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LASER.....

Light amplificaⁿ by stimulated emission of radia

- Coherent Sources - Two sources of light are said to be coherent, if they emit waves of same frequency or wavelength, nearly same amplitude & maintain a constant phase difference b/w them. These are obtained due to stimulated emission of photon. LASER is a good example of coherent sources.

- Incoherent Sources - The light emitted from sun or any other ordinary source of light such as tubelight, bulb, tungston filament, which spreads over a wide range of frequency are called incoherent sources of light.

- Absorption & Emission of radiaⁿs -

We know that atom can excite by applying/supplying energy with an amount equal to difference in two energy levels. Then after the duraⁿ of 10^{-8} s, atom radiates energy & comes down to lower energy state.

An e^- undergoes a transition b/w two energy states E_1 & E_2 if the atom emits or absorbs a photon of appropriate energy as per relaⁿ

$$E_2 - E_1 = h\nu$$

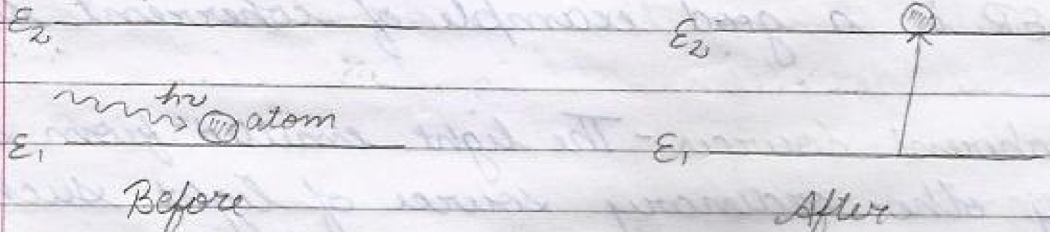
h = planck's constt.

ν = frequency

I Absorption of radia^n - At low temperatures, atoms stay in lower energy states ε_1, raised to the higher energy State ε_2 by abs of a photon of energy $h\nu$ as shown in Fi This is known as absorption of radia^n is represented by

$$\varepsilon_2 = \varepsilon_1 + h\nu$$

$$\varepsilon_2 - \varepsilon_1 = \Delta\varepsilon = h\nu$$

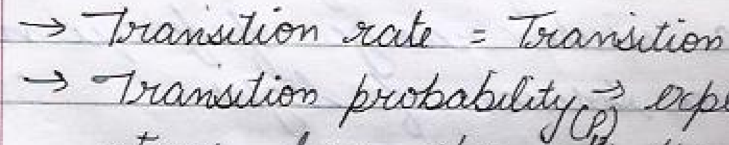


→ Transition rate = Transition probability per unit
→ Transition probability (P) ⇒ explaines that how ma atoms has changed there state

In case of absorption.
Transition probability (P_{12}) depends on,
i) energy density of external source $u(\nu)$
ii) characteristics of energy levels (B_{12})

$$P_{12} = u(\nu) B_{12}$$

where B_{12} = einstein's cofficient for absorption



$\Gamma = \frac{\hbar}{\tau}$ ($\hbar$ - cross) $= \frac{h}{2\pi}$

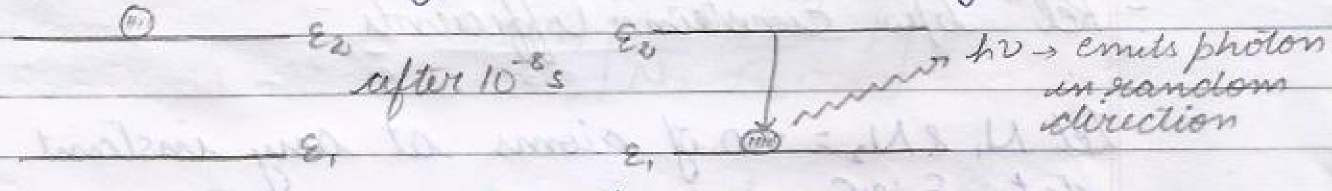
(width) denoted by gamma

τ → (time) denoted by tau

↓

Lifetime of state is 10^{-8} s.

II Spontaneous emission - If an atom is in upper state E_2, it can come down to lower state E_1 by emitting a photon of energy $h\nu$ (after 10^{-8} s). This is known as spontaneous emission. This is the natural radia" decay process that is inherent in all excited states of all materials. However emission is not always a dominent decay process.



