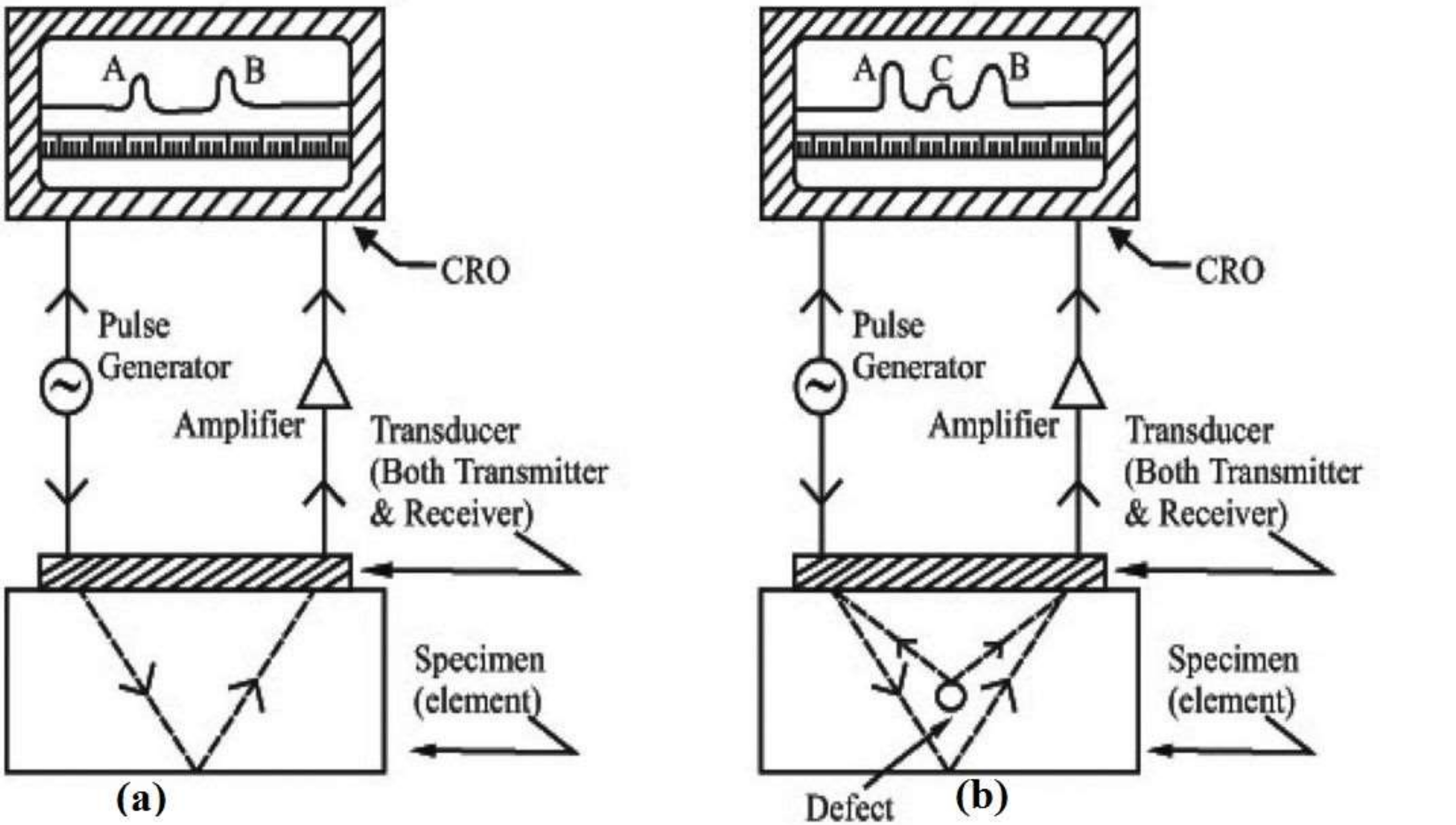
Important testing techniques

- Pulse-echo method
- Through transmission method
- Resonance method.

Pulse-Echo Method

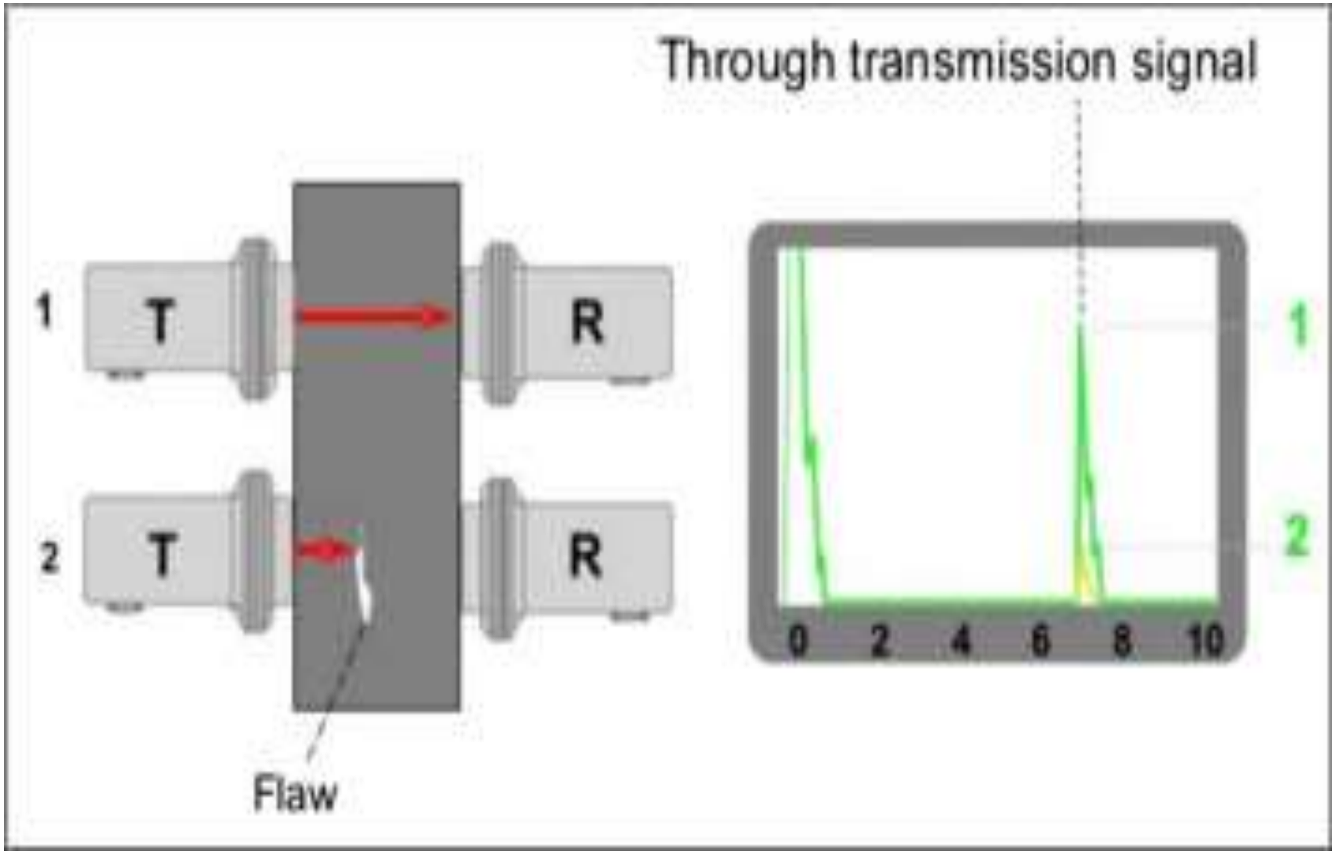
PULSE-ECHO SYSTEM THROUGH REFLECTION MODE

*Reflected ultrasound **(echoes)** comes from an interface, such as the back wall of the object or from an imperfection within the object*



- In this method, high frequency ultrasonic waves are generated with the help of piezoelectric crystal and transmitted into the material under testing.
- The principle of reflection of ultrasonic waves at the interface of two different media is used in this method.
- The reflected sound waves are received by the transducers and converted into electrical energy.
- If the material does not have any flaws inside, the pulses produced in the CRO is as shown in the Fig.(a)
- Two pulses, one is due to the reflection at the front surface and the other is due to the reflection at the back surface of the material are produced.
- If the material has a flaw in the path of ultrasonic waves, one additional reflection is produced as shown in the Fig.(b)
- It shows that there is an acoustical impedance mismatch in the path of ultrasonic waves.
- Using the amplitude and time of travel through the material, the length of the specimen or the distance at which the flaw is located can be determined.
- In this method a single transducer can be used to transmit and receive the signals.

Through Transmission Method



- In this method two transducers are used in which one acts as transmitter (T) and the other acts as a receiver (R).
- The transmitter and receiver are connected in the opposite sides of the specimen which is under testing.
- The ultrasonic beam from the transmitter travel through the material to the opposite face and is received by a receiver.
- The received ultrasonic waves are converted into electrical pulses and then fed into the CRO.
- Any defect in the path of the ultrasonic beam can produce reduction of sound energy reaching the receiver.
- The material with no defect produces the pulses of same height in the CRO as shown in Fig.1
- The existence of flaw in the material can be identified by reduction of sound energy (smaller pulse) as shown in Fig.2
- Thus the defects presents inside the material can be studied using this method.

Resonance Method

- The system consists of a transducer which is connected to the specimen and a CRO with transmitting and receiving signals.
- The transducer produces an ultrasonic wave (longitudinal wave) which is transmitted through the specimen. These waves get reflected between the opposite faces of a specimen. The probe is moved on the surface of the material to study the resonant frequency.
- The frequency of this longitudinal wave is varied continuously till the standing waves are setup in the material. Standing waves are created by adjusting the frequency of the ultrasonic waves.
- Due to the formation of standing waves inside the specimen, the material vibrates at its resonance frequency with maximum amplitude.
- When the probe is moved on the surface, if a change of resonant frequency is observed, it is due to the presence of discontinuity only.
- Knowing the frequency at resonance 'f ' and velocity of the ultrasonic wave in the test piece 'v', the thickness 't' can be calculated from the relation,

$$t = \frac{v}{2f}$$


Thank you

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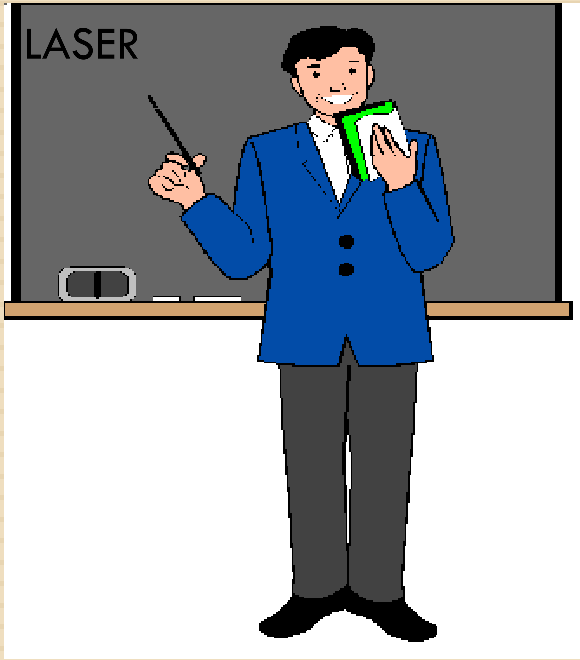
ENGINEERING PHYSICS

UNIT- II LASER

Introduction

- Lasers are optical phenomena used in the field of science and technology now a day. Laser is an acronym for ***Light Amplification by Stimulated Emission of Radiation.***



PROPERTIES (OR) CHARACTERISTICS OF LASERS

- The laser is distinguished from the ordinary conventional source of light due to the following special features;
- High monochromatic
- High degree of coherence
- High intensity
- High directionality

Monochromatic

- The laser light is highly monochromatic (***having single frequency***) than any other light sources. The light from the conventional source spreads over wider range of frequencies.
- The line width $\Delta\lambda$ emitted by a laser is nearly 5×10^{-4} Å but it is only 10^{-5} Å for a conventional source.

Coherence

- It is an important characteristic of a laser beam. The wave trains are said to be coherent when they are having ***same frequency and phase*** that gives high purity of spectral line.
- Due to this coherence property, it is possible to create high power laser in the order of 10^{13}W of 1μm diameter.

Intensity

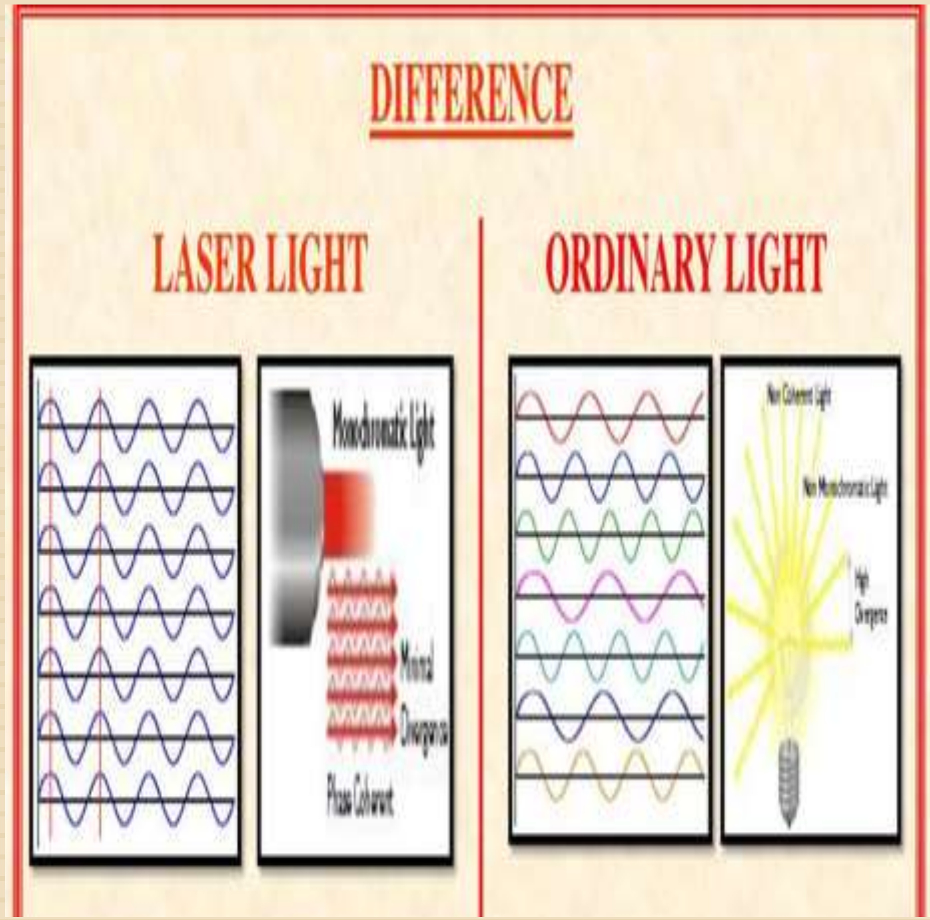
- The intensity of laser light is very high. 1watt laser is many thousand times more intense than 10watt ordinary light.
- Since the beam spread of the laser is very smaller, a narrow beam of light with high energy is concentrated in a smaller region. This concentration of light beam is expressed in terms of intensity.

Directionality

- The ordinary light source emits light in all directions due to ***spontaneous emission***. On the other hand, laser emits light only in one direction due to ***stimulated emissions***.
- Ordinary light spreads in all directions with an angular spread of 1m/metre, whereas in laser it is highly directional with a beam spread of 1mm/metre. i.e., laser beam can be focused to very long distance with smaller angular spread.

DIFFERENCES BETWEEN ORDINARY LIGHT AND LASER LIGHT

Laser light	Ordinary light
The radiations are polychromatic.	The radiations are monochromatic
It is not a coherent beam	It is a coherent beam
Intensity of light is lesser	Intensity of light is higher
Ordinary light is not directional	Laser light is more directional
The angular spread is more	The angular spread is less



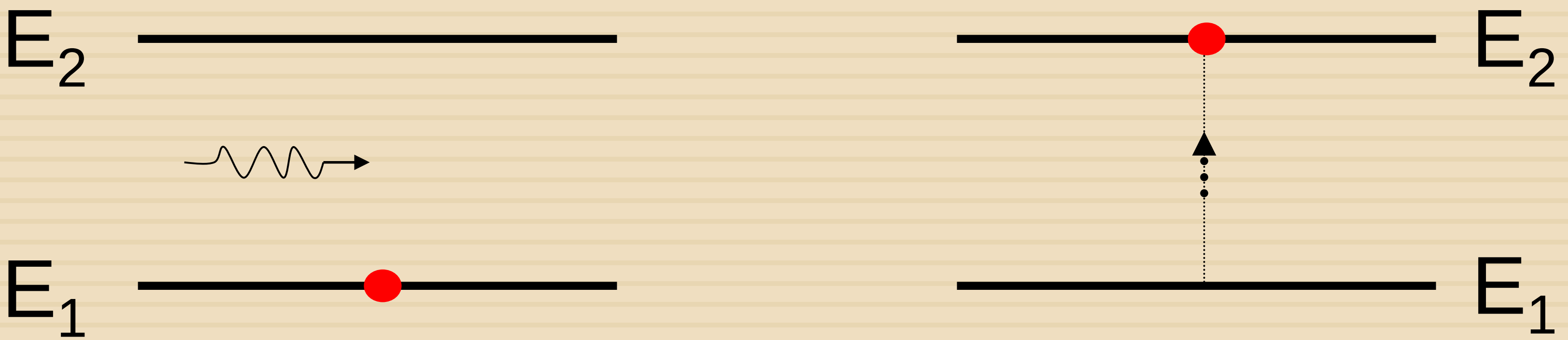
EINSTEIN'S THEORY OF A AND B COEFFICIENTS

Laser makes use of three fundamental phenomena

- Process of absorption
- Spontaneous emission and
- Induced (Stimulated) emission

Process of absorption

- Atom in the ground state of energy E_1 absorbs a photon of energy ($h\nu = E_2 - E_1$) and rises to the higher state of energy E_2



- It is the no.of atoms undergoing absorption per second, N_{ab}

$$N_{ab} \propto N_1, \text{ No.of atoms in } E_1$$

$$\propto Q, \text{ No. of photons}$$

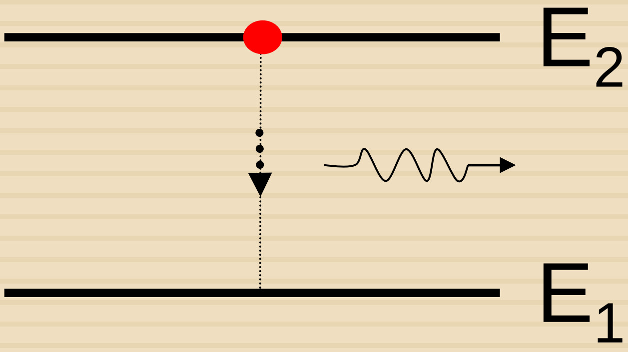
$$N_{ab} \propto N_1 Q$$

$$or \quad \boxed{N_{ab} = B_{12} N_1 Q} \ldots\ldots\ldots\ldots 1$$

- Where B_{12} is the probability of transition of atoms from energy level E_1 to E_2

