(or), $u_\lambda = \frac{A_{21}}{B_{21}} \left\{ \frac{1}{\left(\frac{B_{12}N_1}{B_{21}N_2} - 1\right)} \right\} \longrightarrow (11)$

Recall, Boltzmann statistics $\frac{N_1}{N_2} = e^{\Delta E/kT} = e^{h\nu/kT} \longrightarrow (12)$

(or) $\nu = \frac{c}{\lambda}$

$$\boxed{\frac{N_1}{N_2} = e^{hc/\lambda kT}} \longrightarrow (13)$$

Substitute eq^n (13) in eq^n (11)

$$u_\lambda = \frac{A_{21}}{B_{21}} \left(\frac{1}{\left(\frac{B_{12}}{B_{21}}\right)\left(e^{hc/\lambda kT}\right) - 1} \right) \longrightarrow (14)$$

compare eq^n (14) with plank's radiation law i.e., eq^n (1) we have $\boxed{\frac{A_{21}}{B_{21}} = \frac{8\pi hc}{\lambda^5}}$, & $\boxed{\frac{B_{12}}{B_{21}} = 1}$ (or) $B_{12} = B_{21}$

This implies that the probability of induced absorption = probability of stimulated emission.

Thus, A_{21} & $B_{12} = B_{21}$ can be represented simply as

$$\boxed{A_{21} = A \quad \& \quad B_{12} = B_{21} = B}$$

& substitute in eq^n (14)

$$\boxed{u_\lambda = \frac{A}{B\left(e^{hc/\lambda kT} - 1\right)}} \longrightarrow (15)$$

It is an ~~expers~~ expression for energy density of radiation in terms of Einstein A & B coefficients.

$$\therefore \boxed{\frac{A}{B} = \frac{8\pi h}{\lambda kT}} \longrightarrow (16)$$

$$\boxed{E_\lambda = \frac{A}{B}\left(\frac{1}{e^{hc/\lambda kT} - 1}\right)}$$

$$\boxed{E_\lambda d_\lambda = \frac{8\pi hc}{\lambda^5}\left(\frac{1}{e^{hc/\lambda kT} - 1}\right) d_\lambda}$$

Pumping:~ It is the process of exciting atoms from energy state (E_1) to higher energy state (E_2) by using some external energy.

Lasing:~ The process which leads to the emission of stimulated photons after establishing the population inversion (i.e., $N_2 > N_1$).

Active medium:~ The quantum system b/w whose energy states in which the pumping and lasing action occurs is called active media.

Condition for Laser action:~

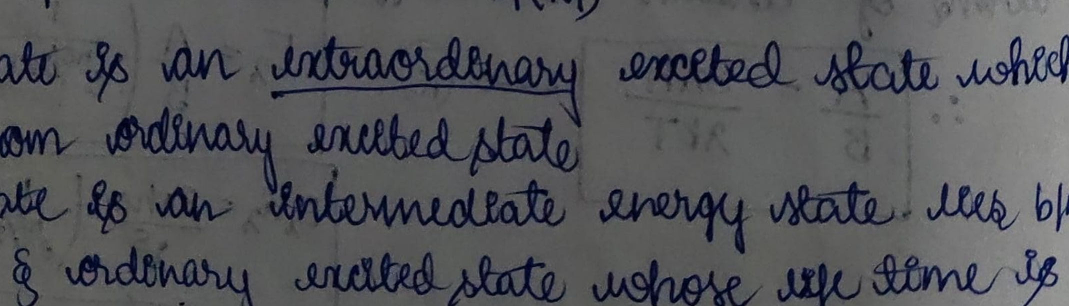
Q: Explain the conditions of Laser action with figures.

There are three conditions required for lasing action:~

1. Stimulated emission
2. Metastable state
3. population inversion

1. Stimulated emission:~ Stimulated emission is the emission of a photon by a system, under the influence of a passing a photon of just the right (same) energy. Due to which the system transists from a higher energy state to the lower energy. The photon thus emitted is called stimulated photon and will have the same phase energy and direcⁿ of momentum as that of the incident photon called stimulating photon.

2. Metastable state:~



- Metastable state is an extraordinary excited state which is different from ordinary excited state.
- Metastable state is an intermediate energy state lies b/w ground state & ordinary excited state whose life time is approximately 10^{-3} sec which is 1,00,000 times greater than that of the life time of ordinary excited state.

