Unit-3 - LASER

Introduction

- LASER is an acronym for Light Amplification by Stimulated Emission of Radiation.
- LASER has some superior properties than conventional light sources that is why laser can be used in different fields like mechanical engineering, medical sciences, military field and so on.
- It is the Stimulated Emission of Radiation that makes Laser better than other conventional sources of light.
- In 1916, Einstein predicted the idea of stimulated Emission of Radiation.
- For lasing action (having a laser light) the stimulated emission should exceed the other processes like absorption and spontaneous emission.

Properties of LASER - (Characteristics of LASER) -

(I) Monochromaticity - LASER is highly monochromatic

Monochromatic light means light having single frequency (or wavelength). ordinary sources emits different wavelengths, so, are polychromatic sources. But LASER source emits a single wavelength, therefore, LASER is highly monochromatic.

(II) Coherence - LASER is highly coherent.

Two waves are said to be coherent when their frequencies are same and phase difference between them is constant with time. ordinary sources are in-coherent but laser is highly coherent

(III) **Directionality** - LASER is highly directional.

Conventional sources emits light waves in all directions. But laser emits the light in one direction only. So, it is highly directional. Therefore Laser has very small divergence. (small divergence means spreading is very small when light incident on any surface after travelling some distance)

(IV) **Intensity** - LASER has high intensity.

As a laser is highly directional, the intensity of laser is very high. Because laser delivers the energy (high energy) to very small area.

Three processes of LASER (Principle of Laser) -

Let us consider two energy levels 'E_1' and 'E_2'

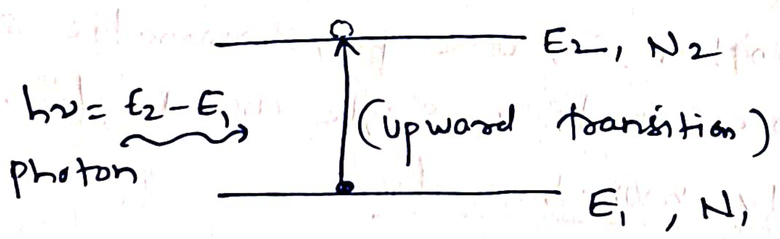
'E_1' is the energy of ground state,

'E_2' is the energy of excited state and

'N_1' is the number of atoms per unit volume of E_1.

N_2 is the number of atoms per unit volume of E_2.

(I) **Absorption** (Induced absorption) -



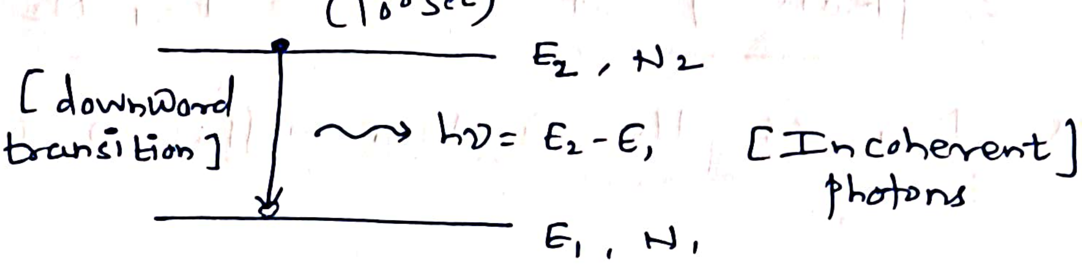
- In absorption process, the atom in the ground state absorbs the energy '$h\nu$' and jumps to excited state.
- The rate of absorption depends on 'N_1' and $\rho(\nu)$ where $\rho(\nu)$ is photon density.

∴ Rate of absorption ∝ $N_1 \rho(\nu)$

∴ **Rate of absorption = $B_{12} N_1 \rho(\nu)$**

Here, B_{12} is the Einsteins coefficients of Absorption.