Spontaneous emission

- Atom in the higher state of energy E_2 emits a photon of energy ($h\nu = E_2 - E_1$) spontaneously and returns to the lower energy state of energy E_1



- It is the no.of atoms undergoing spontaneous emission per second, N_{sp}

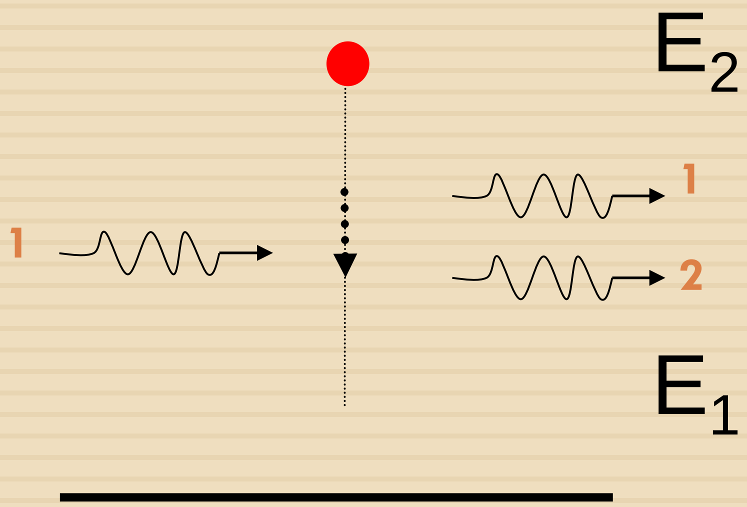
$$N_{sp} \propto N_2, \text{ No.of atoms in } E_2$$

$$or \quad \boxed{N_{sp} = A_{21} N_2} \ldots\ldots\ldots\ldots 2$$

- Where A_{21} is the probability transition from energy level E_2 to E_1

Stimulated emission

Atom in the higher state of energy E_2 is stimulated (by a photon of relevant energy) to emit a photon of energy ($h\nu = E_2 - E_1$) and returns to the lower energy state of energy E_1



- It is the no.of atoms undergoing stimulated emission per second, N_{st}

$$N_{st} \propto N_2, \text{ No.of atoms in } E_2$$

$$\propto Q, \text{ No. of photons}$$

$$N_{st} \propto N_2 Q$$

$$or \quad \boxed{N_{st} = B_{21} N_2 Q} \text{..........3}$$

- Where, B_{21} is the probability of transition of atoms moving from E_2 to E_1 by stimulation

- The coefficients A_{21}, B_{12} and B_{21} are Einstein's coefficients
- At thermal equilibrium,

  the no.of downward transitions =

  the no.of upward transitions

$$A_{21}N_2 + B_{21}N_2Q = B_{12}N_1Q$$

$$A_{21}N_2 = B_{12}N_1Q - B_{21}N_2Q$$

$$= Q\left(B_{12}N_1 - B_{21}N_2\right)$$

$$Q = \frac{A_{21}N_2}{B_{12}N_1 - B_{21}N_2}$$

$$= \frac{A_{21}N_2}{B_{21}N_2\left(\dfrac{B_{12}N_1}{B_{21}N_2} - 1\right)}$$

or

$$Q = \frac{A_{21}}{B_{21}} \frac{1}{\left(\dfrac{B_{12}}{B_{21}}\right)\dfrac{N_1}{N_2} - 1} \quad \ldots\ldots\ldots\ldots\ldots 4$$

- Consider a system in which N_0 – no.of atoms in E_0 and N_1 – no.of atoms in E_1
- According to Boltzmann's distribution law,

$$N_1 = N_0 e^{\left(\frac{-[E_1 - E_0]}{kT}\right)} \quad \ldots\ldots\ldots\ldots\ldots 5$$

$$N_2 = N_0 e^{\left(\frac{-[E_2 - E_0]}{kT}\right)} \quad \ldots\ldots\ldots\ldots\ldots 6$$

where k - Boltzmann constant

From equations 5 and 6, we get

$$\frac{N_1}{N_2} = \frac{N_0 e^{\left(-\frac{E_1 - E_0}{kT}\right)}}{N_0 e^{\left(-\frac{E_2 - E_0}{kT}\right)}} = e^{\frac{E_2 - E_1}{kT}}$$

$$\frac{N_1}{N_2} = e^{\frac{h\nu}{kT}} \qquad (\text{where } \mathrm{h}\nu = \mathrm{E}_2 - E_1)$$

Substituting in equation 4,

$$Q = \left(\frac{A_{21}}{B_{21}}\right) \frac{1}{\left(\frac{B_{12}}{B_{21}}\right) e^{\frac{h\nu}{kT}} - 1}$$

This equation agrees with Planck's energy distribution formula

$$Q = \frac{8\pi h\nu^3}{c^3} \frac{1}{e^{\frac{h\nu}{kT}} - 1}$$

Comparing these two equations , we get

$$B_{12} = B_{21}$$

(Probability of spontaneous absorption is equal to that of stimulated emission)

Also, we get

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}$$

Ratio of spontaneous emission to the stimulated emission is proportional to ν^3

Probability of spontaneous emission dominates over stimulated emission, under normal thermal equilibrium condition.

DIFFERENCE BETWEEN SPONTANEOUS AND STIMULATED EMISSION OF RADIATION

S.No	Spontaneous emission	Stimulated emission
1.	An atom in the excited state is returns to ground state by emitting a single photon without any external inducement.	An atom in the excited state is forced to go to ground state, resulting in two photons of same frequency and energy.
2.	The emitted photons move in all directions and are random.	The emitted photons move in all directions and are random.
3.	The radiation of light is less intense, polychromatic and incoherent	The radiation of light is highly intense, monochromatic and coherent
4.	Angular spread is more	Angular spread is less

PRINCIPLE OF LASER

- **Population inversion**
- Consider two energy level systems E_1 and E_2. Normally the number of atoms (population) presents in the ground state N_1 is higher than the number of atoms in the excited state $N_{2.}$

i.e., $N1 > N_2$.

- The process of making the number of atoms in the excited state higher than that of the ground state is called ***Population inversion (or) Inverted population***.

i.e., $N_2 > N_1$

The condition of population inversion is necessary for achieving the stimulated emission of radiation.

Condition for population inversion

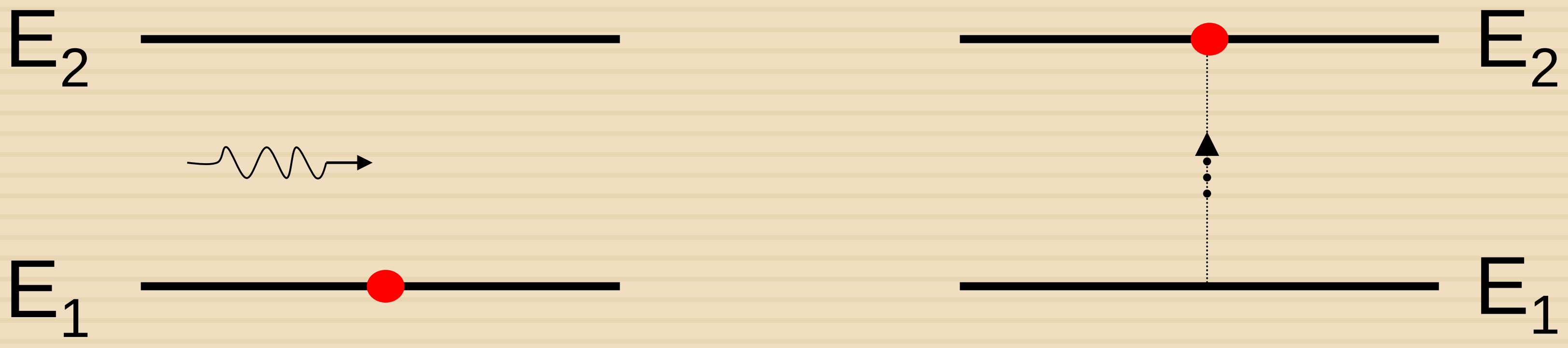
- There must be at least a pair of energy levels separated by a desired radiation
- There must be a source to supply energy to the medium
- The atoms must be raised continuously to the exited state

Pumping

- The process of raising the atoms from ground state to excited state by artificial means is called Pumping process.
- Optical pumping
- Electric discharge method pumping
- Inelastic collision between atoms
- Direct pumping

Optical pumping

- Atoms are excited by means of external optical source



This method is applied in solid lasers like Ruby laser,Nd-YAG laser

Electric discharge method

Electrons are accelerated to high velocity by strong electric field.These electrons collide with neutral atoms and ionize them. Due to ionization, atoms get raised to higher energy state

- This type of pumping is used in gas lasers like CO_2 .
- $A+e \rightarrow A^{*}+e_1$
- Where A is the gas molecules in the ground state

  e is an electron with high velocity

  A^{*} is the same gas molecule in the excited state

  e_1 is the same electron with lesser energy

Inelastic collision between atoms

- Combination of two gases are used
- Excited states of two gaseous atoms coincide or nearly coincide in energy
- First, 'A' atoms get excited to higher energy state(A^*)due to collision with electrons

$$A+e \rightarrow A^*+e_1$$

- Next, excited 'A^* ' atoms will excite to 'B' atoms by inelastic collision

$$A^*+B \rightarrow A+B^*$$

Direct Pumping

- Conversion of electrical energy into light energy
- It is used in semi conducting lasers

Basic requirement for laser system

- Active medium
- Pumping method
- Optical resonator

Active medium

- A medium in which population inversion is achieved for laser action
- Solid laser – active medium is solid
- Gaseous laser – active medium is in the gaseous state

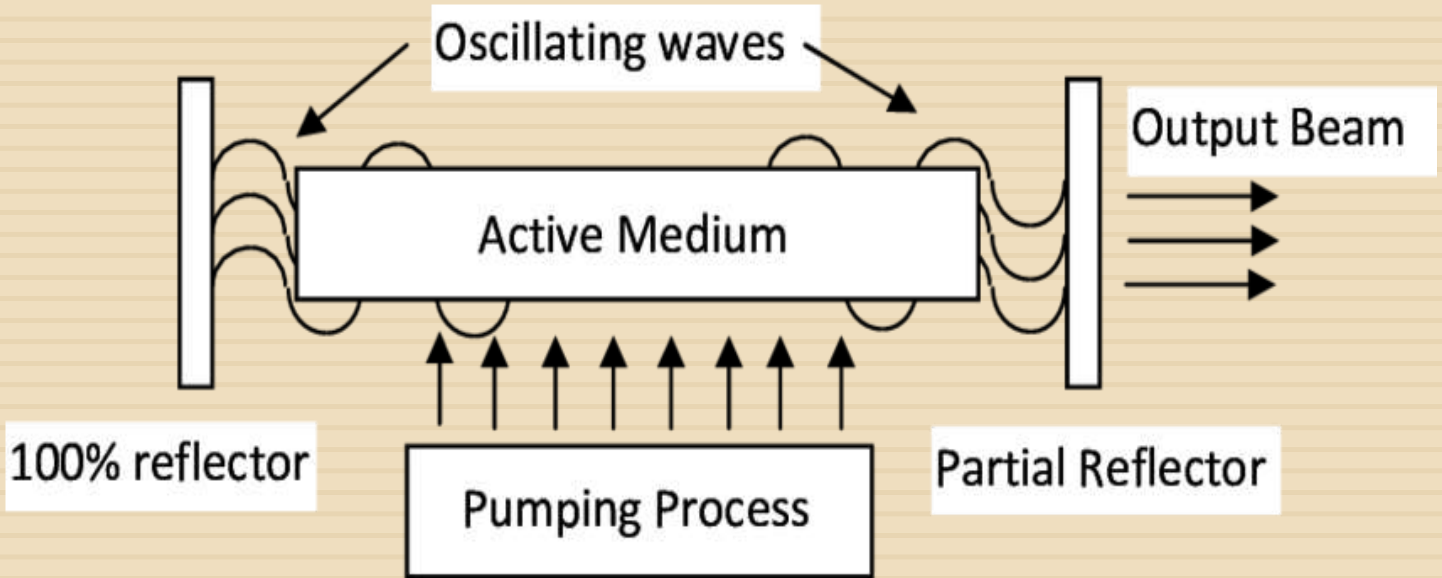
Pumping method

- The process of raising the atoms from ground state to excited state by artificial means is called Pumping process

Optical resonator

Optical resonator - A pair of two reflectors

One is perfect reflector and the other is partial reflector
It is used for **amplification of photons**, thereby increasing the intensity and coherence



TYPES OF LASERS

- Lasers are generally classified into the following categories based on the active medium.
- Solid state laser
- Gas laser
- Semiconductor laser
- Liquid laser
- Dye laser

Solid state laser

- This type of laser is generated from the solid substances like crystalline materials. These are high power lasers. Since it easily achieving population inversion, wastage of power input is low.
- Example: Ruby laser and Nd-YAG laser

Gas laser

- Laser generation from the mixture of gases is called gas lasers. This kind of lasers is used for cutting and welding of materials.
- Example: Co_2 laser and He-Ne laser.

Semiconductor laser

- Emission of lasers from the junction region of different semiconductors are called semiconductor laser. They are used for communication purposes.
- Example: Gallium-Arsenide semiconductor laser.

Liquid laser

- These are low power lasers generated by liquid mixture.
- Example: Europium benzoylacetonate dissolved in alcohol.

Dye laser

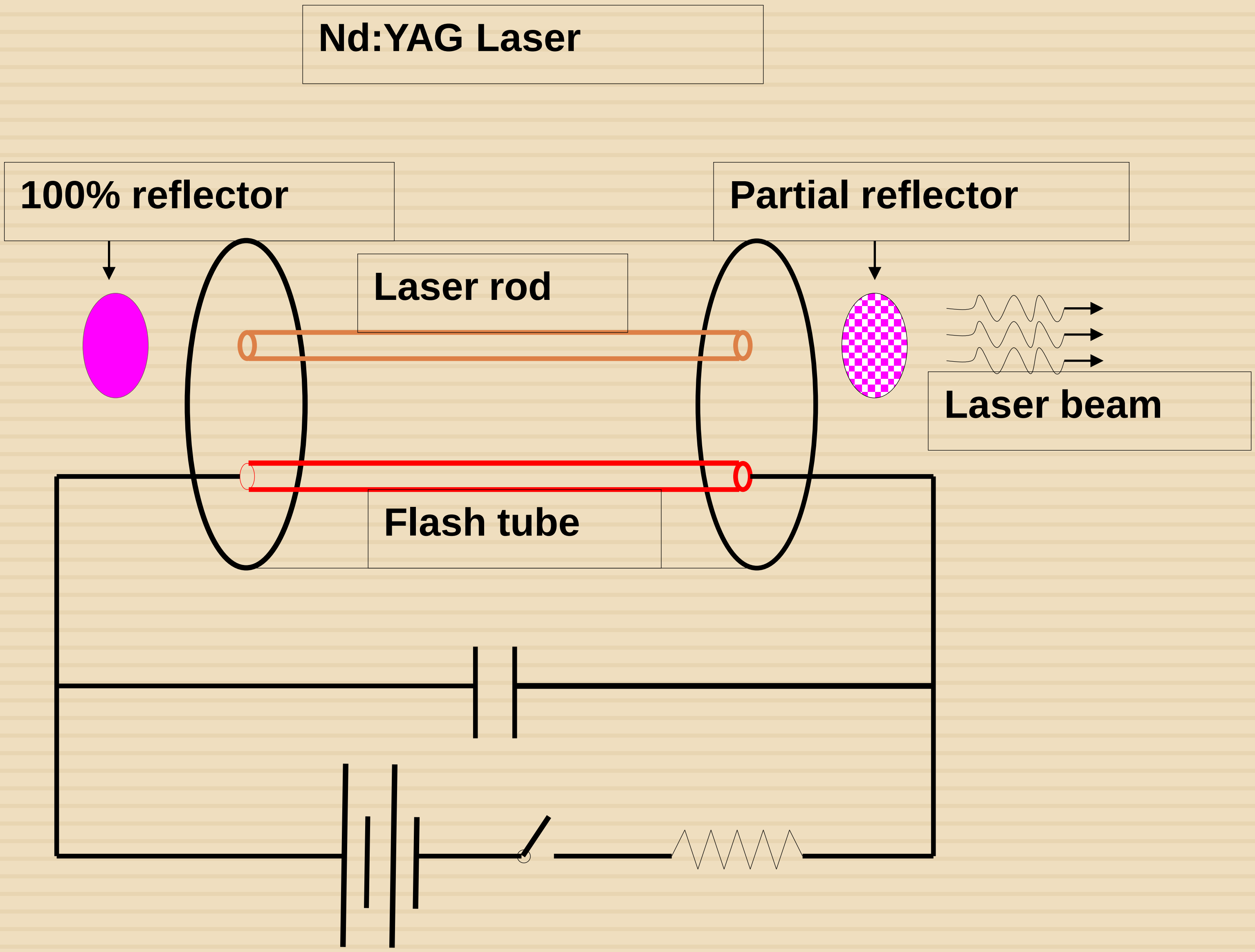
- A dye laser is a laser which uses an organic dye. They have high gain, high efficiency and are widely used in industries.
- Example: Rhodamine

Nd – YAG laser

- **Principle**
- Yittrium Aluminum Garnet crystal doped with Neodymium is used as an active medium. The neodymium ions are excited to higher energy level by optical pumping and fall back to metastable state spontaneously.
- During the downward transition from metastable state to ground state, laser is emitted by stimulation.