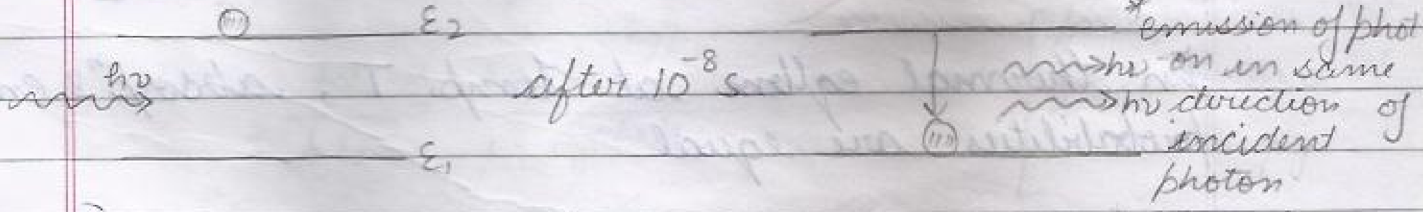
* No external source is reqd.

Transition probability depends only on characteristic of energy level (A_2)

$$P_{21}' = A_{21}$$

where A_{21} = einstein coff. for spontaneous emission

III Stimulated emission - If an atom is in excited state, it comes down when we give a photon. It releases two photons while coming down in G.S.



Photon emitted is of same ν as of incident photon.

Transition probability depends
i. energy of external source
ii. characteristic of energy level.

$$P''_{21} = u(\nu) B_{21}$$

→ Now total transition probability in case of ... is

$$P_{21} = P'_{21} + P''_{21}$$
$$= A_{21} + u(\nu) B_{21}$$

- Rel^n b/w Einstein's Cofficients -

Let N_1 & N_2 = no. of atoms at any instant in e... states E_1 & E_2.

Probability of absorption transition for no. of ato... from state 1 to 2 per unit ~~by~~ time is giv... by:

$$N_1 P_{12} = N_1 u(\nu) B_{12} \quad \text{— (I)}$$

Total probability of transition for no. of ato... from state 2 to 1, either by spontaneously o... by stimulated emission per unit time is given by

$$N_2 P_{21} = N_2 [A_{21} + u(\nu) B_{21}] \quad \text{— (II)}$$

In thermal eqlbm at temp. T, absorp^n & emi... probabilities are equal

$$\therefore N_1 P_{12} = N_2 P_{21}$$

$$N_1 u(\nu) B_{12} = N_2 [A_{21} + u(\nu) B_{21}]$$

$$N_1 u(\nu) B_{12} = N_2 A_{21} + N_2 u(\nu) B_{21}$$

$$N_1 B_{12} (u\nu) - N_2 B_{21} u(\nu) = N_2 A_{21}$$

$$u(\nu)\left[N_1 B_{12} - N_2 B_{21}\right] = N_2 A_{21}$$

$$u(\nu) = \frac{N_2 A_{21}}{N_1 B_{12} - N_2 B_{21}}$$

$$= \frac{N_2 A_{21}}{N_2 B_{21}\left[\frac{N_1}{N_2}\frac{B_{12}}{B_{21}} - 1\right]}$$

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

acc to einstein $B_{12} = B_{21}$

$$\Rightarrow u(\nu) = \frac{A_{21}}{B_{21}} \cdot \frac{1}{\left(\frac{N_1}{N_2} - 1\right)} \quad \text{— (III)}$$

Now, acc to Boltzmann's distribution law, distribution of atoms among energy states ε_1 & ε_2 at thermal eqlb^m at temp. T is given by

$$\left[\begin{array}{l} \text{for } \varepsilon_1 \Rightarrow N_1 = N_0 e^{-\varepsilon_1/kt} \\ \text{for } \varepsilon_2 \Rightarrow N_1 = N_0 e^{-\varepsilon_2/kt} \end{array}\right.$$

$$\frac{N_1}{N_2} = \frac{N_0 e^{-\varepsilon_1/kt}}{N_0 e^{-\varepsilon_2/kt}}$$

$$\frac{N_1}{N_2} = e^{+(\varepsilon_2 - \varepsilon_1)/kt}$$

Here $\varepsilon_2 - \varepsilon_1 = h\nu$

$$\Rightarrow \frac{N_1}{N_2} = e^{+h\nu/kt} \quad \text{— (IV)}$$

Putting eq^n (IV) in eq^n (III)

$$\boxed{u(\nu) = \frac{A_{21}}{B_{21}} \cdot \frac{1}{e^{+h\nu/kt} - 1}} \quad \text{— (V)}$$

Using Planck's radia^n formula

$$u(\nu) = \frac{8\pi h\nu^3}{c^3} \frac{1}{e^{+h\nu/kt} - 1} \quad \text{— (VI)}$$

On comparing (V) & (VI), we get.