(II) Spontaneous Emission [Spontaneous – On it's own]



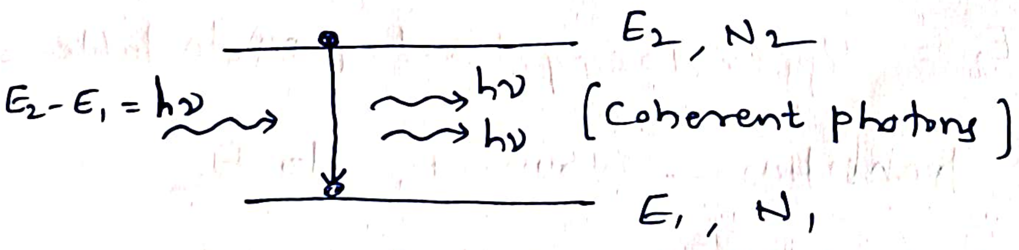
- In spontaneous emission process, an atom in the excited state jumps to the ground state on it's own (without any energy) and emits a photon.
- This process of emission is random, so emitted photons are incoherent.
- Rate of spontaneous emission depends on 'N_2'.

∴ Rate of sp. emission ∝ N_2

∴ **Rate of spontaneous emission = $A_{21} N_2$**

Here, A_{21} is the Einsteins Coefficient of Spontaneous Em

(III) Stimulated Emission [stimulated – with external energy]



- In stimulated emission process, an atom in the excited state is stimulated (forced) by a photon to jump to ground state by emitting two photons

- This process of emission is <u>not</u> random, so emitted photons are <u>coherent</u>.
- Rate of stimulated emission depends on 'N_2' and $\rho(\nu)$.

$\therefore$ Rate of st. emission $\propto N_2 \, \rho(\nu)$

$\therefore$ **Rate of St. emission $= B_{21} \, N_2 \, \rho(\nu)$**

Here, B_{21} is the Einsteins coefficients of st. emission.

Difference between spontaneous and stimulated Emission-

Spontaneous emission	Stimulated emission.
i) An atom in the excited state jumps to the ground state on it's own. and emits a photon.	i) An atom in the excited state jumps to the ground state by interaction with stimulating photon and emits two photons.
ii) This is random process.	ii) This is not a random process
iii) Emitted photons are incoherent	iii) Emitted photons are coherent
iv) Light is not monochromatic.	iv) Light is monochromatic.

Requirements of LASER :-

For LASER action, stimulated emission should be dominating over the spontaneous emission and absorption. Therefore to achieve high percentage of stimulated emission there are some requirements or conditions.

(I) Population Inversion :-

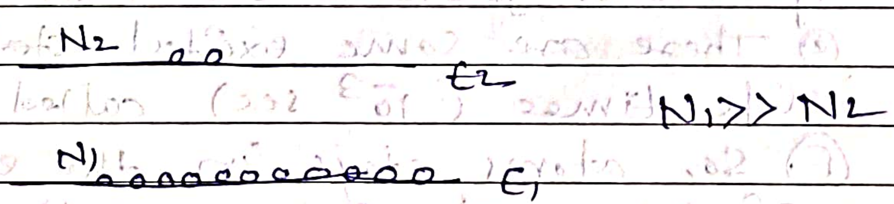
(a) Let us consider two energy levels 'E_1' & 'E_2' where $E_2 > E_1$.

let, N_1 = Population at E_1 (Number of atoms per unit volume at level E_1)

N_2 = Population at excited level 'E_2'. (Number of atoms at E_2 per unit volume)

(b) Under normal condition (thermal eq^n cond^n) the number of atoms in the ground state (N_1) is higher than number of atoms in excited state (N_2).

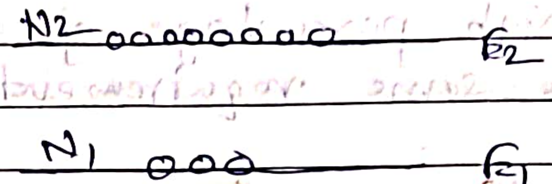
i.e $N_1 >> N_2$



(c) To increase the probability of stimulated emission population inversion is to be created.