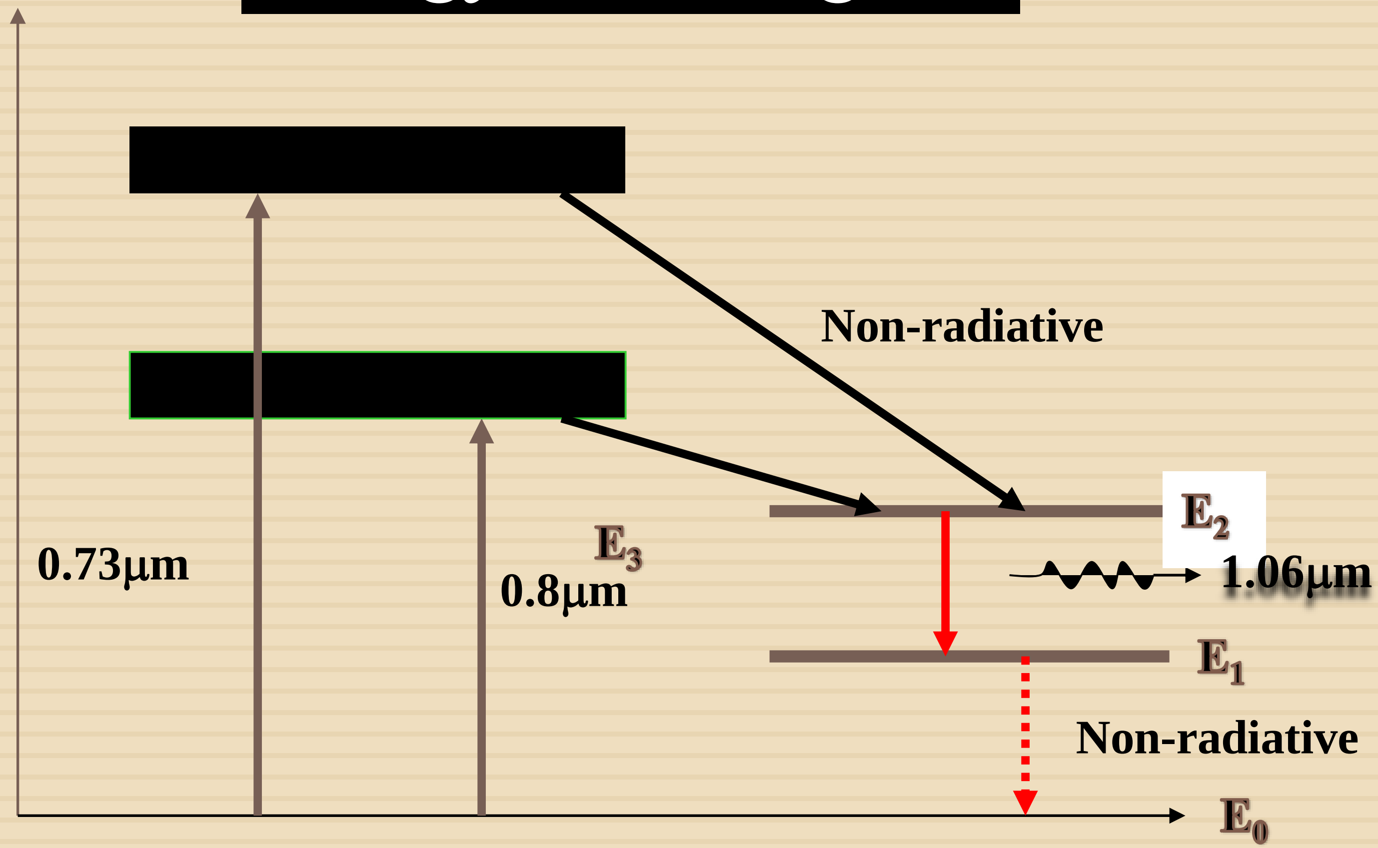
Construction

- It is a 4-level solid state laser
- Active medium – YAG crystal with some Yttrium ions (Y^{3+}) are replaced by Neodymium ions (Nd^{3+})
- The length of the crystalline rod varies from 5-10cm and diameter varies from 6-9mm
- Pumping – Optical pumping
- Xenon lamp – for pulsed output
- Krypton lamp – for continuous output



Nd:YAG Laser
100% reflector
Partial reflector
Laser rod
Laser beam
Flash tube

Energy level diagram



Characteristics

- Type – Solid state laser
- Active medium – YAG crystalline rod
- Active centre – Neodymium ions
- Pumping method – Optical pumping
- Optical resonator – The reflecting plates on either sides of YAG rod
- Power output – $2\ 10^4$ watts
- Nature of output – Pulsed laser
- Wave length – 1.06 μm

He- Ne laser

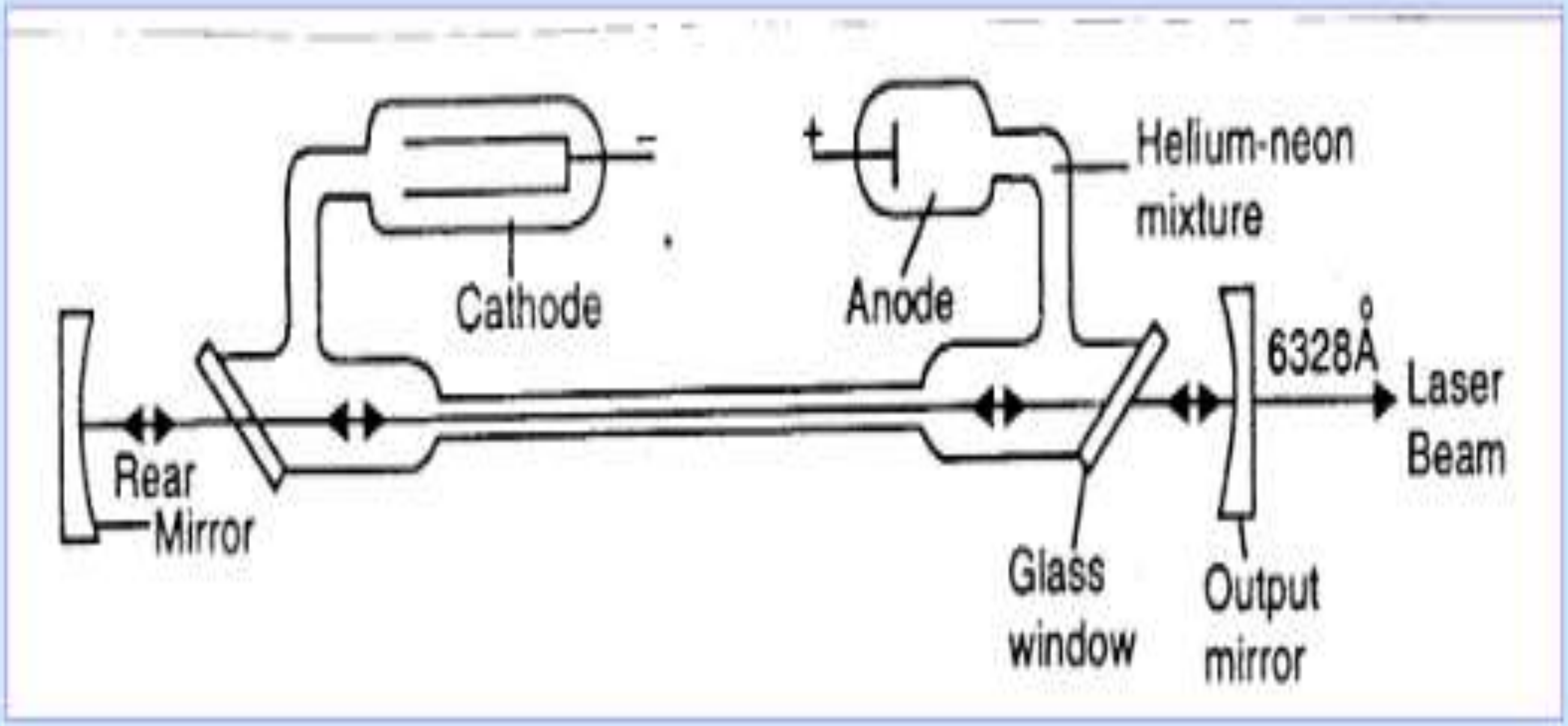
Principle

- In the mixture of helium and neon gases, He atoms are excited by electric discharge method.
- Excited He atoms collides with Ne atoms and raised it to higher energy level.

Construction

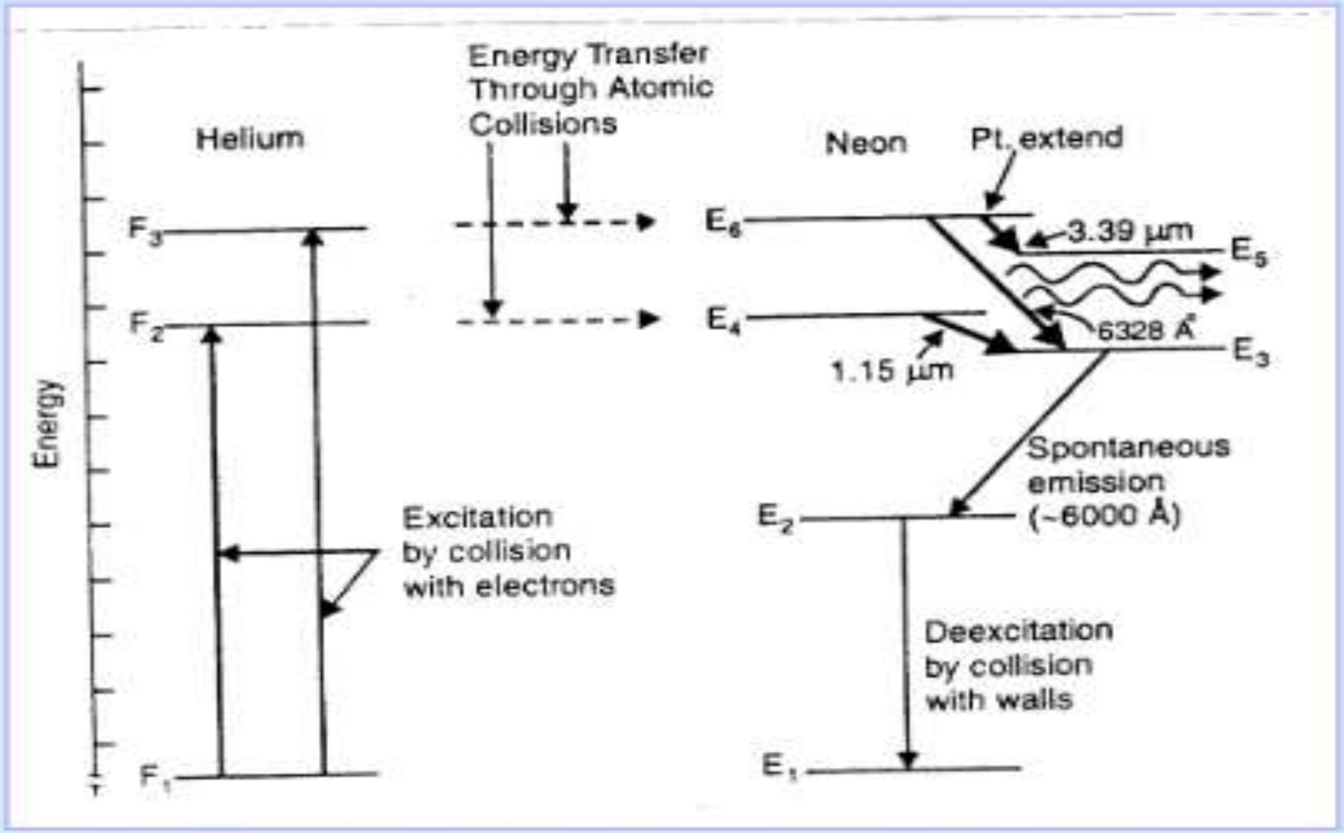
- Consist of gas discharge tube made of quarts with 80 cm long and 1.5 cm width.
- The discharge tube is filled with themixture of neon at 0.1mm of mercury pressure and He at 1 mm of mercury pressure as active medium.
- The ratio of He-Ne mixture is 10:1
- He has the majority and Ne has the minority atoms

Construction



Schematic of a He-Ne laser with external mirrors

- The excited helium atoms transfer their energy to the neon atoms in the ground state by resonance collision method.
- Ne atoms are raised to the excited state E4 and E6
- When the population of the neon atoms in the energy level f4 and f6 becomes dominant, the stimulated emission starts.
- Release of laser of wavelength (E6 $\longrightarrow$ E3) 6328 $\mathring{A}$
- E6 $\longrightarrow$ E5: 3.29 μm



Energy levels of He and Ne atoms and transitions between the levels.

Characteristics

- Type-Gas laser
- Active medium-Mixture of He and Ne
- Active centre-Ne atoms
- Pumping method-Electrical discharge
- Optical resonator-Pair of concave mirror
- Power output-0.5-50MW
- Nature of output-continuous laser
- Wavelength-6328Å

Semiconductor laser

- Generally the semiconductor diode lasers are classified into two types, namely
- **Homojunction semiconductor**
- **Heterojunction semiconductor**

Homojunction Semiconductor laser

Principle

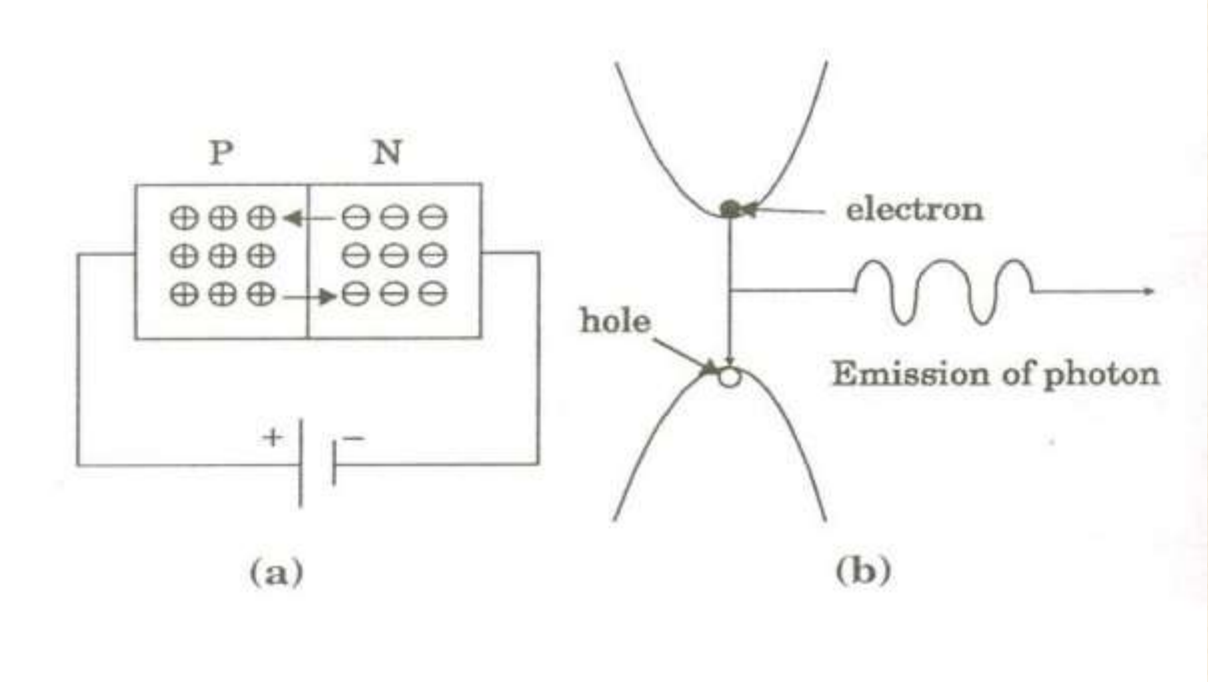
- When p-n junction is forward biased, the holes are moving towards 'n' region and electrons are moving towards 'p' region.
- The recombination of charge carrier takes place in the junction region which results laser radiation.