• The transition from metastable state to ground state is the lasing transition during which stimulated emission of radiation can occur by a passing photon.

3. Population inversion:-

• The term popula^n refers to the no. of atoms available at given energy state. Under normal conditions the population is more in the lower energy state compared to excited state (i.e., $N_1 > N_2$)

: popula^n inversion is an unusual situation but essential for lasing action and can be achieved by some artificial process. This is generally achieved by pumping energy in an active medium ~~state~~ for lasing.

• "Population inversion is the state of the system, under some conditions the population of a particular high energy state is more than that of a specified lower energy state i.e., $N_2 > N_1$.

• The ratio of population of energy levels is given by $\frac{N_2}{N_1} = e^{\frac{-(E_2-E_1)}{KT}}$

PRODUCTION OF LASER:-

Requisites of a laser system:-

V.imp

Q:- Discuss 3 important requisites of laser system.

→ There are 3 requisites for laser system

1. external source for pumping action
2. An active medium which can supports popula^n inversion
3. "A laser cavity" (or) Resonating cavity

1. external source:- A external source is a source for pumping action, and it is called the excitation sources, which are provides energy in an appropriate form for pumping the atoms to higher energy states.

• If the excitation source may be in the form of light energy then the kind of pumping is called "optical pumping"

Ex:- Ruby laser

• If the pumping is achieved by make use of electrical energy input then it is called "electrical pumping".

Ex:- CO_2 laser, He-Ne-laser etc

"If the pumping is achieved by Mechanical ... is called "Mechanical pumping".
Ex:- Dye lasers

Active medium:- An Active medium is one which supports population inversion which is having different quantum energy levels. It is also having metastable ~~state~~ state of energy. The pumping & the lasing actions occurs in the active medium. A part of input energy is absorbed by the active medium in which population inversion occurs at certain state. Particular in the metastable level. Then medium attains a capable to release laser light.

The following are the active medium that are used for lasers.

1. Gas laser - mixture of gases-Ex:He-Ne gas laser, CO_2 gas laser
2. crystals and solids - Solid state laser-Ex:Ruby laser etc
3. Liquids - liquid laser - Ex:- Dye laser
4. Semiconductors - Semiconductor laser - Ex:- Gallium (Ga), Arsenate (As), phosphate (P)

Laser cavity:-

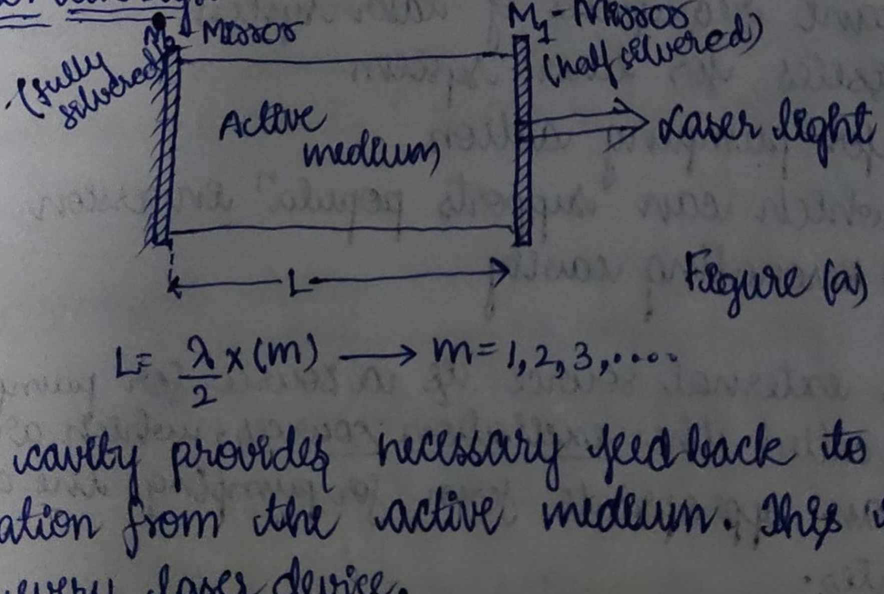


Figure (a)

$$L = \frac{\lambda}{2} \times (m) \longrightarrow m = 1, 2, 3, \ldots$$

The cavity provides necessary feed back to get continuous la... radiation from the active medium. This is a basic struct... for every laser device.