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

$$A_{21} = \frac{8\pi h\nu^3}{c^3} B_{21} \quad \text{— (VII)}$$

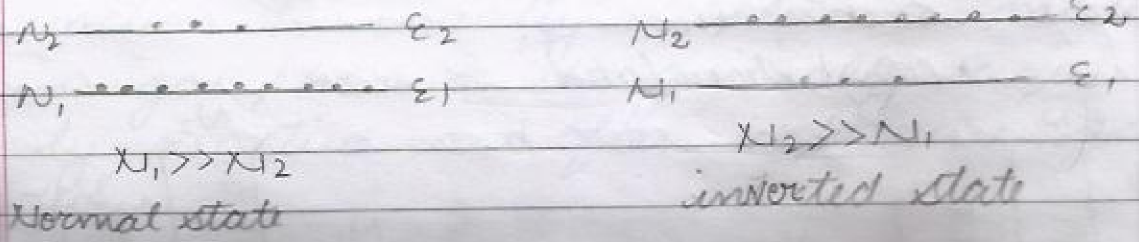
$$\therefore A_{21} > B_{21} \quad \text{— (VIII)}$$

In general from eq^n (VII) or (VIII) we can conc[lude] that spontaneous emission dominates over sti[mu]-lated emission.

Population inversion - The no. of atoms in lower energy state is more thant that in excited state. Acc. to Boltzmann, the ratio of atoms in energy state 2 & 1 at temp. T is given by.

$$\frac{N_2}{N_1} = \frac{e^{-\varepsilon_2/KT}}{e^{-\varepsilon_1/KT}} = e^{-(\varepsilon_2-\varepsilon_1)/KT}$$

For popula^n inversion $N_2 >> N_1$ i.e.

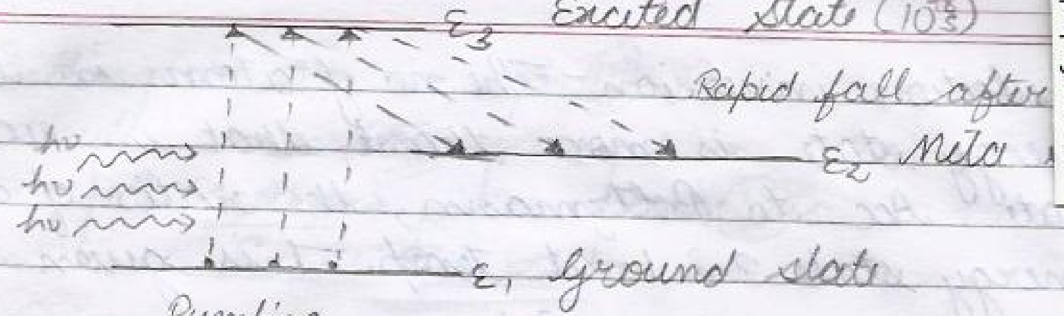


The process of making popula^n of atoms in higher energy state more thant that in lower energy state is known as popula^n inversion

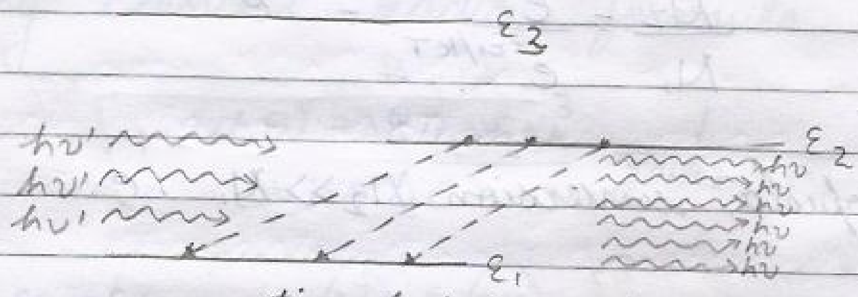
The method by which popula^n inversion is acheived is called pumping In this process, atoms are raised to ES by injecting into system photon of frequency different from stimulating frequency.