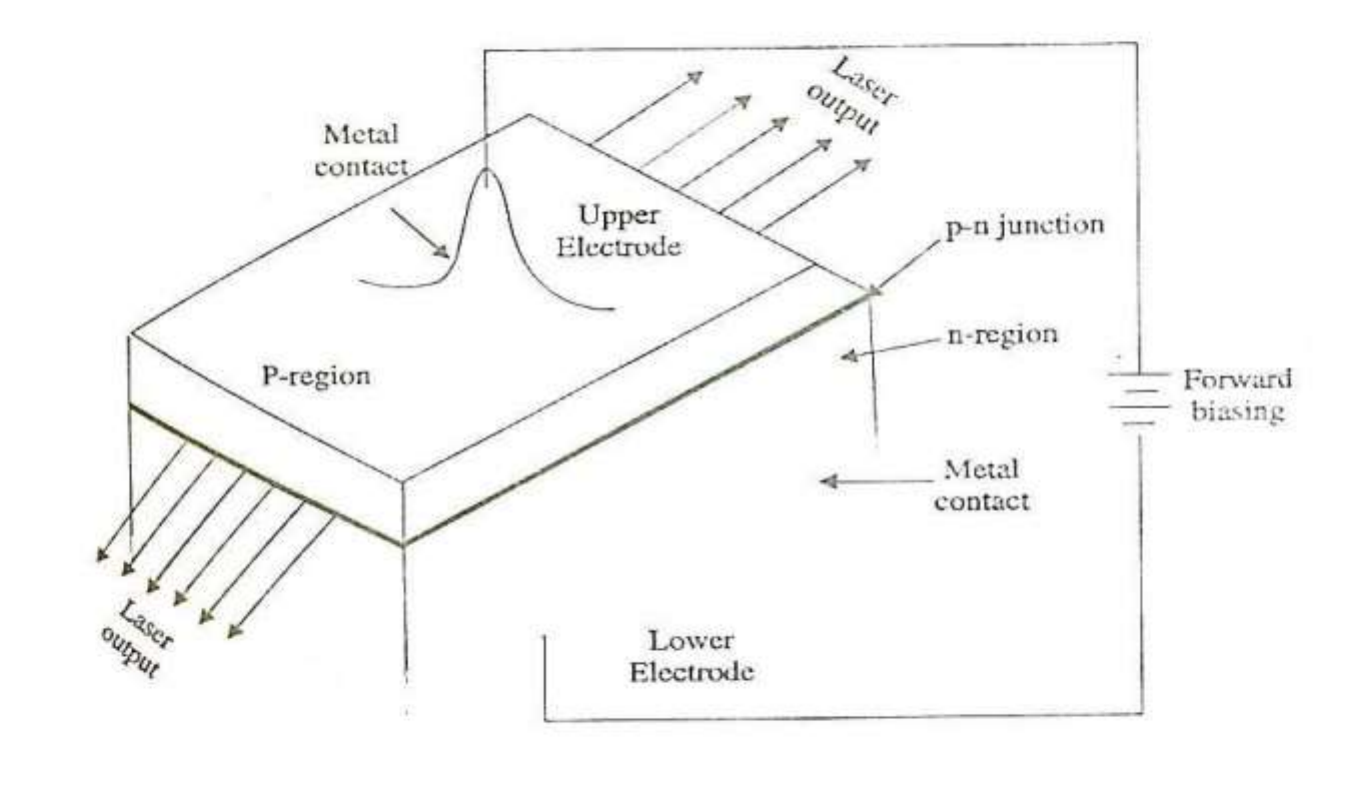
Construction

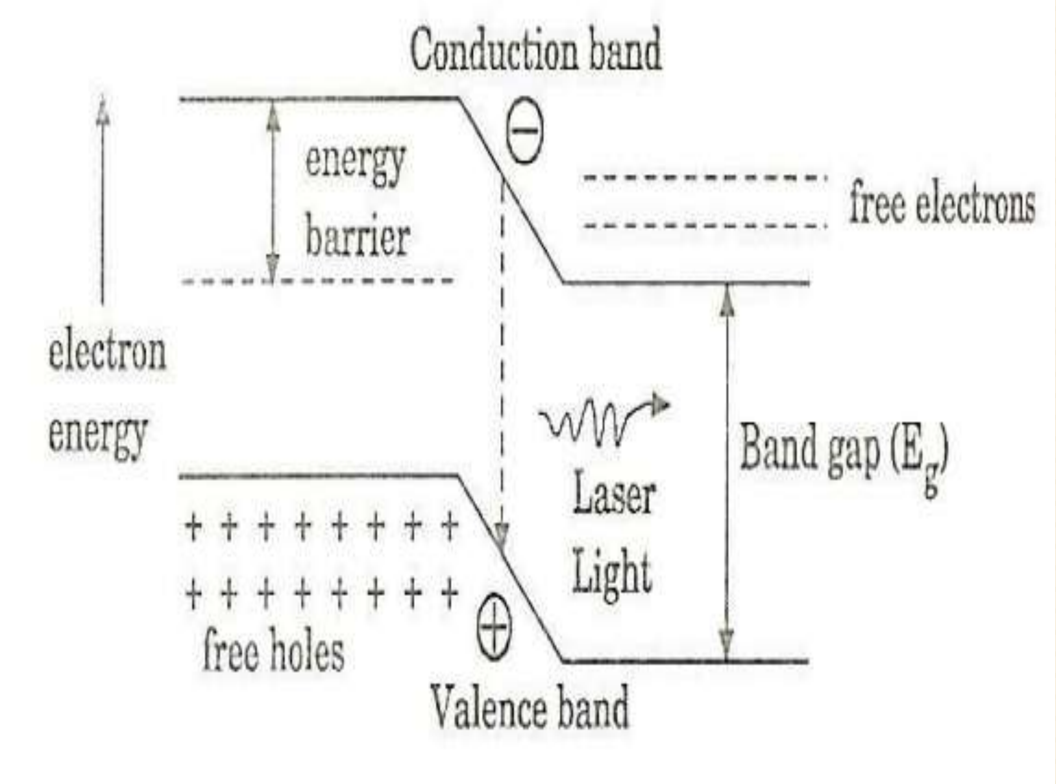
- It is most compact of all lasers and also called ***injection laser.***
- The p-n junction diode of a single crystalline material (Eg: Gallium arsenide) is acts as an active medium. Gallium arsenide is a direct band gap semiconductor used for laser action.
- The indirect band gap semiconductors namely silicon and germanium are not used for laser action.
- The p and n regions of gallium arsenide is highly doped with holes and electrons respectively

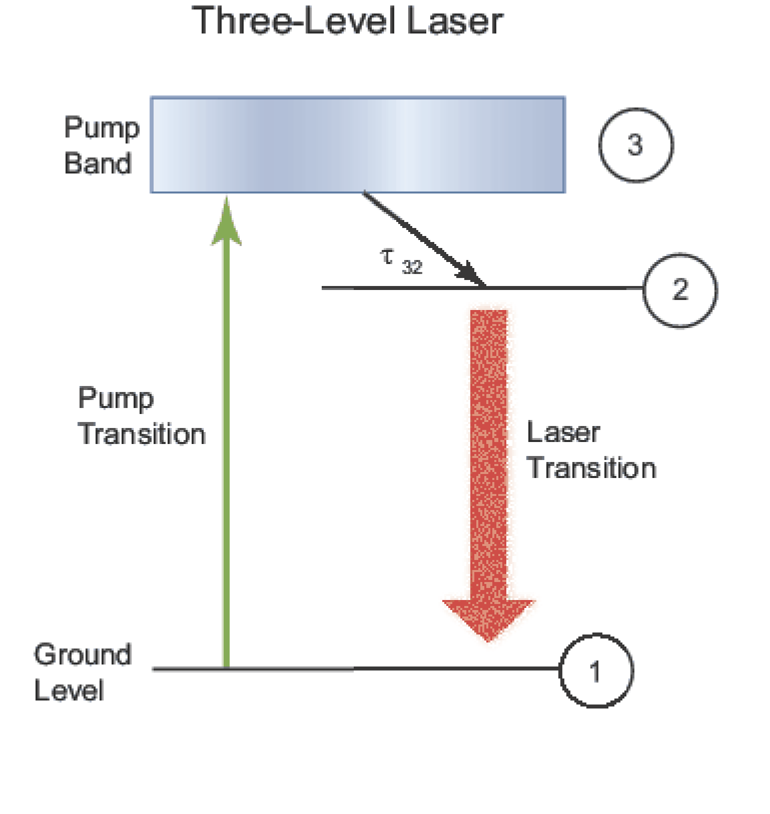
Working

- The population inversion is achieved by injecting the charge carriers across the junction region by forward biasing.
- For direct recombination process, the current in the order of 10^4 ampere/cm^2 is passed through the electrodes
- The photons are emitted during recombination of electrons and holes and the rate of recombination increases


P
N
+
−
(a)
electron
hole
Emission of photon
(b)


Laser output
Metal contact
Upper Electrode
p-n junction
n-region
P-region
Forward biasing
Metal contact
Laser output
Lower Electrode


Conduction band
energy
barrier
free electrons
electron
energy
Laser
Light
Band gap (E_g)
free holes
Valence band


Three-Level Laser
Pump
Band
3
τ_{32}
2
Pump
Transition
Laser
Transition
Ground
Level
1

Characteristics

- Type – Semiconductor laser
- Active medium – Direct band gap semiconducting materials
- Pumping method – Direct pumping
- Power output – Few mW
- Nature of output – Continuous (or) pulsed laser
- Wave length – 8400 to 8800 Å

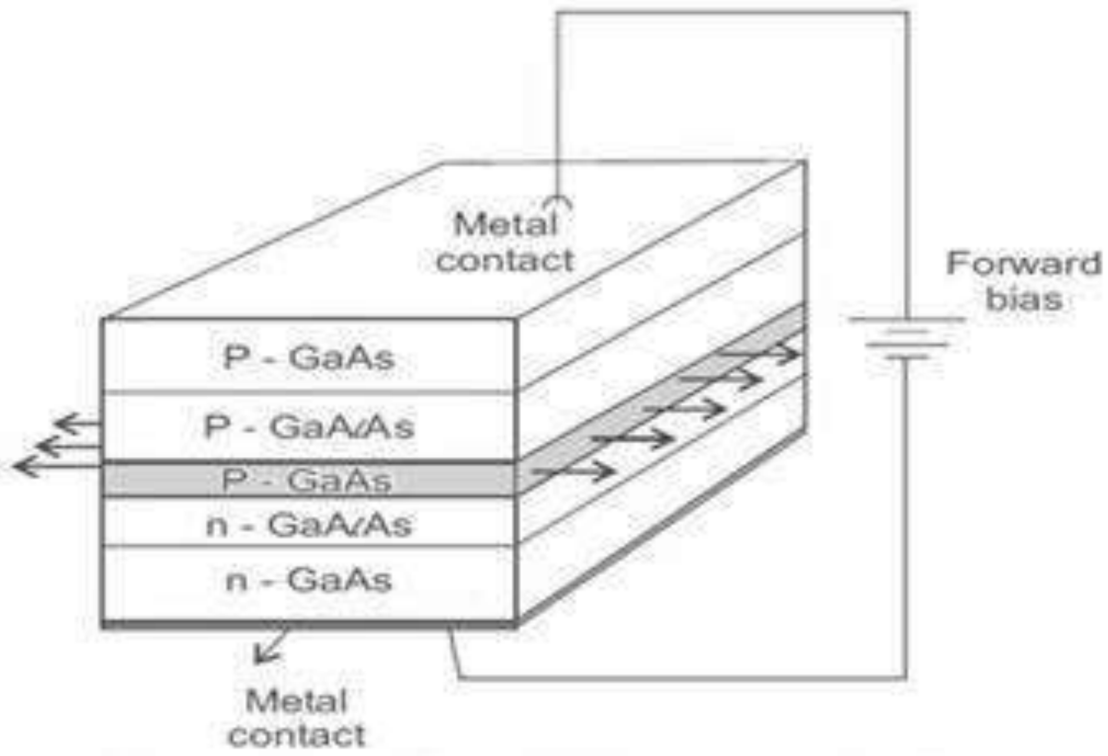
Heterojunction Semiconductor Laser

Principle

- When the p-n junction diode is forward biased, the electrons in conduction band combines with holes in the valence band and hence the recombination of electron and hole produces energy in the form of light.

working

- The Diode is forward biased with the help of electrodes.
- Due to forward biasing the charge carriers are produced in the layers 2 and 4.
- The charge carriers produced are injected into the active region (Layer-3) till the population inversion achieved.



Heterojunction semiconductor Laser

- Some of the spontaneously emitted photons released during recombination process start stimulate the injected charge carriers to emit photons.
- After the condition of population inversion is reached numbers of photons are produced
- The photons are reflected back and forth and hence the intense coherent beam of laser emerges out from the p- n junction region between the layers 3 and 4.

- **Advantages**
- Output power of the device is very high
- It has high coherence and directionality
- It produces continuous wave output
- It has longer life time
- **Disadvantages**
- Cost of the diode is higher
- Since it has 5 layers, growing different layers is more complex


Applications & Uses
of
LASER

APPLICATIONS OF LASER

- laser beams are widely used in many fields of science, engineering and medicine.
- **Laser in welding**
- **Lasers in cutting and drilling**
- **Laser heat treatment**
- **Medical applications**
- **Lasers in microelectronics**
- **Industrial applications**
- **Communication and engineering applications**

Laser in welding

- It is a contact less process, there is no possibility of impurity into the joint.
- Since laser beams are very narrow, the microstructure of the surrounding layers is not affected.
- The materials like titanium, quartz and ceramics which cannot be welded by ordinary method can be welded using lasers.
- Higher welding rates are possible.
- Heating and cooling process are so rapid.
- The work piece is with minimum stress and distortion.
- The weld region is correctly bonded together and there is no dry welding.

Lasers in cutting and drilling

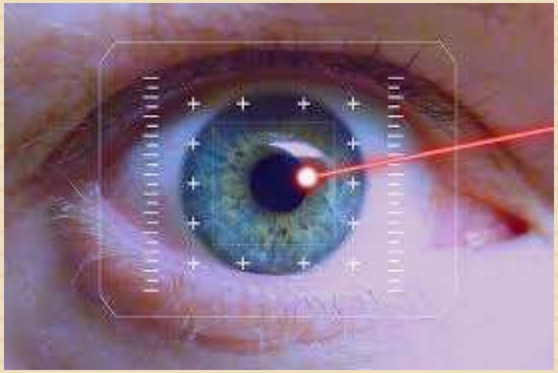
- Laser cutting and drilling can be done at room temperature
- Higher speed can be achieved
- Residual stress and distortion is minimum
- The heating and cooling are so rapid that increases the strength of that region

Laser heat treatment

- The powerful laser beam is made to fall on the surface of the material. The portion which is exposed to the laser beam gets heated.
- When the beam is moved over the surface of the material the heated spot cools down rapidly.
- While moving the laser over entire surface of the material the strength of the material is enhanced by the method called ***quenching***.

Medical applications

- Laser is widely used in surgery in the treatment of detached retina
- It finds applications in bloodless micro surgery
- Lasers are used in cancer treatment and in the treatment of brain tumors
- The availability of optic fibers permitted the combination of laser technology with endoscope



Lasers in microelectronics

- Microelectronics is related to the study and manufacture of very small electronic components. These devices are made from semiconductors with the help of lasers using a process called ***photolithography***
- Laser is used in the fabrication process of microelectronic component due to its unique characteristics

Industrial applications

- Lasers are used in material processing
- Lasers are used in printing and jewelry industry
- Micro drilling of hard materials like diamond is made possible with lasers
- Lasers can be used for micro welding or melting the materials
- Cutting and testing the quality of materials is possible with lasers

Communication and engineering applications

- Lasers have wider applications in connection with optical fiber
- Lasers are used in the transmission of messages
- It is used in forecasting earthquakes

Holography

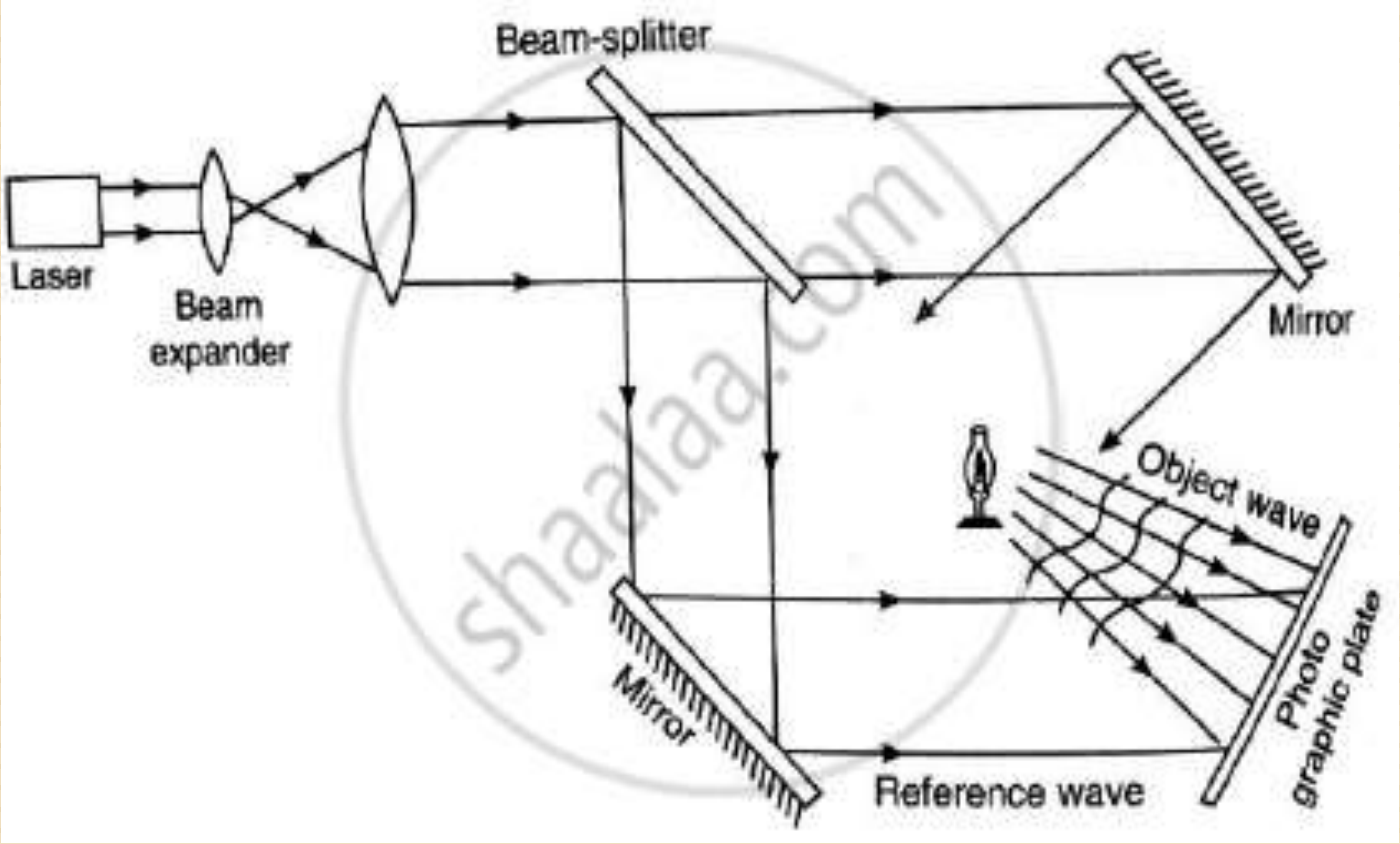
- Holography is a new photography technique in which 3 D images are produced by means of interference patterns without the lens systems.

Principle

- Two beams, one reflected from the object and the other from the laser source are superimposed on a holographic plate from an image called hologram

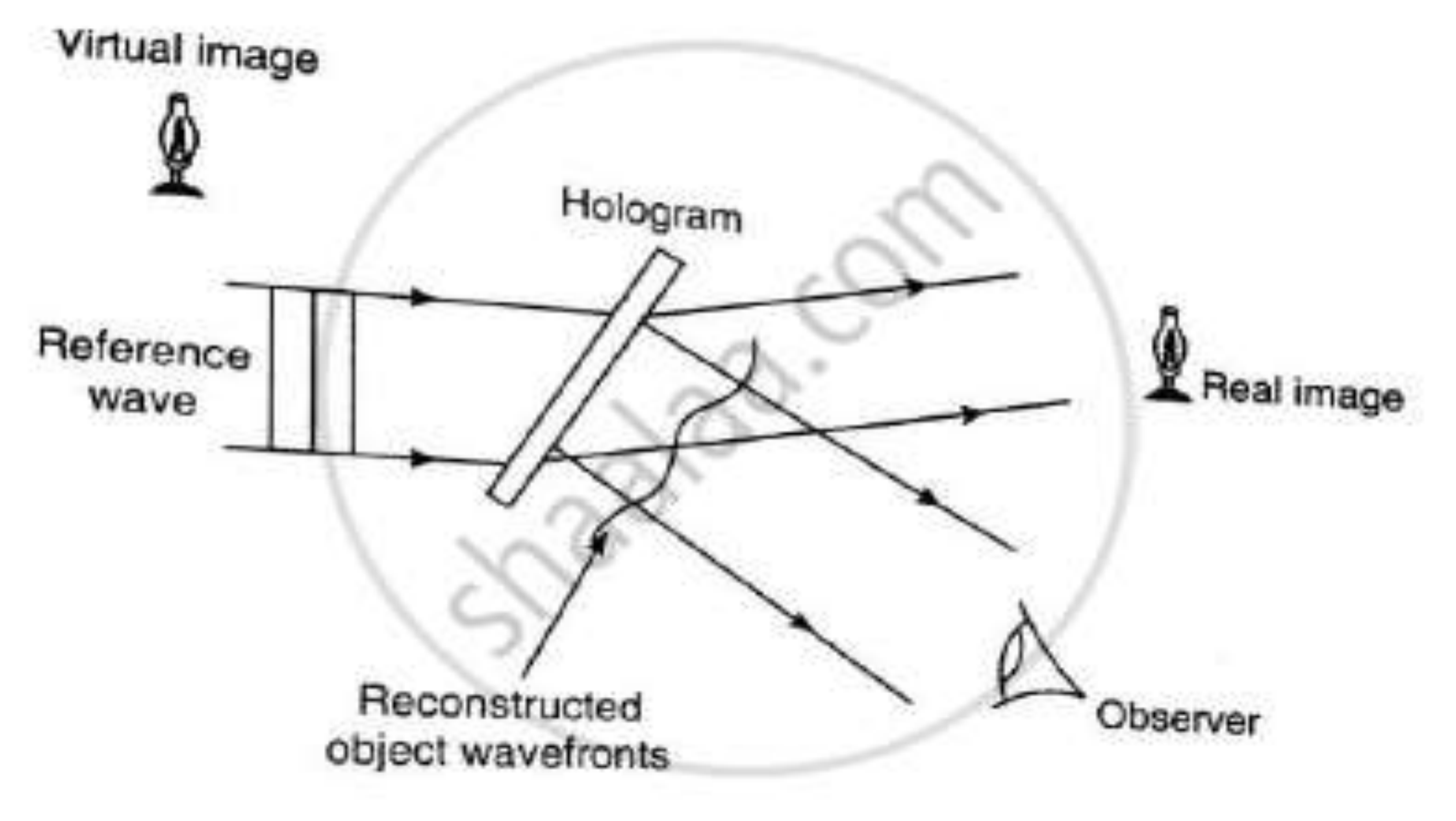
Construction of hologram

- The process of making hologram is called construction of hologram.
- Monochromatic source is used to produced interference pattern.
- The beam splitter splits beam into i) reference beam ii) object beam
- The refernce beam R is directed towards the photographic plate called holographic plate
- Object beam O is directed towards the object.
- The holographic plate is now delevoped and the image can be analysed.