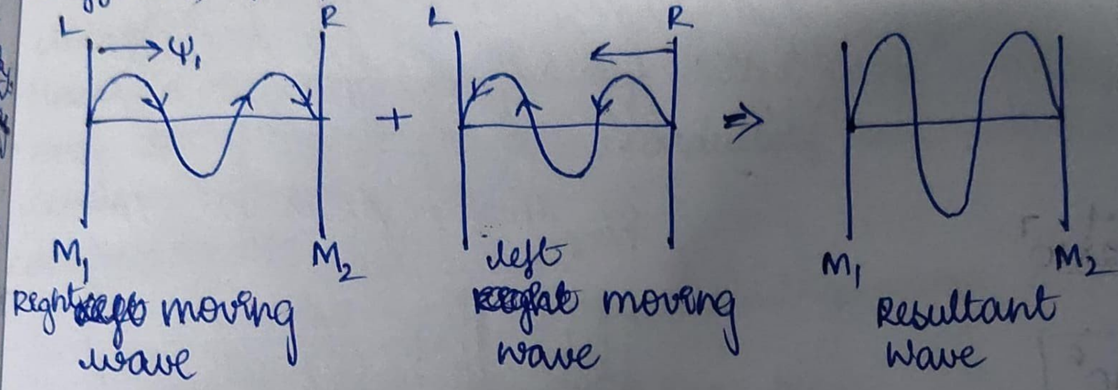
Laser device consists of an active medium bound... b/w two mirrors M_1 and M_2 respectively.

The two mirrors reflect the photons 'to and fro' through the active medium. A photon moving in a particu... direcⁿ represents a light wave move in that direcⁿ. Thus, ... two mirrors along with the active ...

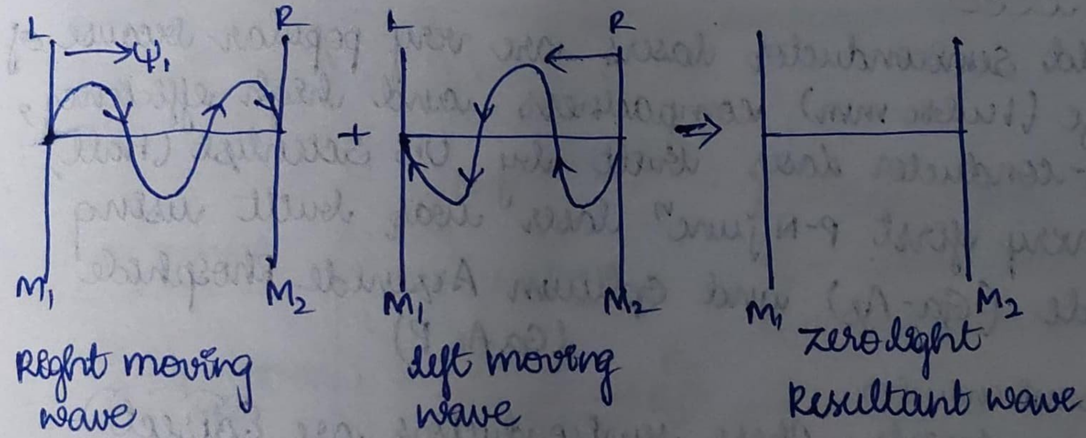
laser cavity as shown in the figure(a).

Inside the cavity of two waves moving one from left to right and another from right to left continuously.

These two waves interfere (superimpose) constructively if there is no phase difference between the two waves. By these interference becomes destructive if the phase difference is ψ



constructive interference



Destructive interference

In order to arrange for constructive interference distance L b/w two mirrors should be such that cavity should support an integral number of half wavelength i.e., $\boxed{L = \frac{\lambda}{2}(m)}$

where $m = 1, 2, 3, \ldots$

In such case a standing wave pattern is established within the cavity and the cavity is said to be resonant at that wavelength and it is called resonant cavity (or) cavity resonator i.e., $\lambda = \frac{2L}{m}$ .... where $m = 1, 2, 3, \ldots$

Q:- If length of the cavity is 1.5m and integral value is 9 calculate the wavelength of laser light from the active medium. If length of cavity is 1.2m. λ of the cavity is 6000Å (CO_2 laser). calculate integral value of the resonator.

