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H2

ECE - I ¼

APPLIED PHYSICS

(G2R)

Lasers.

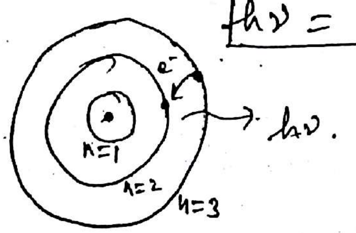
- The origin of light from within gas molecules, liquids, solids is similar in many respects to that within individual atoms.
- We will briefly discuss the concepts of the origin of light from within atoms and then use these concepts to present the principal features of Lasers.

From Bohr's theory of atomic structure we know that:

Light is not emitted by an e^- when it is moving in one of its allowed orbits but only when the e^- jumps from one orbit to another.

The frequency of the emitted light is given by

$$\boxed{h\nu = E_i - E_f}$$



E_i = energy of initial orbit

E_f = energy of final orbit

ν = frequency of the emitted light

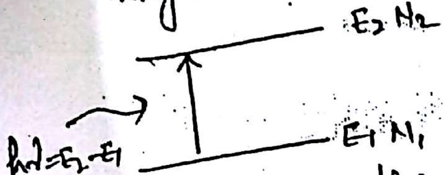
Let us study the different processes occurring in the material when light is incident

Consider a gas enclosed in a vessel, free atoms and white light is incid'

An atom has many energy level.

Stimulated Absorption !

Suppose an atom is in the lower energy level E_1. If a photon is incident on the atom and ~~level E_1~~ and its energy is equal to the difference of the energy b/w two levels then it gets absorbed and the atom is excited in the higher state. This is known as Stimulated Absorption.



The prob of the stimulated absorption $\propto \rho(\nu)$ photon density

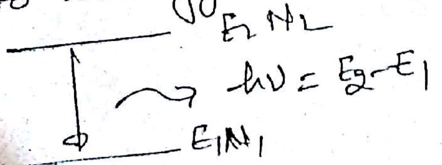
$$= B_{12}\,\rho(\nu)$$

$$\boxed{\text{Total upward absorption (total atoms absorbed)} = B_{12} N_1 \rho(\nu)} \quad \text{— (1)}$$

B_{12} → Einstein coefficient of induced absorption and its characteristic of E_1 and E_2

Spontaneous Emission :

When an atom is excited to higher energy level, it cannot stay in the excited state for long as its lifetime is very small (10^{-8} sec). It jumps to lower energy level releasing photon of the energy equal to the difference in two energy levels.



This is known as <u>spontaneous emission</u>. (3)

The prob of spontaneous Emission $= A_{21}$

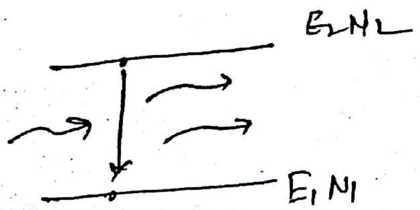
$$\boxed{\text{Total spontaneous transition} = A_{21}N_2} \quad \text{---}(2)$$

A_{21} is the Einstein Coefficient of spontaneous emission.

under <u>steady state</u> $N_1 >> N_2$.

<u>Stimulated Emission</u>:

If an atom in the <u>excited state</u> interacts with a photon (spontaneously emitted) with energy $h\nu$, the atom drops down its lower energy state emitting another photon which propagates in the same direction, frequency and polarization, phase as the primary photon. This is known as <u>stimulated Emission</u>.



The prob of stimulated emission $\propto \rho(\nu)$ photon density

$= B_{21}\,\rho(\nu)$

$$\boxed{\text{Total stimulated Emission} = B_{21}\,\rho(\nu)\,N_2} \quad \text{---}(3)$$

B_{21} is the Einstein coefficient of stimulated Emission.