Beam-splitter
Laser
Beam
expander
Mirror
Object wave
Mirror
Reference wave
Photo
graphic plate
shaalaa.com

Reconstruction of a hologram

- The method of viewing the virtual image of the object recorded on a hologram is called reconstruction.
- During the reconstruction process, the laser beam is made to fall on the holographic plate.
- The light incident on the holographic plate is called reading beam(RB).
- The virtual image is formed behind the laser source. The real image that can be photographed is formed due to diffraction of beam from the hologram.



Virtual image
Hologram
Reference wave
Real image
Reconstructed object wavefronts
Observer

Thank you

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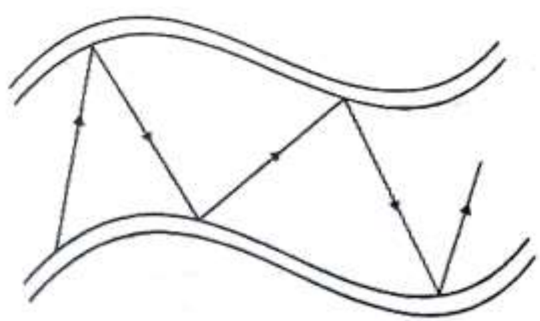
Unit-III : FIBRE OPTICS AND ITS APPLICATIONS

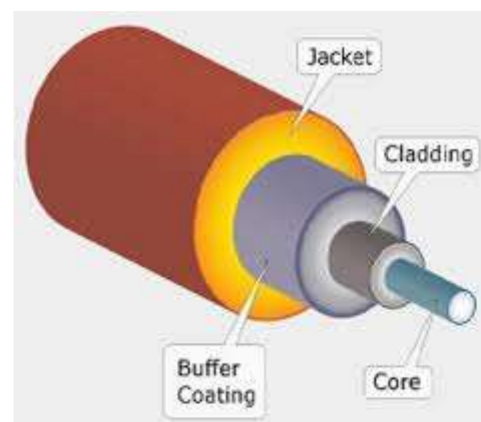
FIBRE OPTICS INTRODUCTION

- Optical fibers are the light pipes or photon conductors made of transparent materials like glass and plastics. The development of lasers and optical fibers has brought a revolution in communication systems.
- To have an efficient communication system, the information carried out by light waves requires a guiding medium through which it can be transmitted safely. This guiding medium is called ***optical fiber***.
- Fibre optics is a technology in which the electrical signals are converted into light signals, transmitted through a glass fibre and reconverted into electrical signals

CONSTRUCTION OF THE OPTICAL FIBRE

- An optical fibre is a transparent media as thin as human hair, made of glass or plastic used to guide the light waves along its length. An optical fibre works on the principle of ***total internal reflection***. When the light enters at one end of the fibre it undergoes total internal reflection from the side walls and travel the length of the fibre
- The inner cylinder made of glass or plastic called ***core*** is used to guide the light. It is surrounded by a middle region of glass or plastic called ***cladding*** which is used to confine the light to the core.
- The cladding is covered by the outermost region called ***buffer***, which protects the inner region from the moisture. The refractive index of core region is always higher than the cladding.

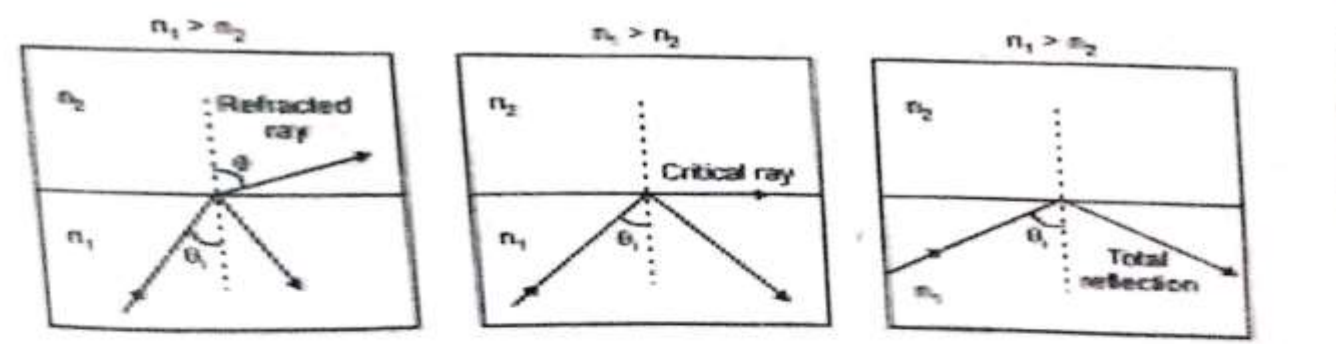




PRINCIPLE OF FIBER TRANSMISSION

The principle of transmission of light through optical fiber is ***total internal reflection***.

For total internal reflection, the angle of incidence (θ_i) should be greater than the critical angle (θ_c) of the medium



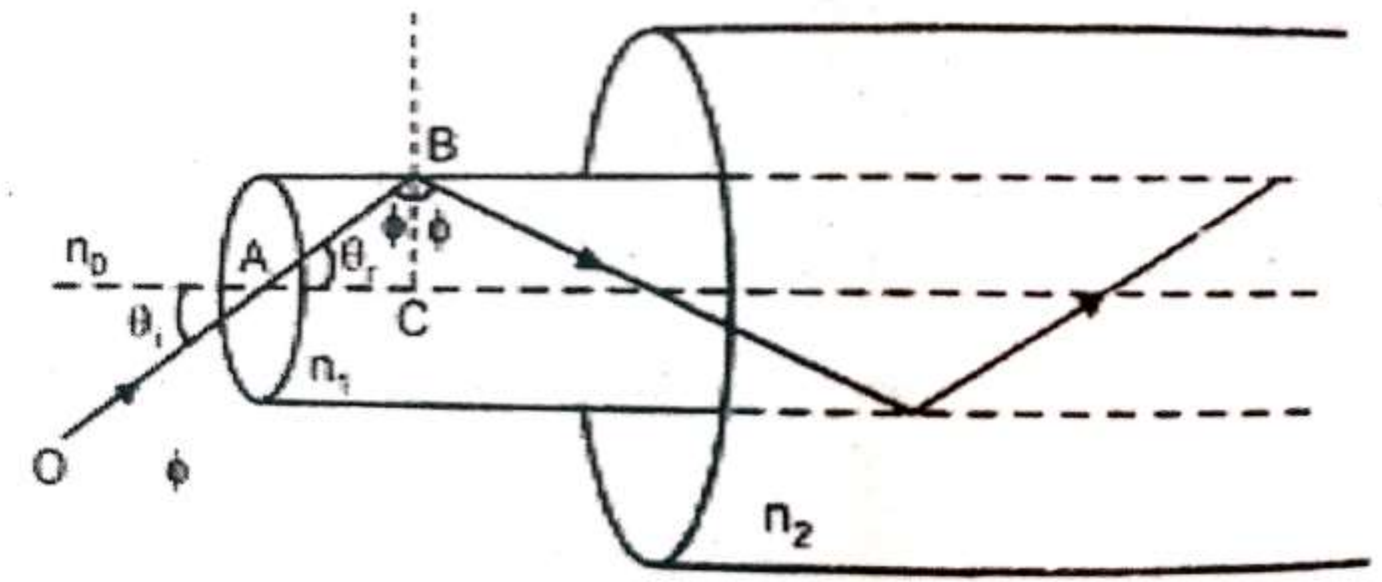
a) when $\theta_i < \theta_c$ b) when $\theta_i = \theta_c$ c) when $\theta_i > \theta_c$

Principle of total internal reflection

- ***Case 1:*** When $\theta_i < \theta_c$, the light ray is refracted into the rarer medium (cladding) i.e., no light is transmitted through the core region.
- ***Case 2:*** When $\theta_i = \theta_c$, the angle of incidence is increased to a certain value called ***critical angle*** so that angle of refraction is 90°. The refracted ray just emerges along the core-cladding interface.
- ***Case 3:*** When $\theta_i > \theta_c$, the light is reflected back into the denser medium (core). In order to arrive at the condition of total internal reflection, the angle of incidence must be higher than the critical angle. The reflection of light in the core region .

PROPAGATION OF LIGHT IN OPTICAL FIBERS

- Let us consider the optical fibre into which light is entered at one end as shown in Fig.
- Let n_1 is the refractive index of core and n_2 is the refractive index of cladding. The refractive index of the core is always greater than the refractive index of cladding i.e., $n_1 > n_2$.
- Let n_0 is the refractive index of the medium (air) where the light is entering into the fibre.
- The light is allowed to travel along the path OA and enters into the core at an angle of θi to the axis of fibre.
- The light is refracted at an angle of θr and strikes the core-cladding interface at an angle of φ at B.
- If f is greater than the critical angle θ_c, the ray undergoes total internal reflection and propagates through the fiber.


B
A
n_0
θ_r
ϕ_i
ϕ
θ_i
C
n_1
O
ϕ
n_2

According to Snell's law,

$$n_0 \sin \theta_i = n_1 \sin \theta_r \qquad \ldots (1)$$

At B, on the interface of core-cladding,

$$\varphi = 90 - \theta_r$$

Applying Snell's law again,

$$n_1 \sin (90 - \theta_r) = n_2 \sin 90$$

$$n_1 \cos \theta_r = n_2 \qquad \because \sin(90 - \theta_r) = \cos \theta_r \text{ and } \sin 90 = 1$$

$$\cos \theta_r = \frac{n_2}{n_1} \qquad \ldots (2)$$

Rewriting equation (1),

$$\sin \theta_i = \frac{n_1}{n_0} \sin \theta_r$$

$$= \frac{n_1}{n_0} \sqrt{1 - \cos^2 \theta_r} \qquad \ldots (3)$$

$$\sin^2 \theta + \cos^2 \theta = 1$$

$$\sin \theta = \sqrt{1 - \cos^2 \theta}$$

Substituting $\cos \theta_r$ value in equation (3) from equation (2),

$$\sin \theta_i = \frac{n_1}{n_0} \sqrt{1 - \frac{n_2^2}{n_1^2}}$$

$$= \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$

$$\theta_i = \sin^{-1} \frac{\sqrt{n_1^2 - n_2^2}}{n_0} \qquad \dots (4)$$

Equation (4) refers *Acceptance angle* (θ_i), the maximum angle at which a ray of light can enter through the fibre so that the light will be totally internally reflected.

Numerical aperture

It is the measure of amount of light rays that can be accepted by the fibre. The sine of the acceptance angle of the fibre is called ***numerical aperture***.

$$\text{i.e,} \quad NA = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$

When the medium surrounding the fibre is air, $n_0 = 1$

$$NA = \sqrt{n_1^2 - n_2^2}$$

Fractional index change (Δ)

It is the ratio of difference in refractive index of core and cladding to the refractive index of core.

$$\text{i.e. } \Delta = \frac{n_1 - n_2}{n_1} \quad \dots (5)$$

Relation between Numerical aperture (NA) and Fractional index change (Δ)

From equation (5), we can write

$$n_1 \Delta = n_1 - n_2 \quad \dots (6)$$

We know, $\text{NA} = \sqrt{n_1^2 - n_2^2}$

$$= \sqrt{(n_1 + n_2)(n_1 - n_2)} \quad \text{... (7)}$$

Substituting the equation (6) in (7),

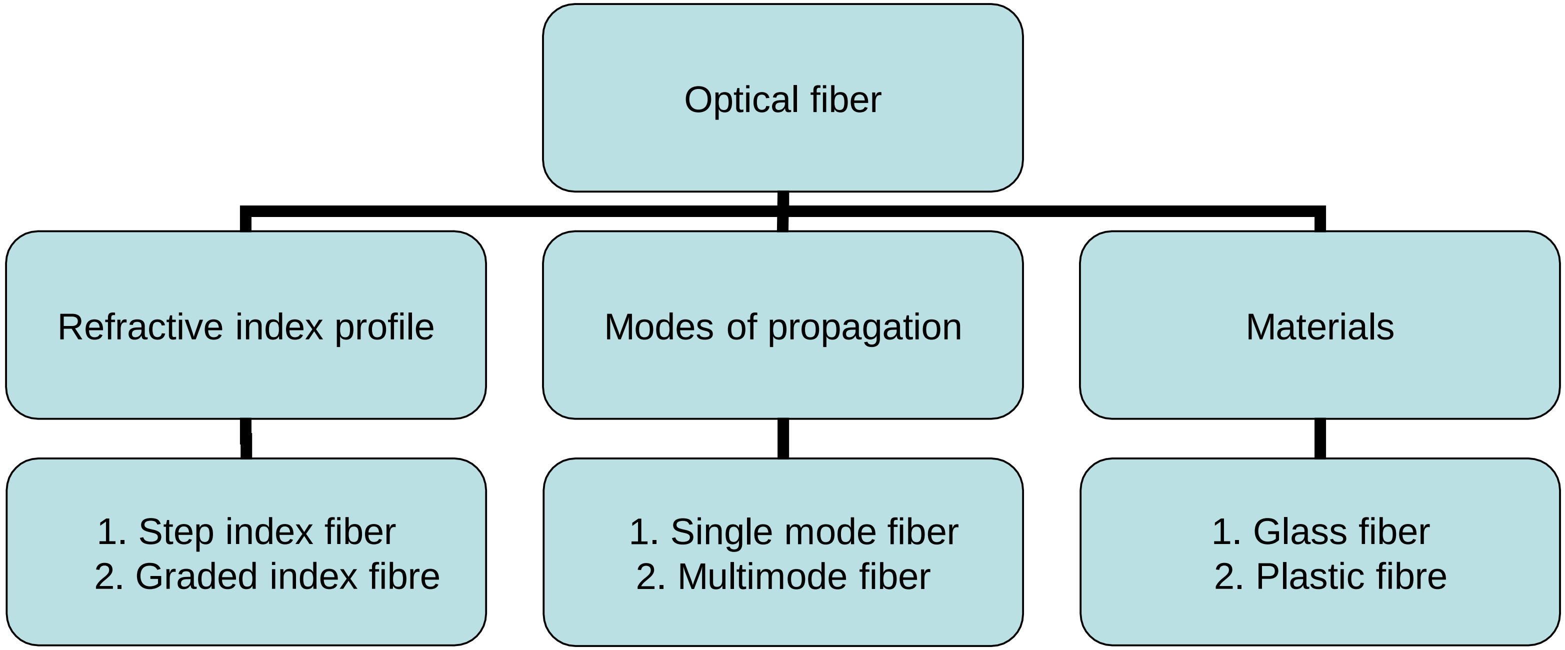
$$\text{NA} = \sqrt{(n_1 + n_2)(n_1\Delta)}$$

If $n_1 \approx n_2$,

$$\text{NA} = \sqrt{2n_1^2\Delta} \quad \text{... (8)}$$

$$\text{NA} = n_1\sqrt{2\Delta}$$

CLASSIFICATION OF OPTICAL FIBERS



Optical fiber based on refractive index profile

Based on the refractive index of core and cladding materials, fibres are classified into

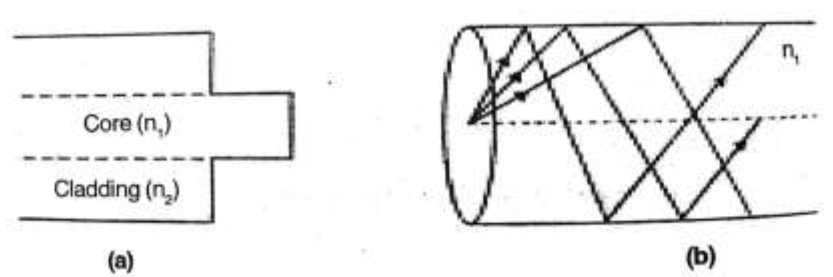
i) Step index fibre and

ii) Graded index fibre

i) Step index fibre

If the refractive index of the core is uniform throughout and undergoes a change only at cladding boundary is called *step index fibre*.

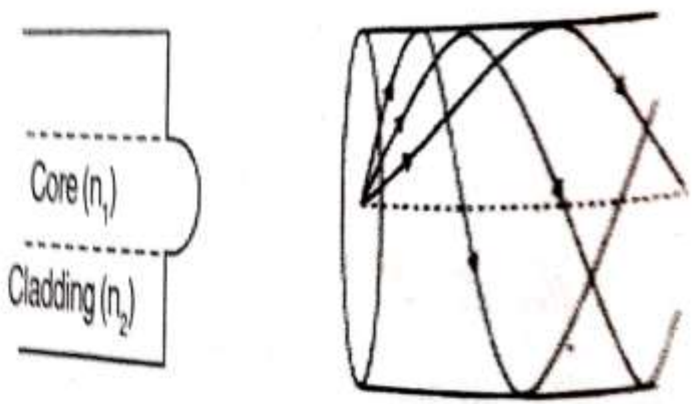
As the refractive index of core (n_1) and cladding (n_2) is changed step by step, it is called step index fibre. The light ray is propagated in the form of meridinal rays (Fig.) and it passes through the axis of the fibre.



ii) Graded index fibre

If the refractive index of the core is varying with the radial distance from the axis of the fibre it is called graded index fibre.