→ $\lambda = \frac{2L}{m}$

$\lambda = \frac{2\times1.5}{9}$

$\boxed{\lambda = \frac{1}{3}m}$

$m = \frac{2L}{\lambda}$

$m = \frac{2\times1.2\times10^{7}}{6}$

$\boxed{m = 4\times10^{6}}$

Semi-conductor lasers:-

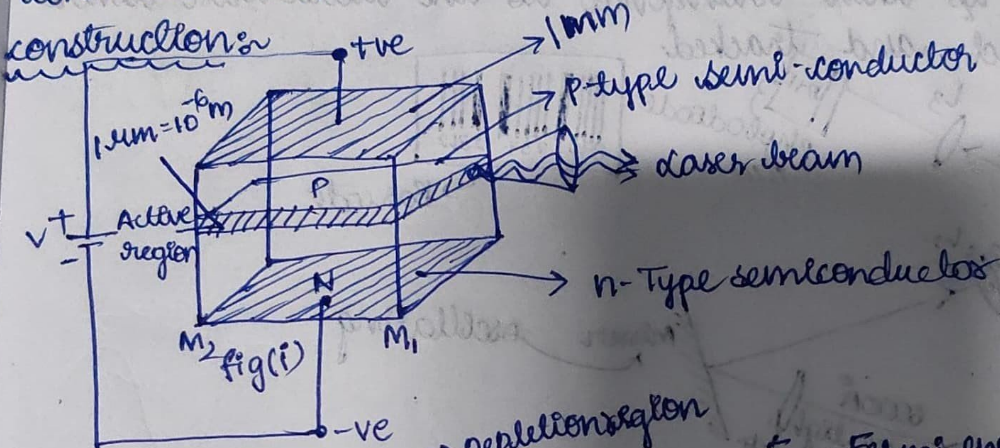
In modern world semiconductor lasers are very popular because of their small size (1 cubic mm) compactness and high efficiency, the first semi-conductor laser built by U.S Scientist (Hall) in 1962. The very first P-N junc^n laser was built using Gallium Arsenide (Ga-As) and Gallium Arsenide Phosphide (Ga As P)
↳ direct band-gap semiconductor
semiconducting materials. These semiconductors are direct bandgap semiconductors

- Semiconductor lasers are continuous wave lasers.
- Semiconductor lasers are widely used in CD players, optical communication, communication networks, laser printers for different medical applications and also for different technological applications.
- n-type section of the semiconductor is derived by doping the substrate (Ga As) with pentavalent impurity Tellurium
- The P-type section is derived by doping the substrate (basic semiconductor) with Zinc (Zn)

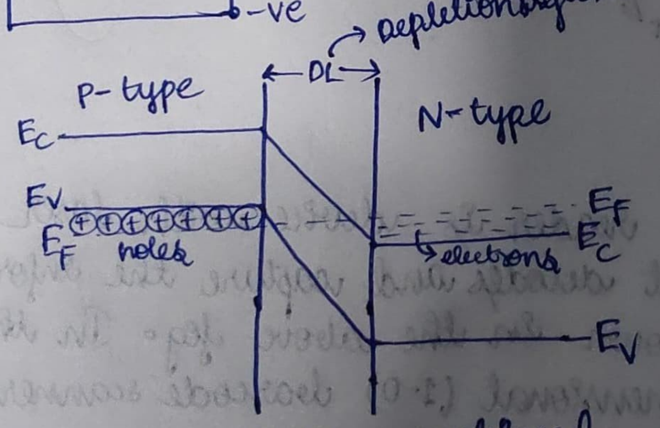
Principle:- We are aware that when electrons and holes are injected across the P-N junction an incoherent light emission occurs at the junc^n due to their spontaneous recombination. This is termed as a light-emitting diode [LED]. But in the case of semi conductor lasers we have to achieve population inversion to get a coherent light from P-N junction. That coherent light is called the laser.

- The laser action take place only within the zone of junc^n the photons generated can come out only through the edge. Hence laser diodes are always called edge emitters.
- Only direct band gap semi-conductors are employed for semi-conductor lasers.