To find the relation between the Einstein coefficients in steady state:

At equilibrium

The number of atoms absorbing photons per sec per unit volume = The number of atoms emitting photons per sec per unit volume

total upward absorbtion = Total downward emission.

from eqn (1), (2) and (3) we can write

$$B_{12} N_1 \rho(\nu) = A_{21} N_2 + B_{21} N_2 \rho(\nu) \quad \text{--- (4)}$$

$$\rho(\nu) = \frac{A_{21} N_2}{B_{12} N_1 - B_{21} N_2} \quad \text{--- (5)}$$

divide by $B_{12} N_2$

$$\boxed{\rho(\nu) = \frac{A_{21}/B_{12}}{N_1/N_2 - \frac{B_{12}}{B_{12}}}} \quad \text{--- (6)}$$

• we assume that the population densities N_1 and N_2 are constant in time and are distributed acc to Boltzman law in the energy levels.

$$\frac{N_2}{N_1} = \exp -\left(\frac{E_2 - E_1}{KT}\right)$$

$$\boxed{\frac{N_2}{N_1} = \exp\left(-\frac{h\nu}{KT}\right)} \quad \text{--- (7)}$$

Putting (7) in (6) we get

$$\boxed{\rho(\nu) = \frac{A_{21}/B_{12}}{\exp\left(\frac{h\nu}{KT}\right) - \frac{B_{12}}{B_{12}}}} \quad \text{--- (8)}$$

we also assume that

The radiation is in equilibrium with the surrounding atoms. Therefore the radiation is identical with black body radiation and consistant with Planck's radiation law for any value of T.

A/c to Planck's law

$$\boxed{\rho(\nu) = \frac{8\pi h \nu^3 \mu^3}{c^3}\left(\frac{1}{e^{h\nu/KT}-1}\right)} \quad -(9)$$

ν = frequency μ = refractive index

now comparing (8) and (9) we get

$$\boxed{\frac{A_{21}}{B_{12}} = \frac{8\pi h \nu^3 \mu^3}{c^3}}$$

Eq shows that $\frac{A_{21}}{B_{12}}$ varies as third power of frequency of radiation.

$$\frac{B_{21}}{B_{12}} = 1 \quad \text{or} \quad \boxed{B_{21} = B_{12}}$$

B_{21} and B_{12} are numerically equal.

These coefficients are characteristic of the energy levels E_1 and E_2.

Q: How do we amplify Light ?

- In order to amplify light, the probability of Stimulated Emission should be high.

- The prob of stimulated Emission depends on $\rho(\nu)$ and N_2 (population density in the higher level).

Therefore in order to increase stimulated emission, $\rho(\nu)$ and N_2 should increase.

Therefore.

- Photon density $\rho(\nu)$ should be increased to amplify light.

- Under steady condn we know that

$$\boxed{\frac{N_2}{N_1} = \exp\left\{-\frac{(E_2 - E_1)}{KT}\right\}}$$

as $E_2 > E_1$, $N_2 << N_1$ under steady state.

In order to increase stimulated emission, N_2 should be made large.

when $N_2 >> N_1$, we call it as Population Inversion.

- Large number of atoms should be pumped to the higher state i.e. large Pumping should be done.

- The lifetime of atoms in excited states is very small (10^{-8} sec) therefore they drop down to ground state thereby increasing N_1.

In order to achieve <u>Population Inversion</u> ie $N_2 >> N_1$, we should have some levels ~~in which the~~ whose life time of the atoms is large. These levels are known as <u>Metastable levels</u>.

The life time of atoms in metastable levels is approx (10^{-3} – 10^{-6} sec).

<u>Therefore for Light Amplification by Stimulated Emission (LASER) we require</u>.

- Large Pumping
- Population Inversion
- Existence of Metastable state.

Various Components of a Laser :

- **Active medium :** The atoms which cause laser action are called active centers and the medium which supports active centers is called as active used. when these active centers are excited, they reach the state of population inversion and stimulated emission is enhaced causing Light amplification.

- **Pump :** It is a external source which supplies energy to achieve population inversion
  eg optical pumping (flash lamp)
  electrical pumping (electrical discharge).

- **Optical Resonator**
  A pair of optically plane parallel mirror, enclosing laser medium in between them is known as an optical resonant cavity.
  one of these mirrors is partially reflecting and the other is fully reflecting.
  It helps in collimating The laser beam aued by ceeing the photon waves over and over again.

Working of a Laser :→

(9)

- We introduce an appropriate solid, liquid or gas having metastable states into the optical resonant cavity.

- By optical or electrical pumping, the atoms are excited to higher state levels, thereafter they settle in metastable state achieving Population Inversion.