- The refractive index is maximum at the axis of the core and goes on decreasing while moving towards core-cladding interface i.e., the refractive index of core and cladding are equal, at the core-cladding interface. The light ray is propagated in the form of skew rays and it will not cross the axis of the fiber.



Difference between step index fibre and graded index fiber:

S.No	Step index fibre	Graded index fibre
1	The refractive index of core (n_1) and cladding (n_2) is changed step by step, it is called step index fibre	The refractive index of the core is varying with the radial distance from the axis of the fibre it is called graded index fibre
2	The light ray is propagated in the form of meridinal rays and it passes through the axis of the fibre.	The light ray is propagated in the form of skew rays and it will not cross the axis of the fibre
3	It has lower bandwidth	It has higher bandwidth
4	Distortion is more	Distortion is lesser

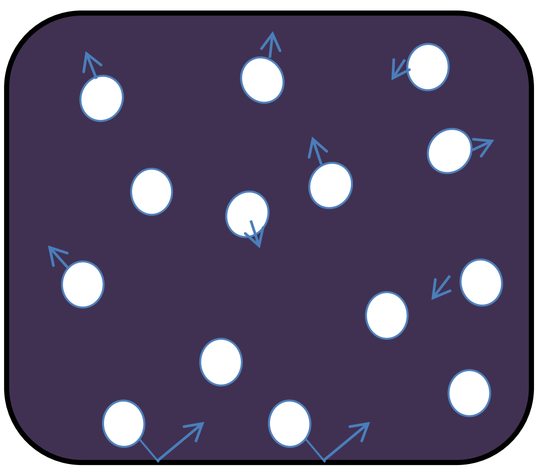
Unit-IV
CRYSTAL PHYSICS

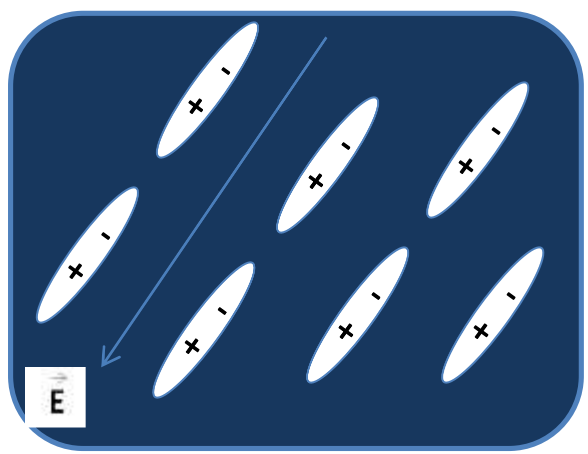
- **INTRODUCTION TO CRYSTAL PHYSICS**
- **CRYSTALLINE AND NON-CRYSTALLINE SOLIDS**
- **SPACE LATTICE**
- **CRYSTAL STRUCTURE**
- **LATTICE PARAMETERS**
- **CRYSTAL SYSTEMS**
- **BRAVAIS LATTICES**

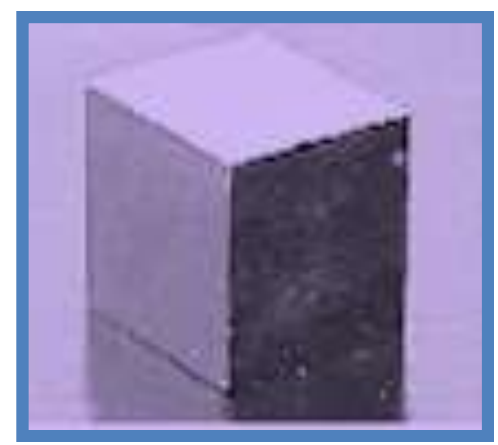
INTRODUCTION TO CRYSTAL PHYSICS

MATTER

- **GASES**
- **LIQUIDS AND LIQUID CRYSTALS**
- **SOLIDS**







What is Crystal Physics

- physical properties of crystalline solids

- determination of their actual structure by using

X-rays, neutron beams and electron beams.-

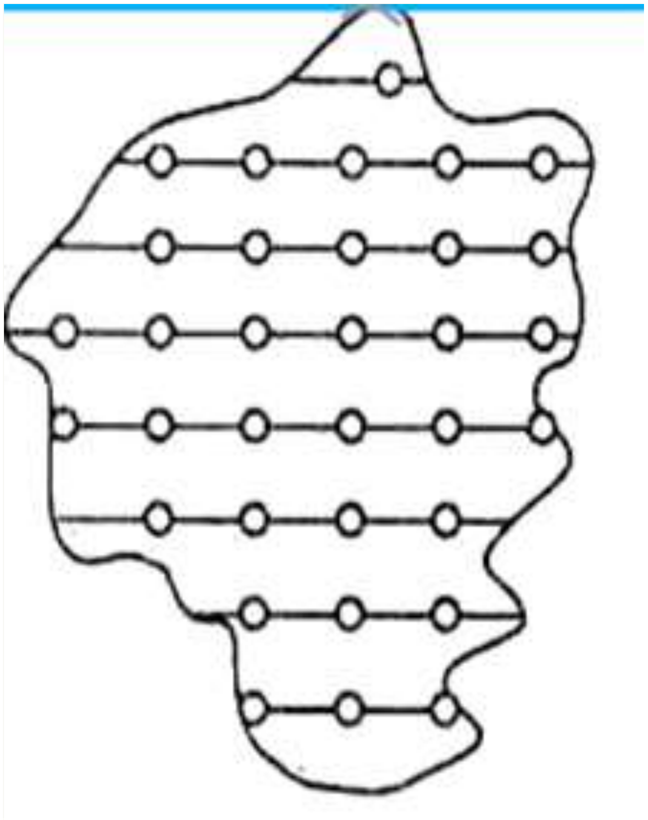
CLASSIFICATION OF SOLIDS

SOLID MATERIALS

- **CRYSTALLINE**
  - **Single Crystal**
- **POLYCRYSTALLINE**
- **AMORPHOUS (NON-CRYSTALLINE)**

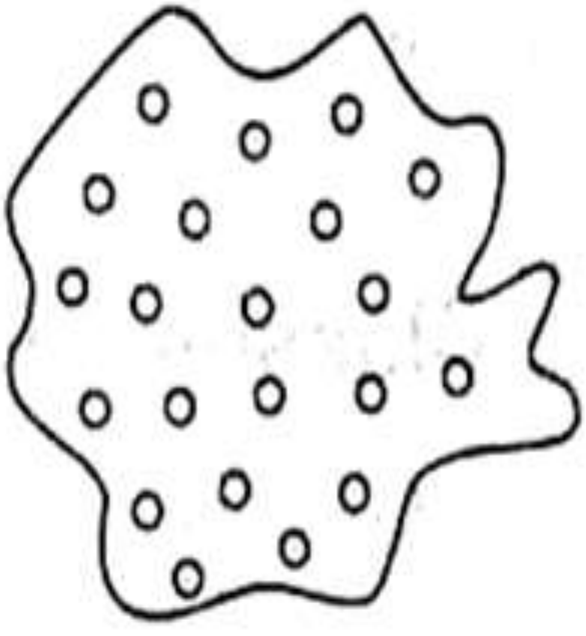
CRYSTALLINE SOLIDS

- arrangement of units of matter is regular and periodic.
- anisotropic substance.
- sharp melting point.
- possesses a regular shape
- **Ex: Iron, Copper, Carbon, Germanium**



NON CRYSTALLINE SOLIDS

- amorphous solids
- particles are randomly distributed.
- `isotropic' substances.
- have wide range of melting point
- **Examples: Glass, Plastics, Rubber etc.,**



POLYCRYSTALLINE SOLIDS

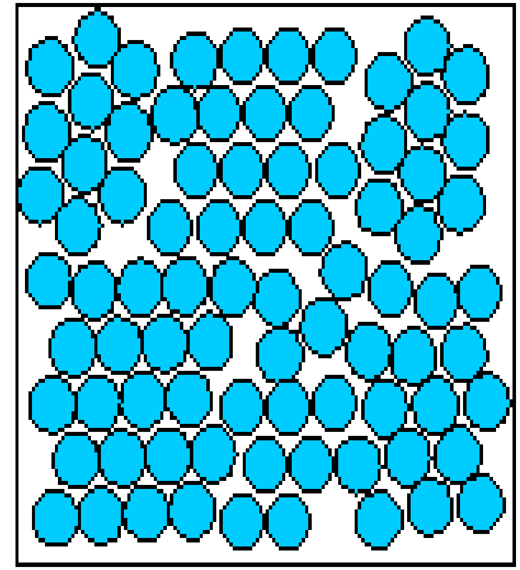
- aggregate of **many small single crystals**

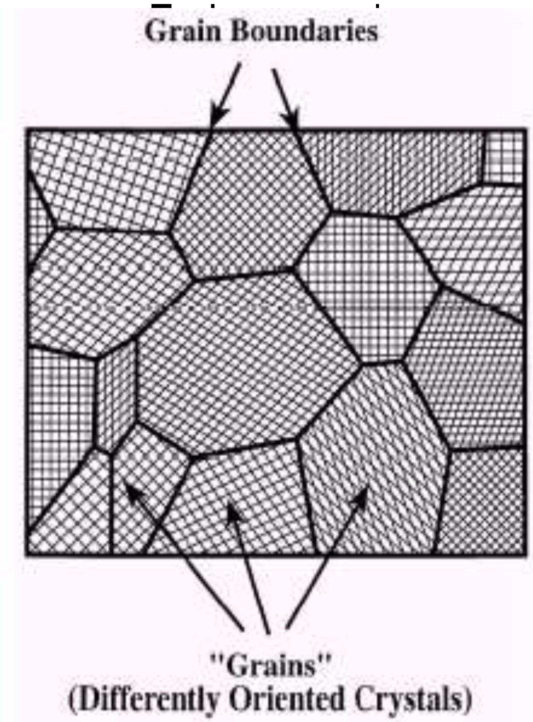
- **grain boundaries.** A grain boundary (GB) is the interface between two grains, or crystallites, in a polycrystalline material. **Grain boundaries** are defects in the crystal structure and tend to decrease the electrical and thermal conductivity of the material.

  grains are usually **100 nm - 100 microns in diameter**.

- Polycrystals with grains < 10 nm in diameter are **nanocrystalline**

- Examples: , Most of the metals and Ceramics





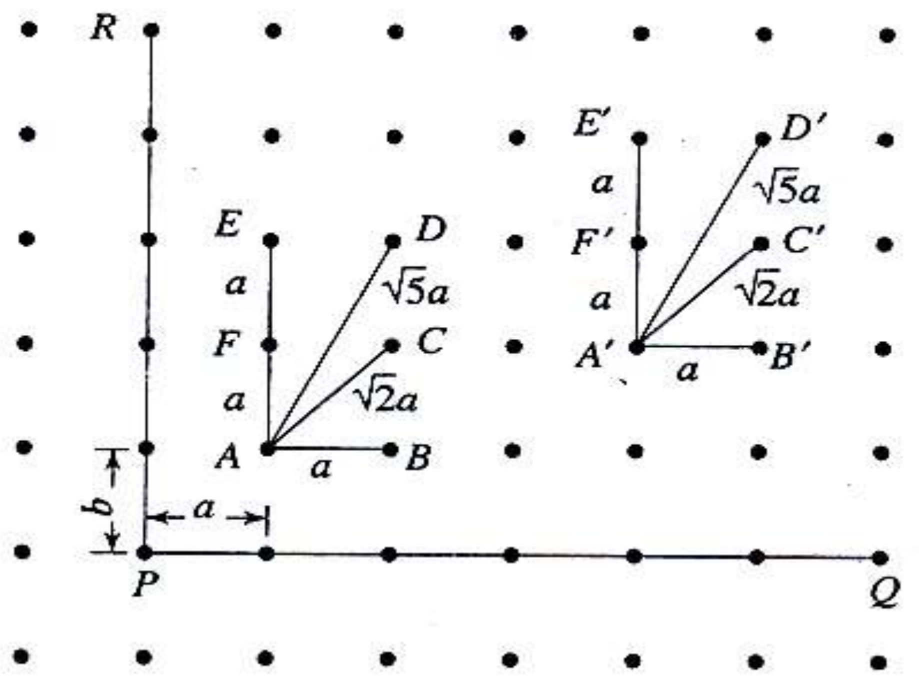
CRYSTALLOGRAPHIC TERMS

- SPACE LATTICE
- LATTICE POINTS
- LATTICE LINES
- LATTICE PLANES
- BASIS or MOTIF
- CRYSTAL STRUCTURE
- UNIT CELL
- LATTICE PARAMETERS

SPACE LATTICE

- Lattice Points: it denotes the position of atom or molecules in the crystal.
- regular and periodic arrangement of points in three dimension.

- identical surroundings to that of every other point in the array.



BASIS

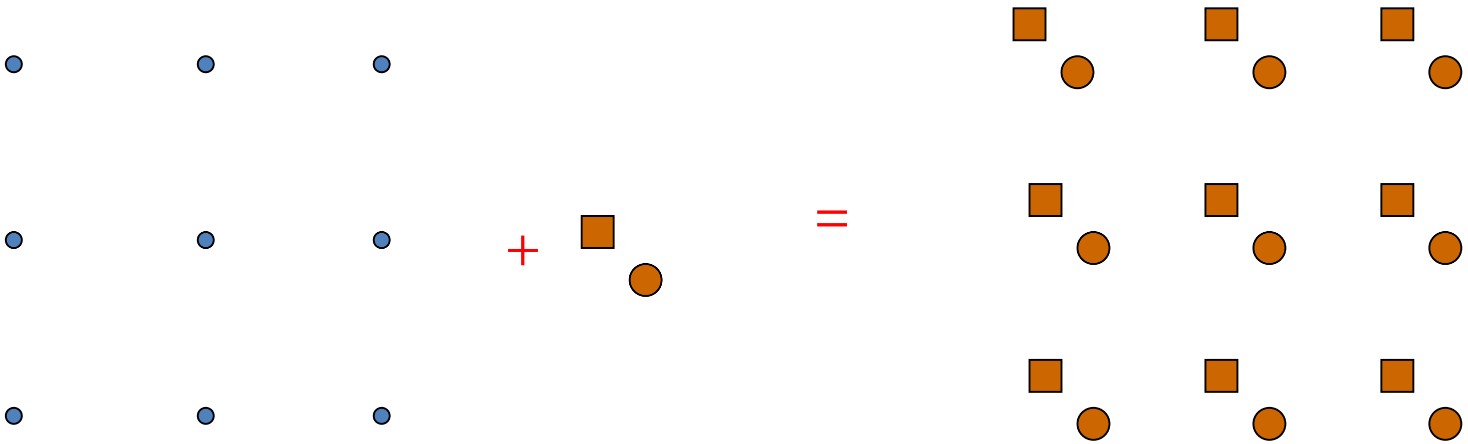
- a unit assembly of atoms or molecules identical in composition, arrangement and orientation.

- repeatation of basis correct periodicity in all directions

- The crystal structure is real, while the lattice is imaginary.

Examples	No. of atoms in Basis
Aluminim	01
Barium	01
NaCl	02
KCl	02

CRYSTAL STRUCTURE

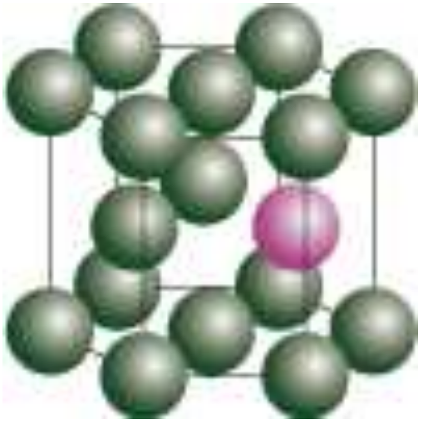


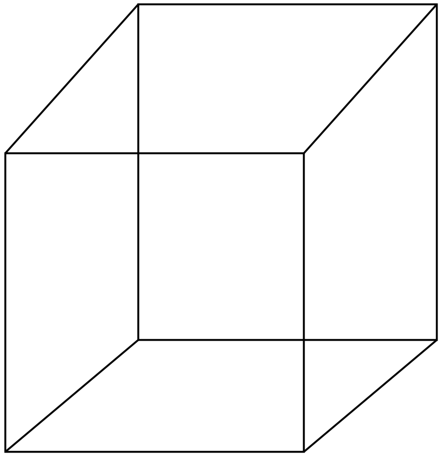
Lattice + Basis = Crystal structure

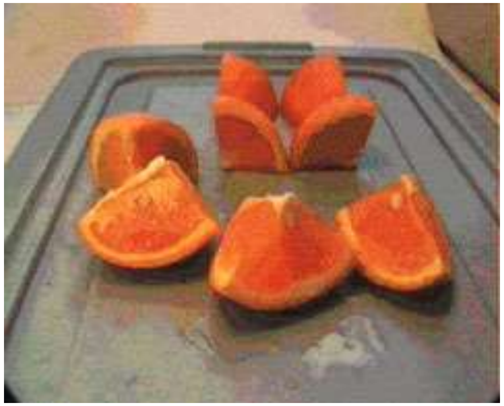
UNIT CELL

- a fundamental building block

- repeating its own dimensions in various directions gives crystal structure







Lattice parameters

x, y and ***z*** *are* crystallographic axes

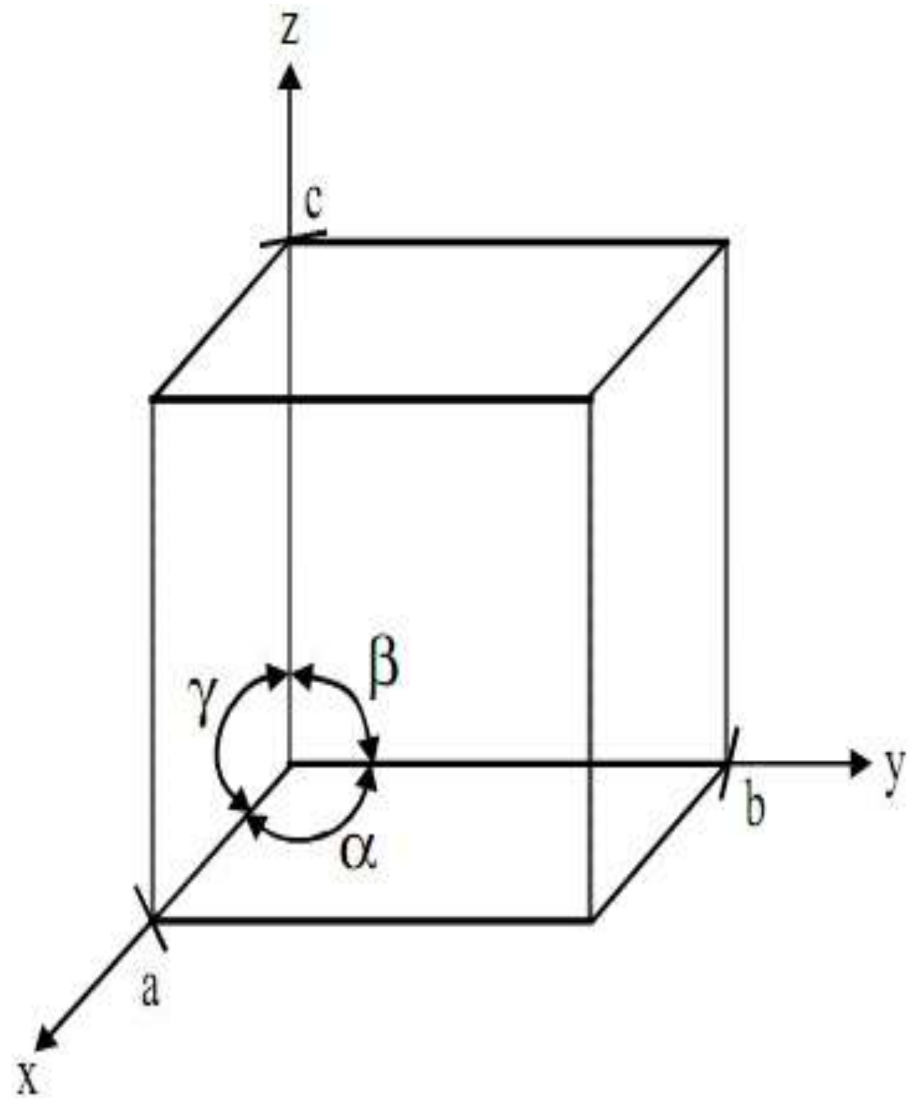
Length of the unit cell along the *x*, *y*, and *z* direction are ***a, b***, and ***c***