(d) The state in which there is larger number of atoms in excited state (higher energy state) than the ground state (lower state) is called as population inversion.

(e) That is, in a state of population inversion $N_2 >> N_1$



(II) Metastable state :-

(a) An atom can be excited to a higher level by supplying energy to it.

(b) Normally, atom stays in excited state for very short period (10^{-8} sec) & jumps to ground state spontaneously & emits a photon.

(c) So, population inversion can not be established.

(d) In order to create population inversion, the atoms in the excited state are required to wait at excited state till a large number of atoms gathered at that level.

(e) These are some excited states with larger life times (10^{-3} sec) called as metastable states.

(f) So, atoms stays in the excited state for 10^{-3} sec. Therefore population inversion can be achieved.

(g) If metastable state do not exist then there could be no population inversion & hence no laser action.

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(iii) High radiation density [$\rho(\nu)$] →

A high radiation density $\rho(\nu)$ is required in the active medium so that stimulated emission dominates spontaneous emission and absorption.

Components of LASER :-

The important components of LASER are,

i) An active medium ii) pumping agent
iii) an optical resonator

i) An active medium :-

(a) Active medium is a material in which the laser action takes place.

(b) The atoms which cause the laser action are called as active centres.

(c) Active medium acts as a host and support active centres.

(d) For ex. in Ruby laser, Ruby crystal rod (Al_2O_3) acts as a active medium and Cr^{3+} atoms (ions) acts a a active centres.

(e) Active medium achieves a state of population inversion & laser action can takes place.

ii) Pumping agent :-

(a) To achieve a condition of population inversion we have to raise continuously the atoms in the ground state (lower) to excited state.

(b) It requires the energy to be supplied to atoms.

(c) The process of raising the atoms from lower energy state to higher state is called as pumping.

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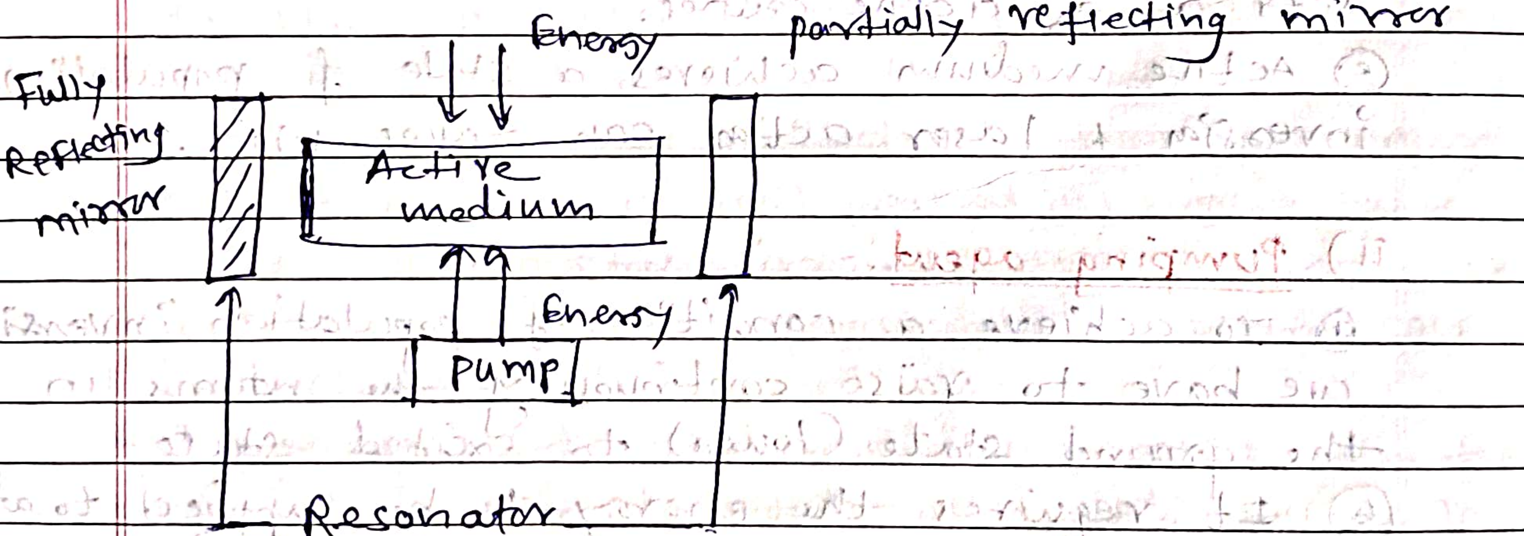
(d) Energy can be supplied to atoms in diff^nt forms.
(1) optical pumping - (Excitation by photons)
(2) Electrical pumping - (Excitation by electrons)