Construction:-

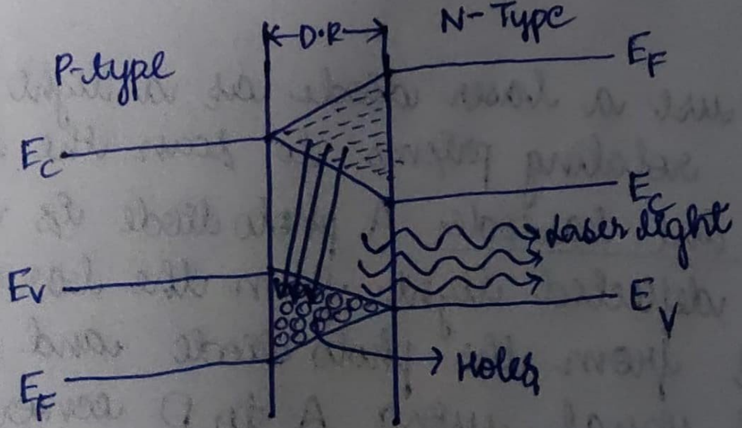


fig(i)



E_F - Fermi energy level
E_V - Valence band
E_c - conduction band

fig② unbiased



fig③ biased

Discuss, construction and working of laser diode with neat diagram principle,

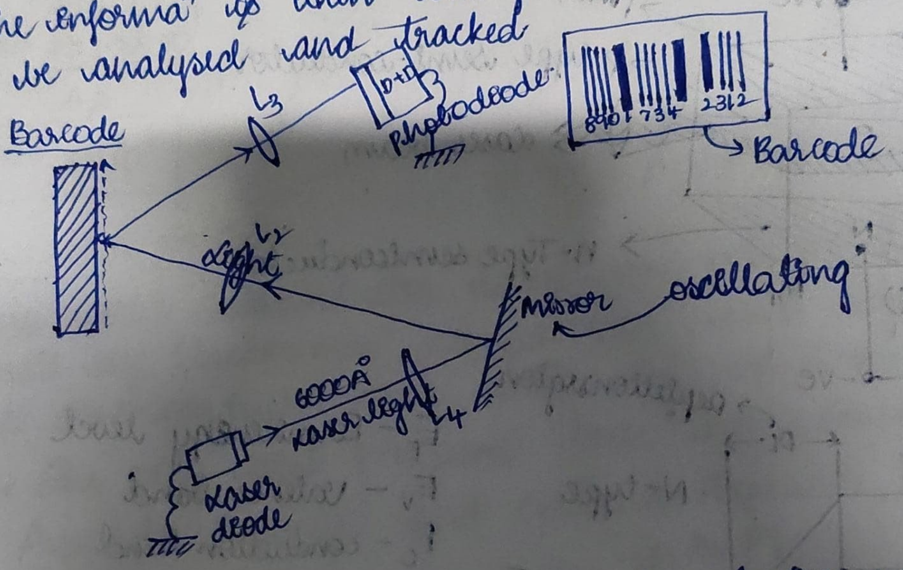
APPLICATIONS of Laser:~

1. **Laser bar code scanner / reader:~** Barcode is a machine readable pattern in the form of lines applied to products, packages or parts. Generally, any goods.

Barcode contain data used for informal information of the goods for the purpose of marketing throughout their life cycle.

Barcodes are read by special reader or scanner with laser light, lenses and sensors that decode the data in the barcodes.

The information is then transferred to the data base where it can be analysed and tracked



A barcode scanner or bar code reader is device with laser light, lenses and a sensor that decodes and capture the information contained in the barcode as shown in the above fig. In the early days we have one dimensional (1-D) barcode scanners presently we have (2-D) code and (2-D) scanners could be read by laser devices.

Laser scanners use a laser diode as a light source and oscillating mirror or rotating prisms to scan the laser beam back & forth across the barcode. A photo diode is a detector it measures the deflected light from the barcode A analog signal is created from the photo diode and it then converted to digital signal using A to D convertor (A → Analog, D → Digital) and then processed.

Benefits:-

1. Laser scanner do not require any image processor.
2. They are also fast and capable of conducting 1300 scan per second.
3. The scanners can read 1-D bar codes from relatively long distance with use of specific optics.

Q★★★ most prominent

Discuss with neat figure and mention the parts and explain briefly laser printers.

Ans:-