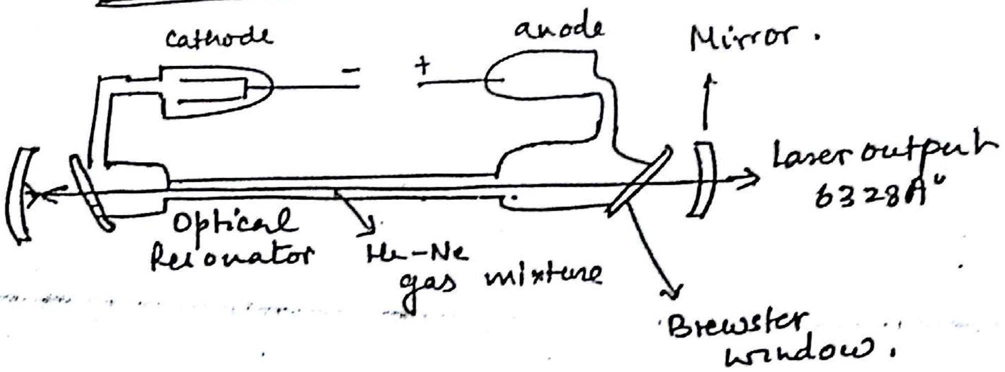
- The photon emitted by spontaneous emission will in turn give rise to stimulated emission in the metastable states.

- The photons moving at an appreciable angle to the walls of the cavity will escape and be lost and those emitted parallel to the axis will reflect back and forth from end to end.

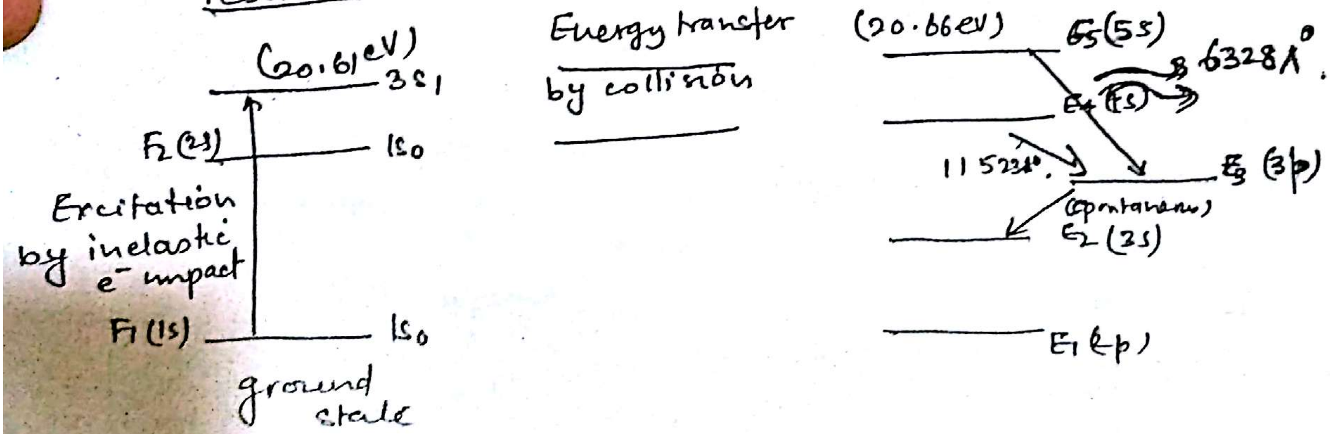
- If high reflectance at the end mirror and high population density of metastable atoms is maintained, then the build up of photons surging back and forth through the cavity can be self sustaining and the system will lase spontaneously.

Types of Laser

1) He-Ne Laser



- It has He and Ne in the ratio of 10:1.
- Ne gas is the active med.
- Electrical discharge is used for pumping.
- e^- but in the discharge transfer energy to the atoms in the Laser gas by collisions.
- On the axis of the tube, two mirrors are arranged externally which form the optical resonator.



The Pumping Mechanism :-

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- A high voltage (10kV) is applied across the gas mixture which ionizes it.
- The e^- and ions produced, accelerate towards the anode and cathode and collide with He and Ne atoms.
- He atoms are excited to higher level (20.61eV) which in turn transfer its energy to Ne atoms ($E_5 < E_4$) through Collision.

Population Inversion

- The upper state of neon atom E_5 is a metastable state where Ne atoms accumulate.
- spontaneous emission occurs at E_5 producing few random photons which in turn start stimulated emission of photons. (6328 A°)
  As the photon density increases in the metastable level (E_5), stimulated emission is enhanced.
- the photons bounce back and forth between the end mirrors causing more and more stimulated Emissions.
- Thus the transitions $E_5 \rightarrow E_3$ generate a laser beam of wavelength 6328A°.