(III) Optical Resonator :-

(a) A pair of plane parallel mirrors, enclosing laser medium in between them is known as optical resonator cavity.
(b) one of the mirror is partially reflecting & other mirror is fully reflecting.
(c) The photons emitted by spontaneous emission, travels along the optical axis of resonator and initiates the stimulated emission.
(d) These photons are reflected by mirror & fed back to medium causing more stimulated emissions.
(e) So, after several reflections, light beam gains strength & laser beam emerges out from the mirror.



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Role of optical Resonator –

* optical resonator makes the laser beam directional.
* optical resonator increases the radiation density [$\rho(\nu)$].
* optical resonator selects & amplifies only certain frequencies causing laser output to be highly monochromatic.

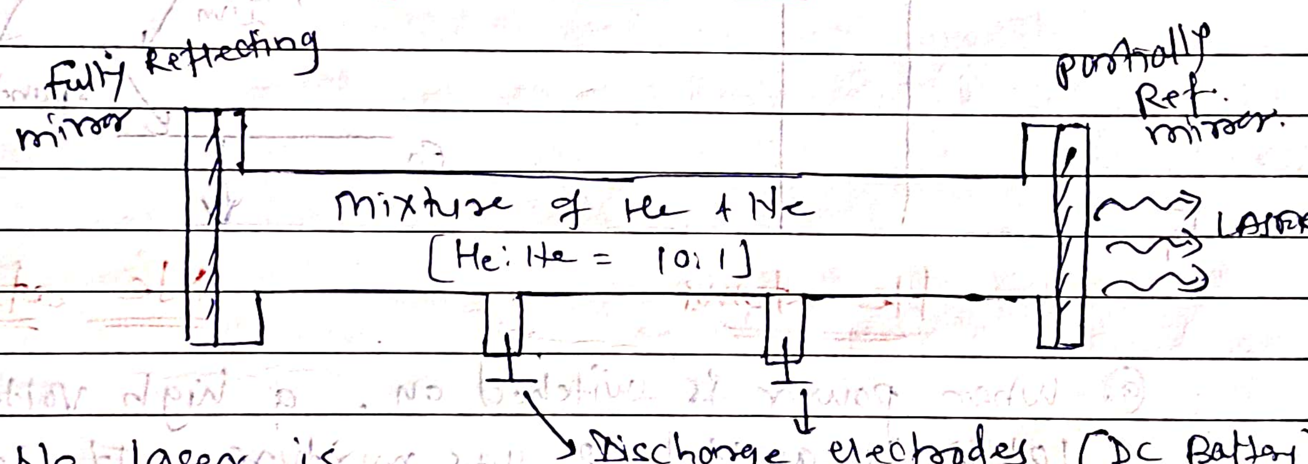
$$L = \frac{n\lambda}{2} \quad \text{(condition of stationary)}$$

$$v = f\lambda \quad , \quad \lambda = \frac{v}{f}$$

$$\therefore L = \frac{nv}{2f}$$

$$\boxed{f = \frac{nv}{2L}}$$

Helium – Neon [He – Ne] LASER :-



He – Ne laser is a gas laser.