Interaxial angles:

α = the angle between *a* and *b*

β = the angle between *b* and *c*

γ = the angle between *c* and *a*



a, b, c, α, β, γ are collectively known as the **lattice parameters**

PRIMITIVE CELL

- A unit cell consists of only one full atom

- A primitive cell got the points or atoms only at the corners

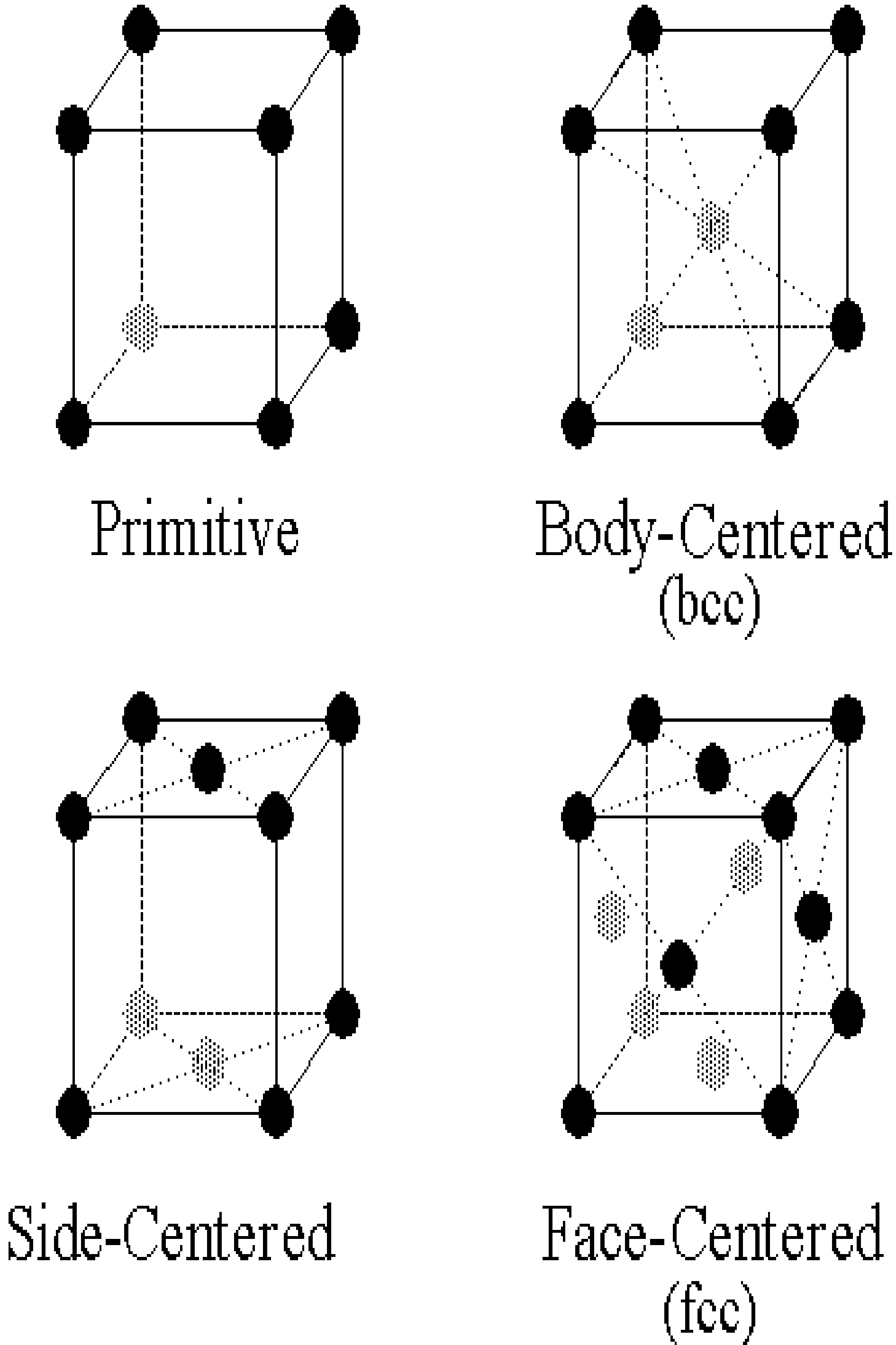
- If a unit cell consists more than one atom, then it is not a primitive cell.

- Example for primitive cell :

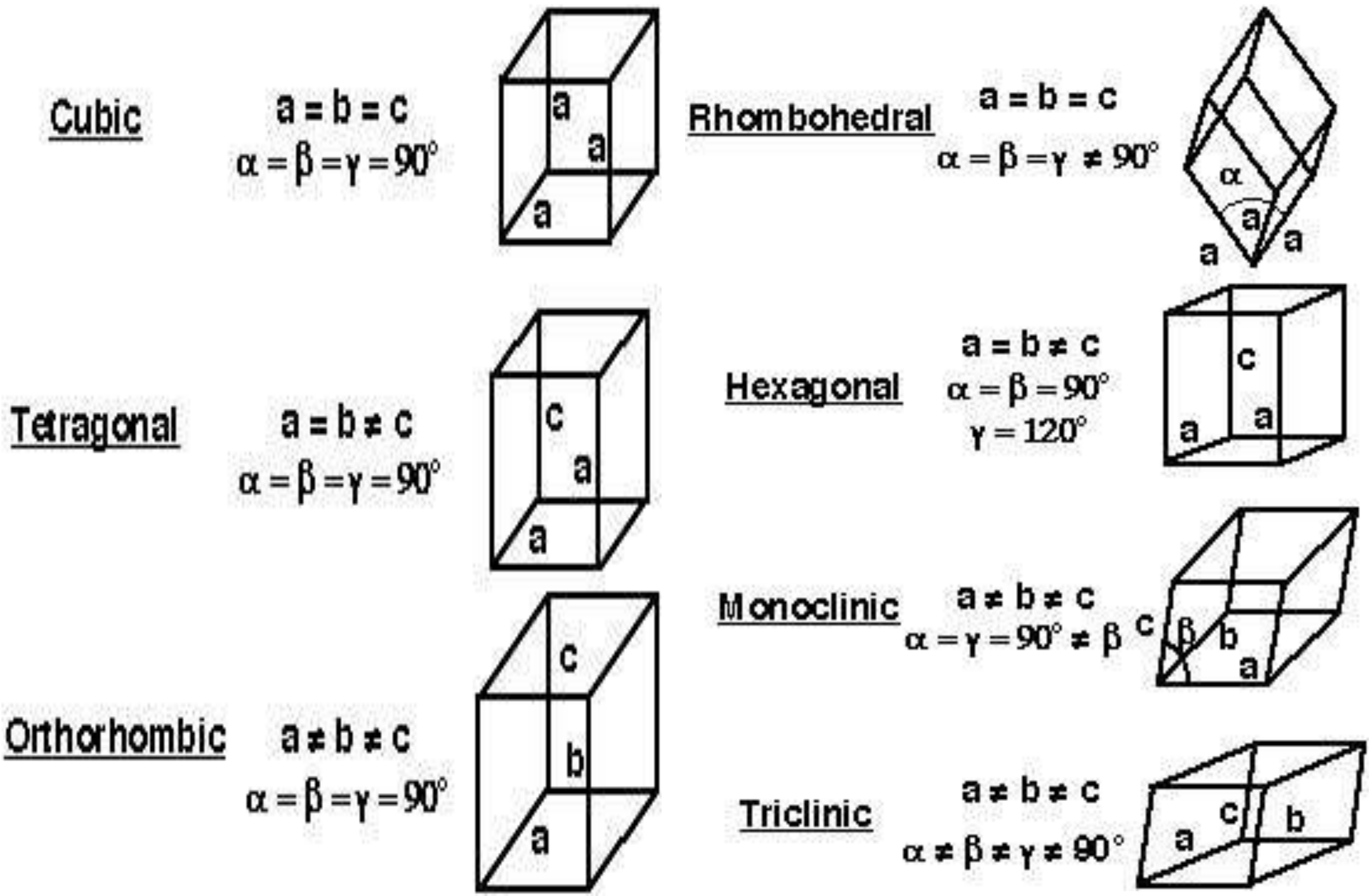
  Simple Cubic(SC)

- Examples for non-primitive cell :

  BCC and FCC unit cell.



Seven crystal systems

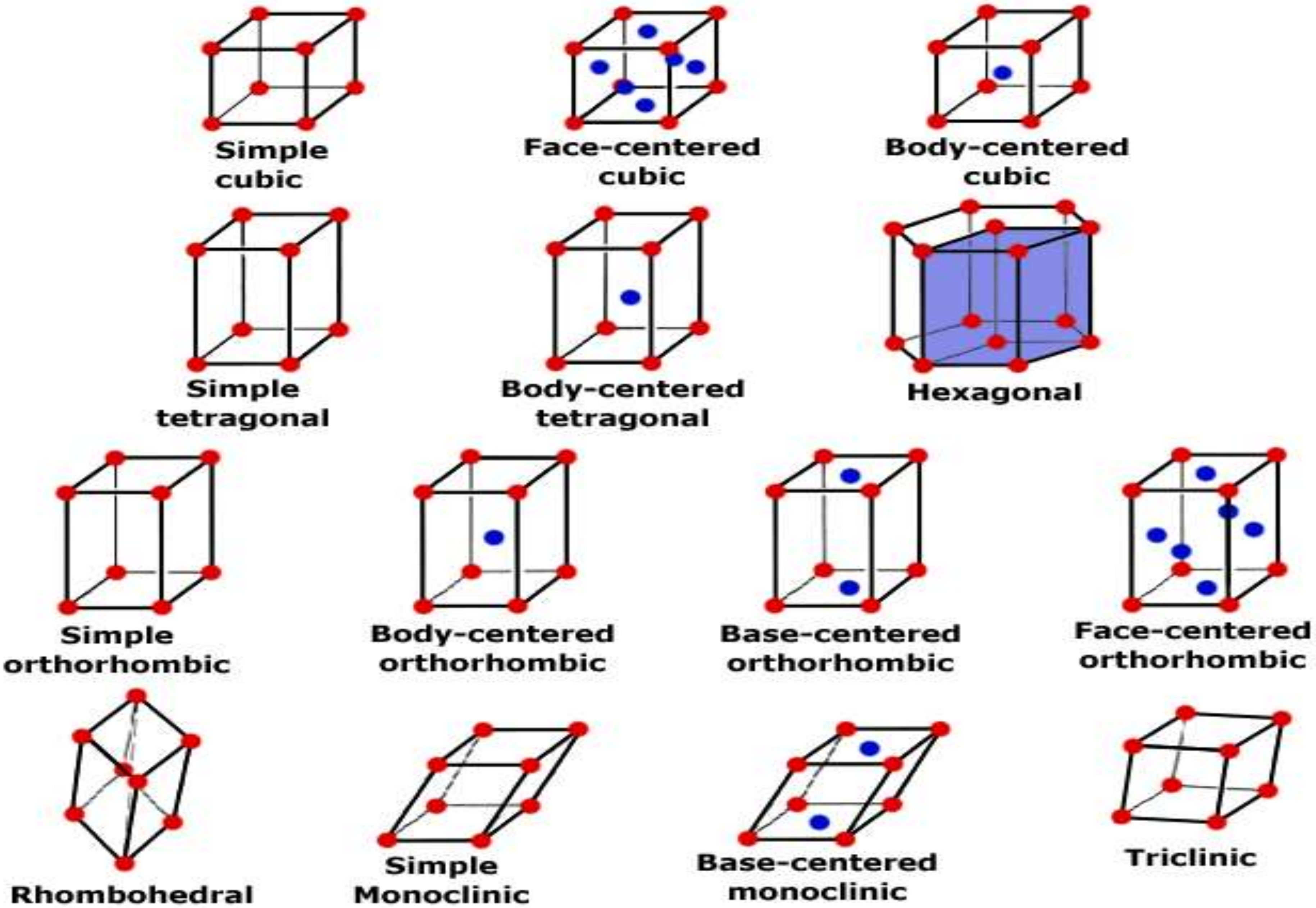


Seven crystal systems and its lattice Parameters

Sr. No.	Crystal System	Axial length of Unit Cell	Inter axial angles	Number of Lattice in the system
1	Cubic	$a = b = c$	$\alpha = \beta = \gamma = 90^0$	3
2	Tetragonal	$a = b \neq c$	$\alpha = \beta = \gamma = 90^0$	2
3	Orthorhombic	$a \neq b \neq c$	$\alpha = \beta = \gamma = 90^0$	4
4	Monoclinic	$a \neq b \neq c$	$\alpha = \beta = 90^0 \neq \gamma$	2
5	Triclinic	$a \neq b \neq c$	$\alpha \neq \beta \neq \gamma \neq 90^0$	1
6	Trigonal	$a = b = c$	$\alpha = \beta = \gamma < 120^0, \neq 90^0$	1
7	Hexagonal	$a = b \neq c$	$\alpha = \beta = 90^0, and\ \gamma = 120^0$	1

BRAVAIS LATTICE

Bravais in 1948 showed that **14 types of unit cells under seven crystal systems** are possible.



Characteristics of unit cell

- **Number of atoms / unit cell**

- **Coordination number**

  No. of equidistant nearest neighbouring atoms to a particular atom

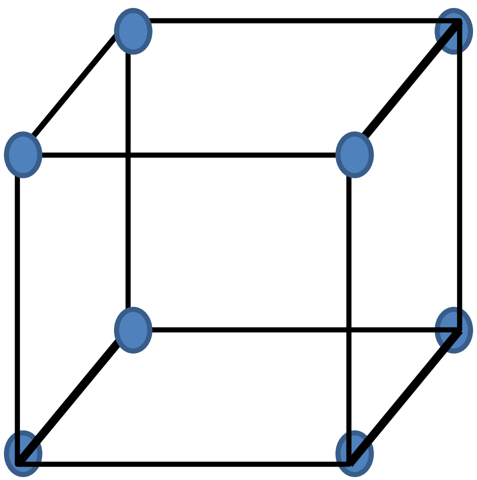
- **Atomic Radius (r)**

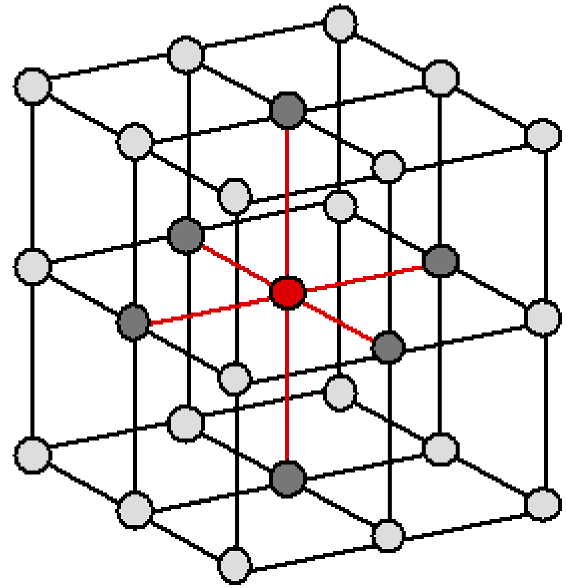
  half of the distance between the nearest neighbouring atoms

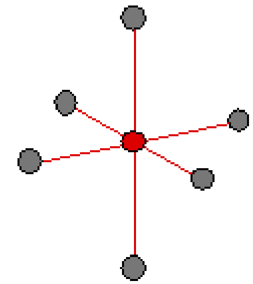
- **Atomic Packing factor or Packing Density**

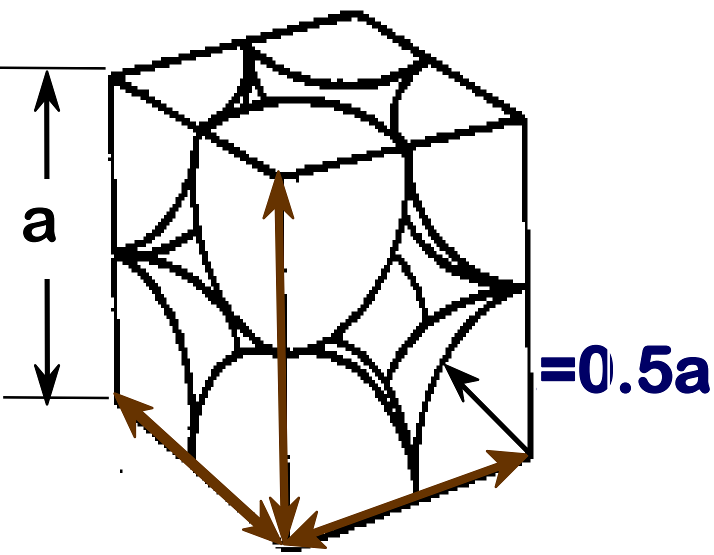
  ratio of the volume occupied by the atoms in an unit cell (v) to the volume of the unit cell (V)