Semiconductor Laser :

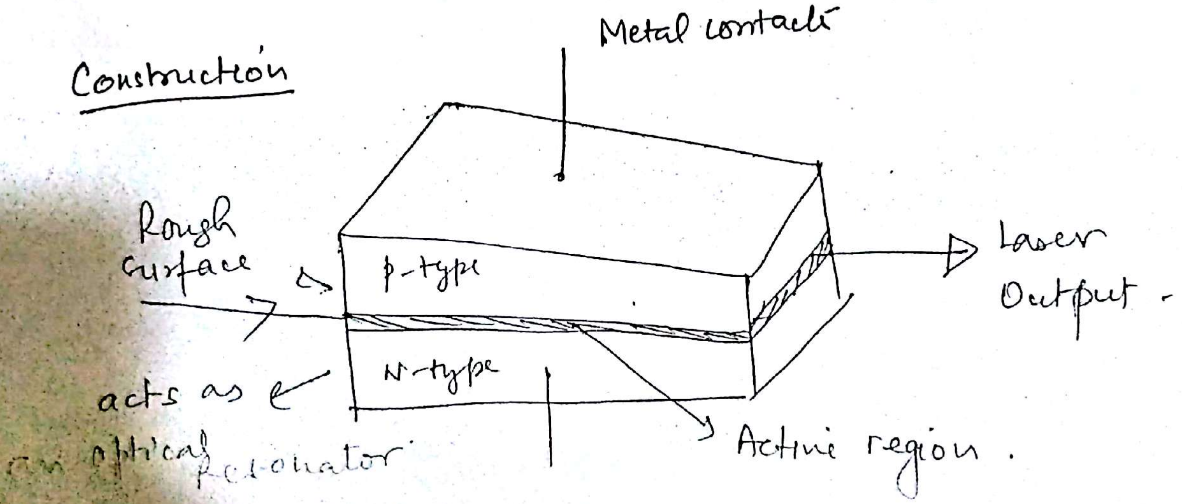
- It is a p-n junction device which emits coherent light when it is forward biased.
- eg GaAs emits light in near IR region
- small in size, portable.
- Direct recombination of conduction band e^- with a hole in the valence band leads to emission of light.
- when an e^- jumps from conduction band into a hole in the valence band, the excess of energy is given out in the form of a photon whose frequency is given by

$$h\nu = E_g \text{ (band gap)}$$

$$\boxed{\frac{hc}{\lambda} = E_g}$$

- A diode Laser which makes use of the same semiconductor material on both the sides of the junction is known as Homojunction diode Laser.

Construction

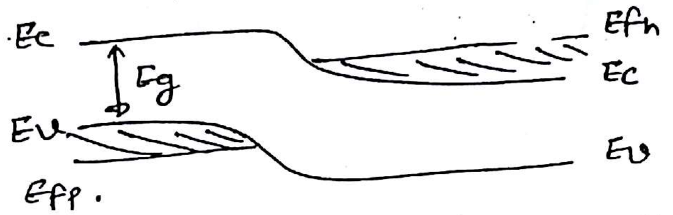


- we have heavily doped n-type GaAs material and p-type is formed by diffusing Zn on ~~top~~ one side.

- The top and bottom faces are metallized to pass current.

- The front and rear faces are polished to act like an optical resonator.

Working :→



- Due to high doping on n-side, the donor levels extend into conduction band along with the Fermi level. e^- occupy the portion of conduction band lying below the Fermi level.

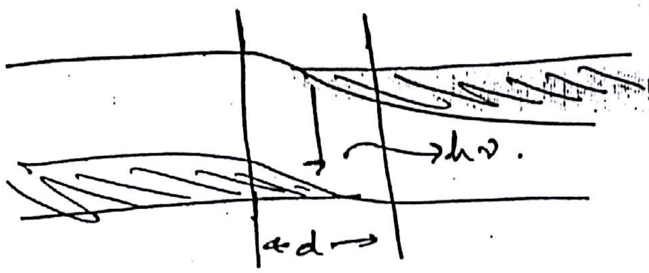
- on the heavily doped p-side, the Fermi level lies within the valence band and holes occupy the portion of the valence band that lies above the fermi level.

- when the junction is forward biased, e^-s and holes are injected into the depletion region in high conc.

- Thus upper energy levels in the narrow region have high e^- conc while lower are vacant. Thus population inversion is achieved.