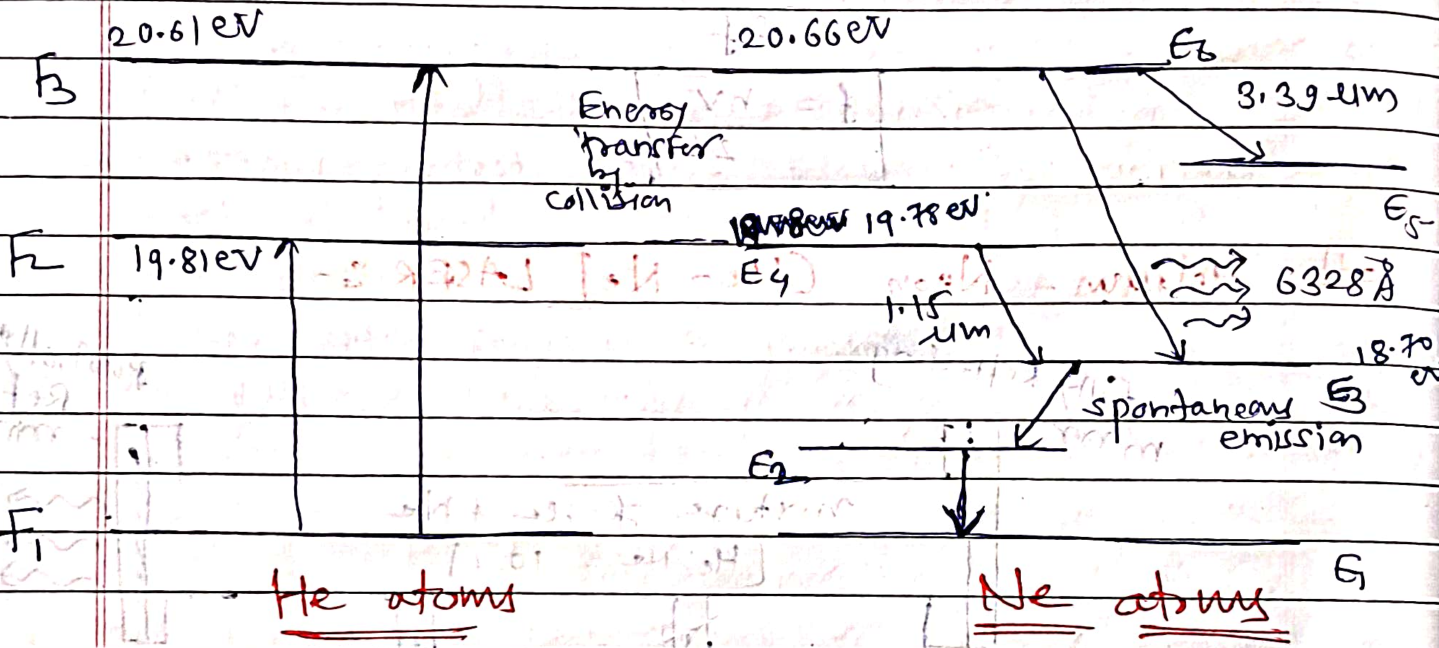
Constructions:-

(a) He – Ne laser consists of a long discharge tube filled with a mixture of He & Ne gases in the ratio 10 : 1.

(b) Two electrodes are connected to high voltage power supply.
(c) Two mirrors are used to form optical resonator cavity.
(d) Neon atoms are the active centres while He atoms helps in exciting Ne atoms.

Working:-

Energy level diagram:-



(a) When power is switched on, a high voltage of about 10 KV is applied to gas mixture. It ionises gas.
(b) The highly energetic electrons collides with He & Ne atoms.
(c) He atoms are lighter and therefore get excited from its ground state 'F_1' to metastable states 'F_2' & 'F_3'

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(d) These excited He' atoms at E_2 & E_3 can return to ground level by transferring its excess energy to Ne' atoms.