Simple Cubic Structure (SC)



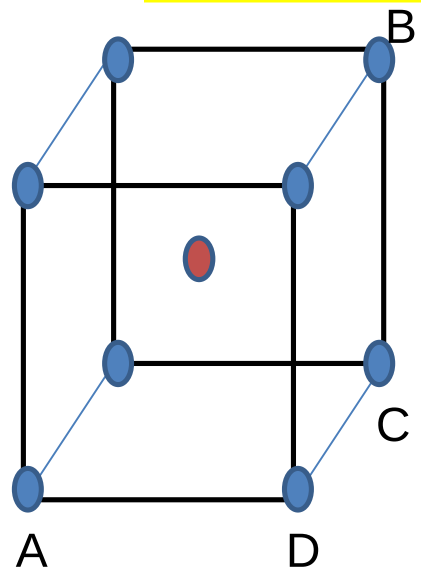


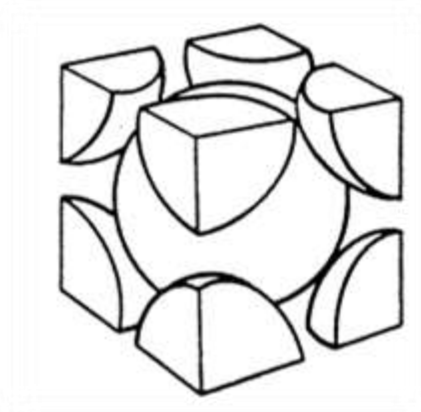


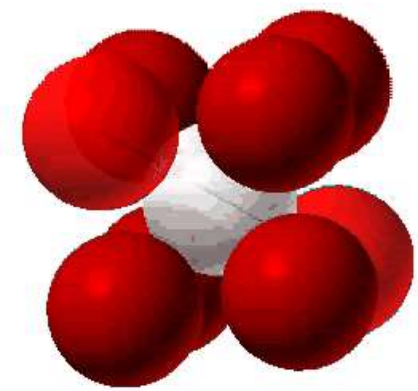


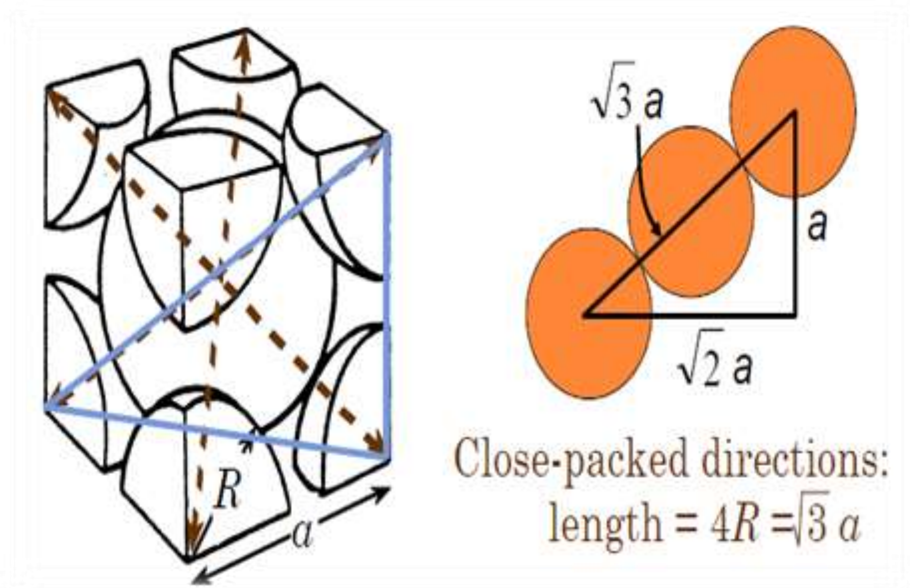
Only 8 atoms, one at each corner of the cube , each corner atom contribute only 1/8th of its part	
No. of atoms/unit cell	1
Atomic Radius	a/2
Coordination No.	6
APF	0.52

Body Centered Cubic Structure (BCC)



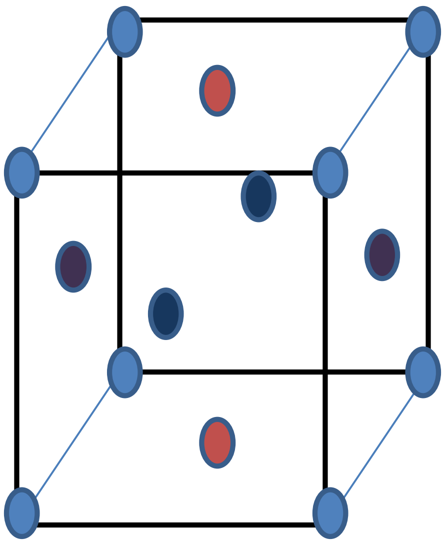


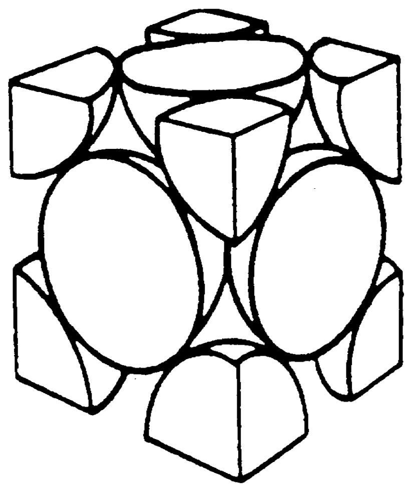


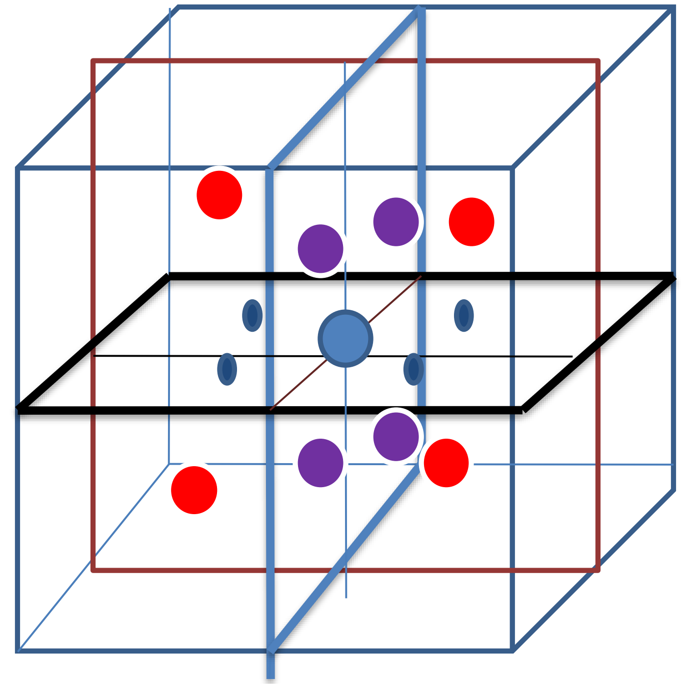


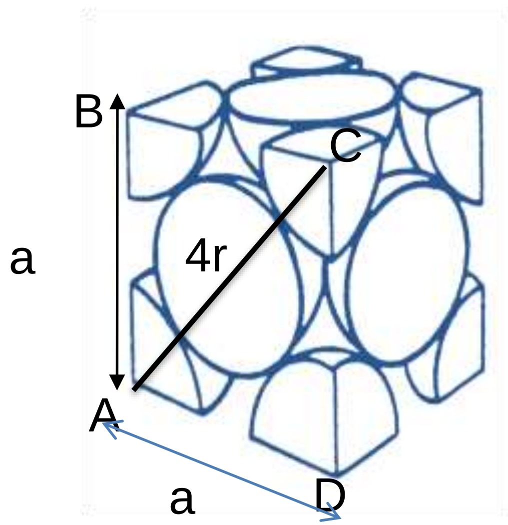
No. of atoms/unit cell	**2**
Atomic Radius	**√3 a/4**
Coordination No.	**8**
APF	**√3π/8 or 0.68**

Face Centered Cubic Structure (FCC)



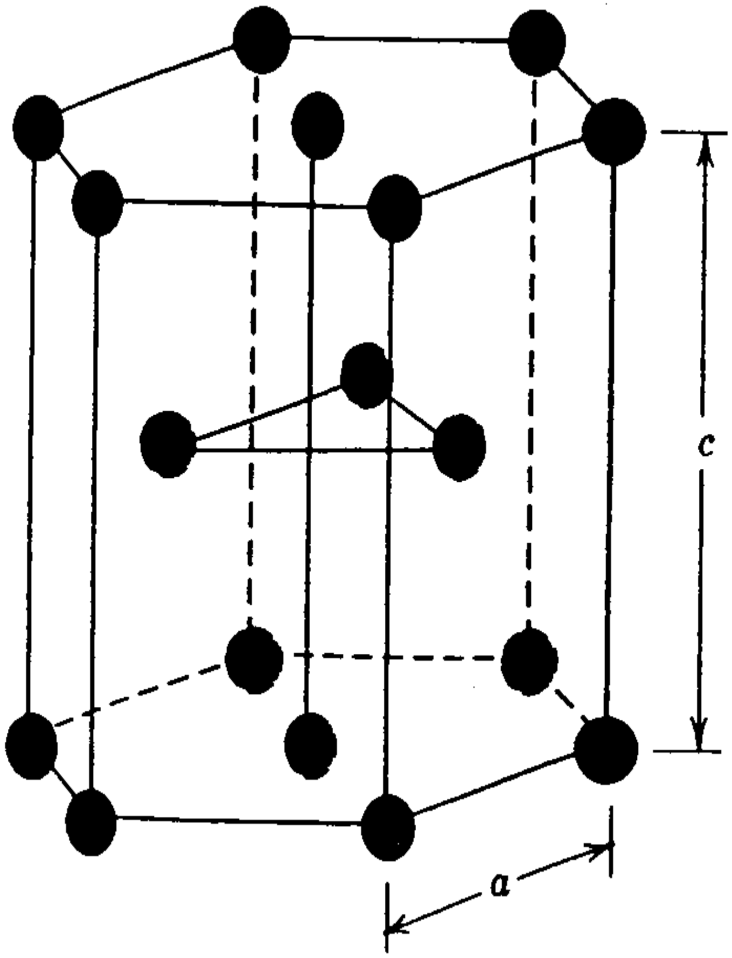




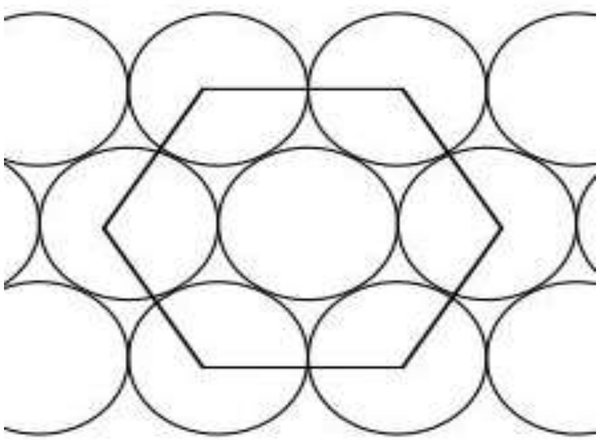


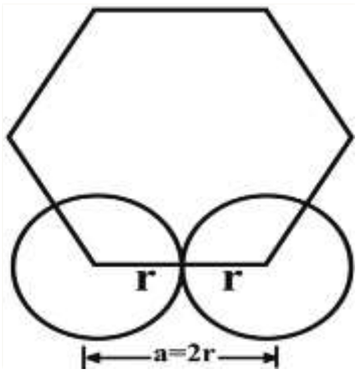
No. of atoms/unit cell	4
Atomic Radius	$\sqrt{2}a/4$
Coordination No.	12
APF	$\pi/(3\sqrt{2})$ or 0.74

HEXAGONAL CLOSED PACKED STRUCTURE



HCP





POLYMORPHISM & ALLOTROPHY

POLYMORPHISM - Ability of material to have more than one structure

ALLOTROPHY - If the change in structure is reversible

MILLER INDICES

- set of three possible integers represented as (h k l)
- reciprocals of the intercepts made by the plane on the three crystallographic axes
- designate plane in the crystal.

Procedure for finding Miller Indices

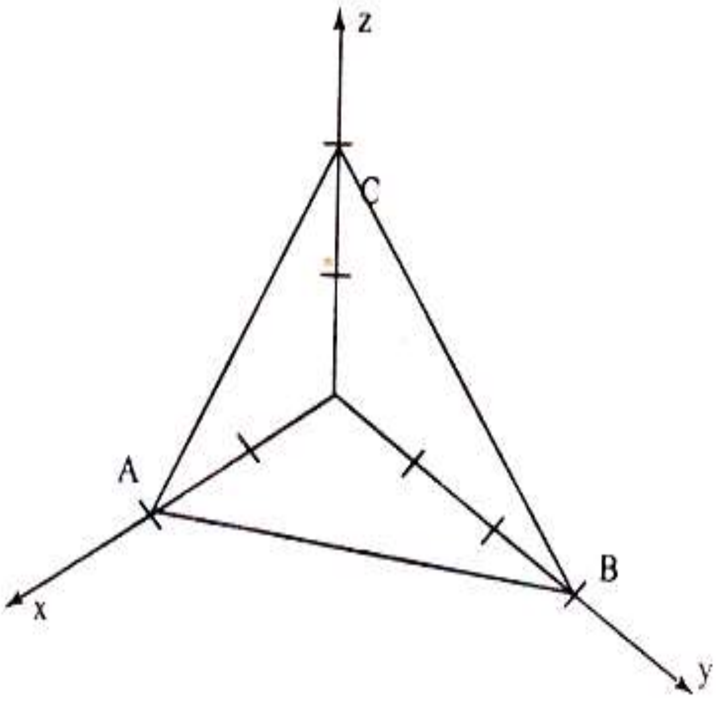
- **Step 1 :** Determine the intercepts of the plane along the axes
- **Step 2 :** Determine the reciprocals of these numbers.
- **Step 3 :** Find the ***LCD*** and multiply each by this *LCD*
- **Step 4 :** Write it in paranthesis in the form (h k l).

ILLUSTRATION

Step 1 : intercepts - **2a,3b and 2c**

Step 2 : reciprocals - **1/2, 1/3 and 1/2.**

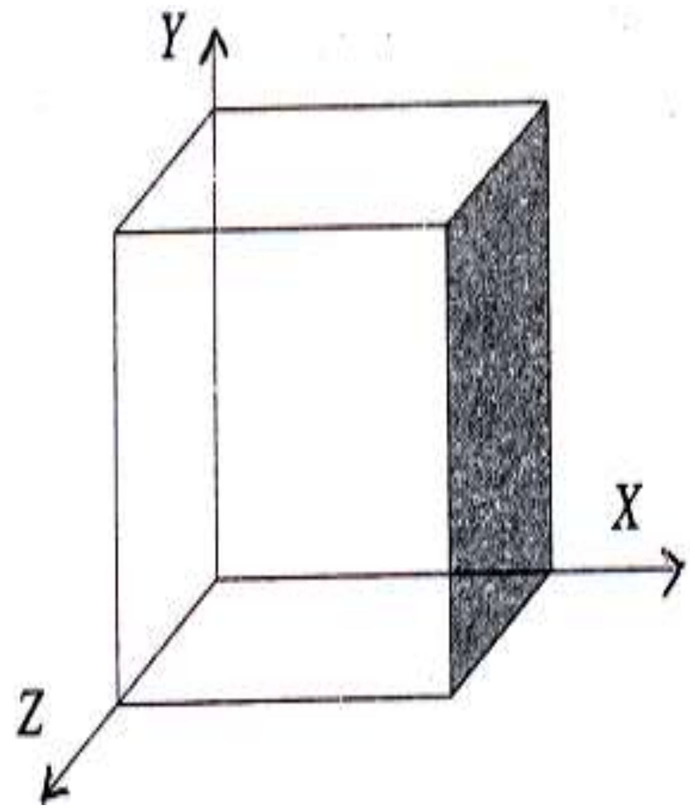
Step 3 : **LCD** is '6'.
Multiply each reciprocal by lcd,
we get, **3,2 and 3**.



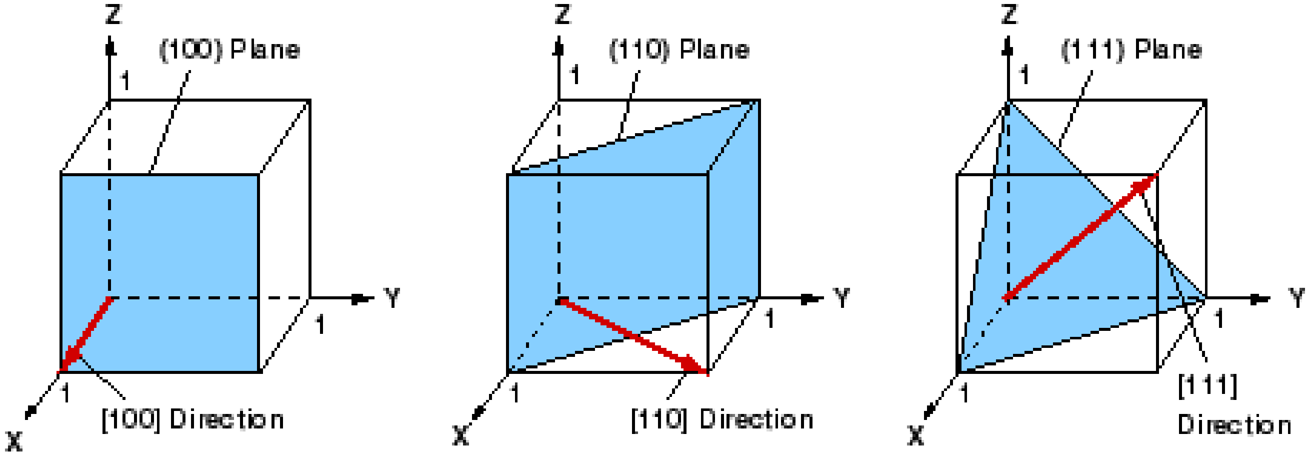
Step 4 : Miller indices for the plane
ABC is **(3 2 3)**

EXAMPLE

- intercepts are **1, ∞ and ∞.**
- reciprocals of the intercepts are **1/1, 1/∞ and 1/∞.**
- Miller indices for the plane is **(1 0 0).**



MILLER INDICES OF SOME IMPORTANT PLANES



IMPORTANT FEATURES OF MILLER INDICES

- a plane parallel to the axes has an intercept of infinity (∞).

- a plane cuts an axis on the negative side of the origin, is represented by a bar, as ($\bar{1}$ 0 0).

- a plane passing through the origin have non zero intercepts

- All equally spaced parallel planes have same Miller indices