- Recombination of e's and holepairs leads to emission of spontaneous photons which in turn stimulate the neighbouring e's to jump into valence band to emit more photons. This stimulated e⁻-hole recombination produces coherent radiation.

- GaAs laser emits light at wavelength of 9000 A° in IR region.



Characteristics of Laser:

- **Directionality:** The laser beam is highly directional. The active material in laser is enclosed in a cylindrical resonant cavity and the emerging light propagates only along the axial direction which makes it directional.

- **Divergence:** The divergence of laser beam is very less. The divergence of laser beam in the form of plane waves it propagates. The extent of divergence can be estimated as follows.

$$\boxed{\phi = \frac{d_2 - d_1}{l_2 - l_1}} \text{ radian}$$

$d_1, d_2 \rightarrow$ diameters of the spot produced by laser.

$l_1, l_2 \rightarrow$ distance of laser from the screen.

- **Intensity :**

Laser beam is very intense as whole energy is concentrated in a small region of space. It is emitted in the form of a narrow beam.
The intensity is very large and stays constant with distance.

- **Coherence :**

Laser beam is highly coherent. This is due to the fact that photons emitted by stimulated emission are in phase with the primary photons. By multiplication of the same phase photons, we get a highly coherent Laser beam.

- **Monochromatic :**

Laser beam is highly monochromatic and contains a very narrow range of few angstroms ~~A^0~~ $< 10 A^0$.

HW.
Q. Write few applications of Lasers ?.

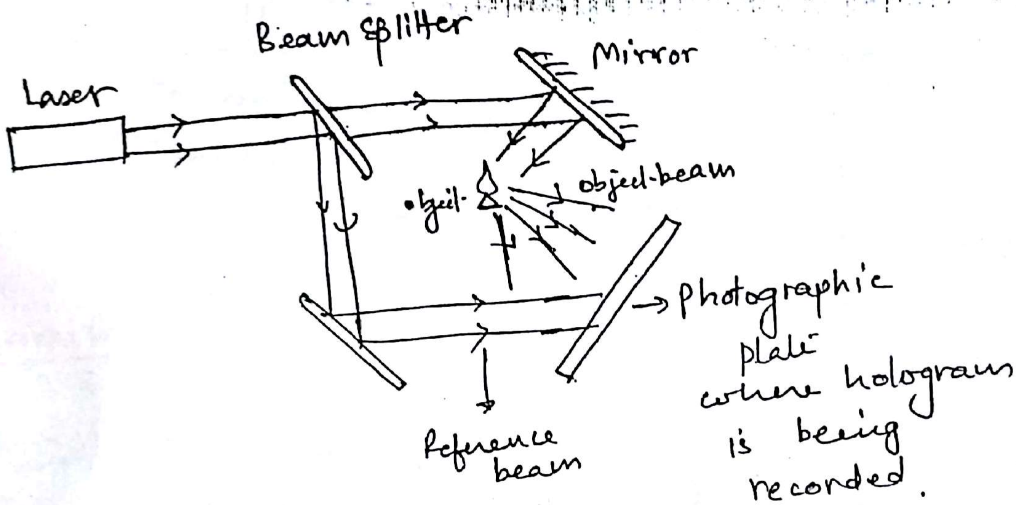
Scanned by CamScanner

Dr. Neelima Agarwal. (1)

Holography

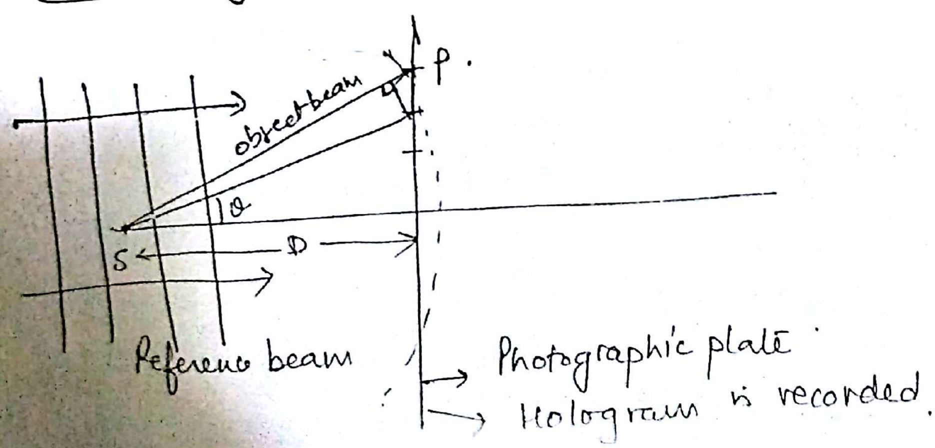
Principal of Holography

- ~~It is~~ lensless imaging process which is a result of interference occuring between two waves, an object beam scattered off the object and a reference beam i.e. a coherent beam reaching directly the photographic plate:



It is a two step process:

(i) Recording of the Hologram :-

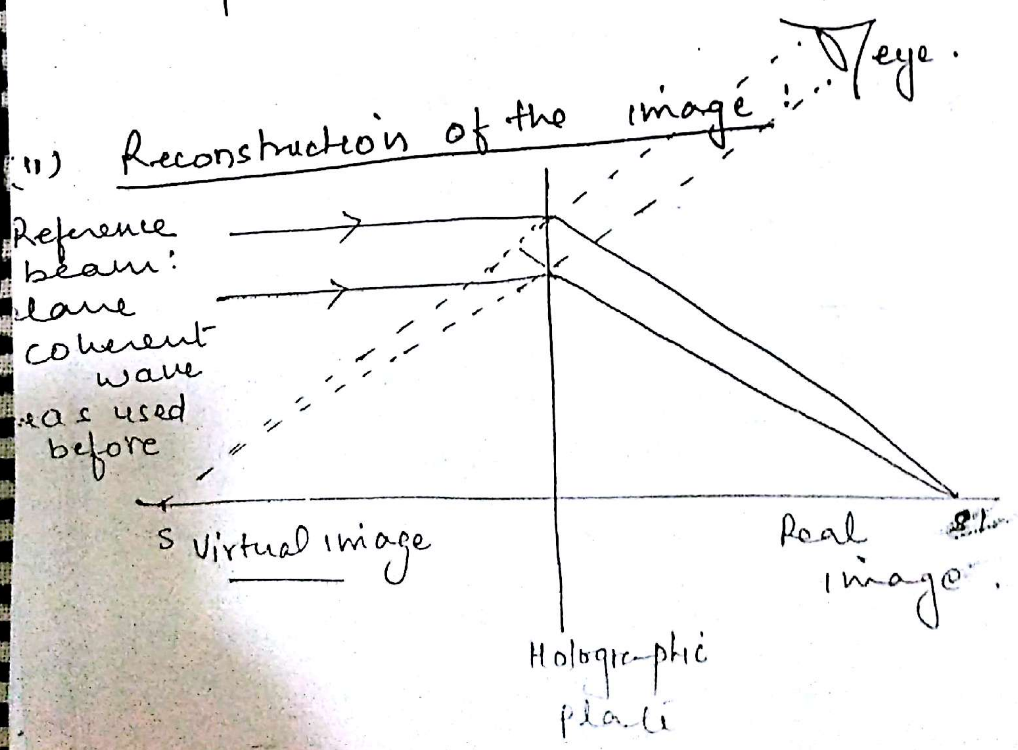


- A broad beam is splitted into an object beam and a direct referena beam by a beam splitter and made to fall on the photographic plate.

- Each point of the object scatters the incident beam and act as a source of spherical waves from the object. These innumerable sphesical waves from the combine with the plane light wave from the reference beam at the photographic plate to give interference pattern as they are coherent.

- The developed negative of these interference fringes is a hologram. It carries a record of both the intensity and the relative phase of the light waves at each point.

(ii) Reconstruction of the image



(:-) . . .

- The Hologram is illuminated by a parallel beam of light from the same source as used before to record it but in the absence of the object.
- The fine fringes act as elaborate diffraction grating.
- All the points from the hologram will produce diffracted light forming a virtual image appearing at the location formerly occupied by the object. It can be viewed from right of the hologram. And a real image is formed by the light diffracted in the opposite direction and it can be photographed.
- Observer can move in different directions and look around the image to the same extent as the real object.
- In a hologram, each part contains information about the entire object, so even a small part can be used to reconstruct the full image.

several images can be recorded on a hologram, therefore its information holding capacity is high.

- A three dimensional image can be viewed from a hologram as it contains the information of phase along with amplitude.

HW.

Q.1. Compare Hologram with ordinary photograph?

Q.2. Give few applications of Holography?