(e) So, Ne atoms are excited to upper levels E_4' & E_6'. This transfer of energy from He' to Ne' is called as resonant energy transfer.

(f) E_4' & E_6' are metastable states and therefore population inversion is achieved between E_6, E_4 to the levels E_5, E_3 respectively.

(g) So, spontaneous emission initiates stimulated emission in any of the following three transitions.

i) $E_6 \rightarrow E_5$ ⇒ transition generates light of 3.39 μm wavelength (far IR)

ii) $E_6 \rightarrow E_3$ ⇒ transition generates laser light of wavelength 6328 Å.

iii) $E_4 \rightarrow E_3$ ⇒ transition generates laser light of wavelength 1.15 μm (IR).

(h) Then Ne atoms come down to E_2' level. Atoms from E_2' level comes to ground E_1' very quickly by collision with walls of tube.

(i) These Ne' atoms are again available for lasing action.

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Applications of LASER :-

① **Holography :-** [Danis Gabor – 1948]

Holo (Whole) + graphein [to write (record)] → Holography

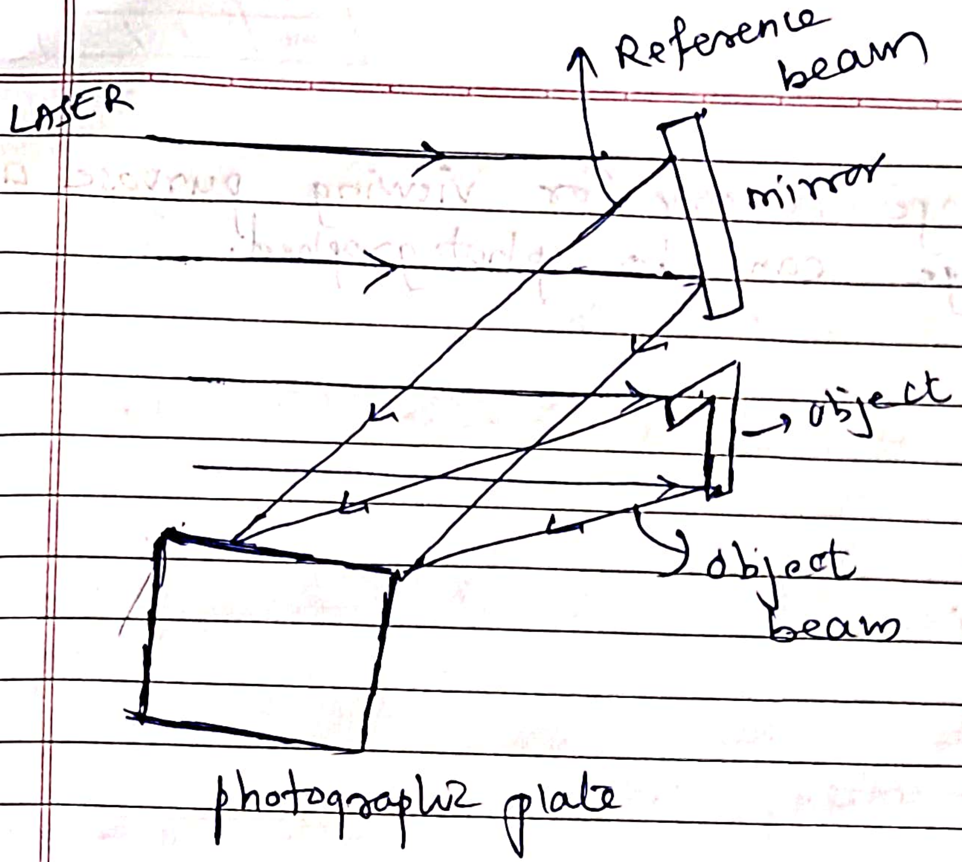
(a) Holography is a technique of producing three dimensional images.
(b) In conventional photography, two dimensional images are formed on photographic plate.
(c) In conventional photography only intensity of light is recorded.
(d) In holography, the intensity as well as phase of light waves coming from the object are recorded in the form of interference fringes.

Principle :-

(a) Holography is a two step process.
i) Recording of hologram.
ii) Reconstruction of image.

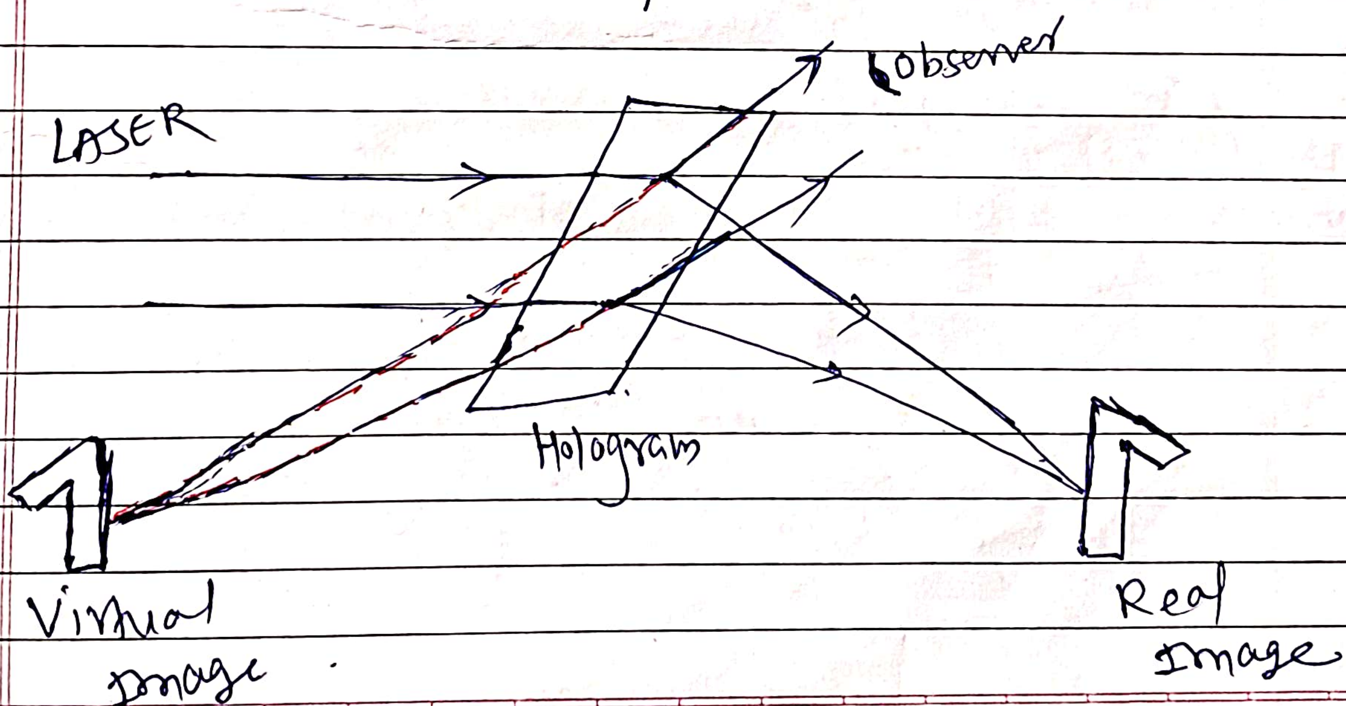
i) Recording of hologram :-

(a) Coherent light from a laser is partly reflected from a mirror known as reference beam and partly reflected from object known as object beam.
(b) The interference patterns of these beams are recorded on photographic plate.
(c) The developed photographic plate is a hologram.



ii) Reconstruction of image:-

ⓐ To see the 3-D image, hologram is illuminated by the laser light.
ⓑ The hologram acts as a diffraction grating.
ⓒ The diffracted ~~beam~~ rays form two images one is virtual images and other is real image.



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(d) Virtual image is only for viewing purpose and real image can be photographed.