Popula^n inversion can be understood by 3 energy level atomic system

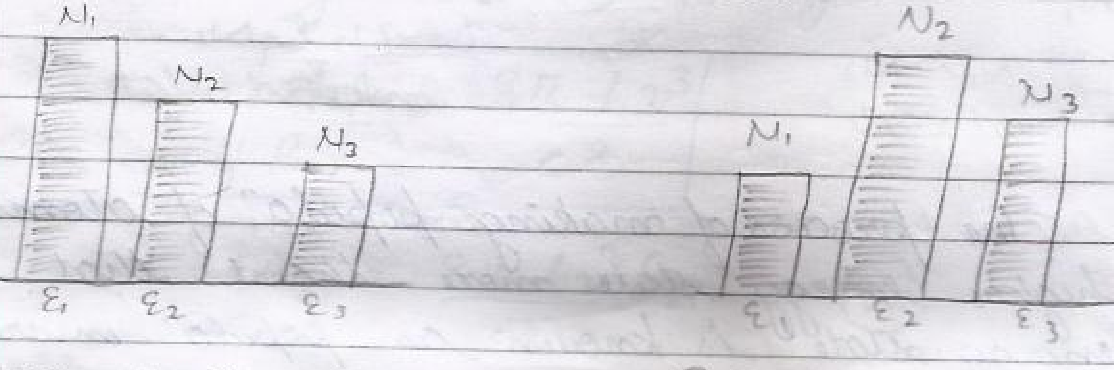
PTO



Pumping



stimulated emission



THERMAL EQULIBRIUM POPULATION INVERSI

- Pumping - A system in which popula^n^ inversion is acheived is called an active med^m^. The method of raising a particle from lower s to higher state is called pumping

i) Electrical pumping - Atoms can be excited by e impact in sufficiently intense gaseous disc -ge known as electrical pumping. The electr pumping is suited to gas & semicondu lasers.

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$10^{3}s$).

ii) Optical pumping- In this case atoms are excited by powerful lamp or laser source whose light populates excited states by photon absorption. This method is particularly suitable to solid state or liquid lasers.

iii) Chemical pumping- Here populaⁿ inversion is acheived from exothermic chemical reaction. It usually applies to materials in gas phase & it generally requires highly reactive and often explosive gas mixtures.

- Three components of laser device-

i) The pump-

a) It is an external source which supplies energy to obtain populaⁿ inversion. The pump can be optical, electrical or thermal. In Ruby Laser, we use optical pumping and in He-Ne Laser we use electric discharge pumping.

b) The energy supplied by pump excites the atoms to higher energy levels and through spontaneous emission ~~of through~~ & non radiative processes the populaⁿ inversion occurs.

c

c) The life time of metastable energy, which popula" inversion occurs is very large as compared to normal life time of excited atom in any other energy state.

ii) The Laser Med^m/Active Med^m- It is material in which laser action is made to take place. It may be solid, liquid or gas. The very imp. characteristic requirement for medium is that inversion should possible in it. Many lasers are named after the material used.

eg output of Ruby laser - 694.3nm
" " He-Ne " = 632.8nm

iii) The rasonator - It consists of pair of plane or spherical mirrors having common principle axis. The reflection coff. of one of the mirrors is very near to 1 and that of other is kept less than 1. The rasonator is basically a feed back device that directs the photons back and forth through the laser med^m and in the process, the no. of photons is multiplied due to stimulated emission.

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- Principle of Laser -

- An atomic system having one or two meta-stable state is chosen.
Normally no. of atoms in lower energy state is greater than in meta stable state

- Populaⁿ is inverted by technique known as pumping

- The atoms are made to fall from meta-stable state to lower energy state & photons are emitted by stimulated emission

Thus a large no. of photons are emitted simultaneously which possesses same energy, phase & direction. This process is called amplificaⁿ of light

To produce a laser beam, conditions to be fullfilled are-
1. Metastable state should ~~have~~ all the time have larger no. of atom than lower energy state
11. The photons emitted due to stimulated emission should stimulate other atoms to multiply in active medᵐ.

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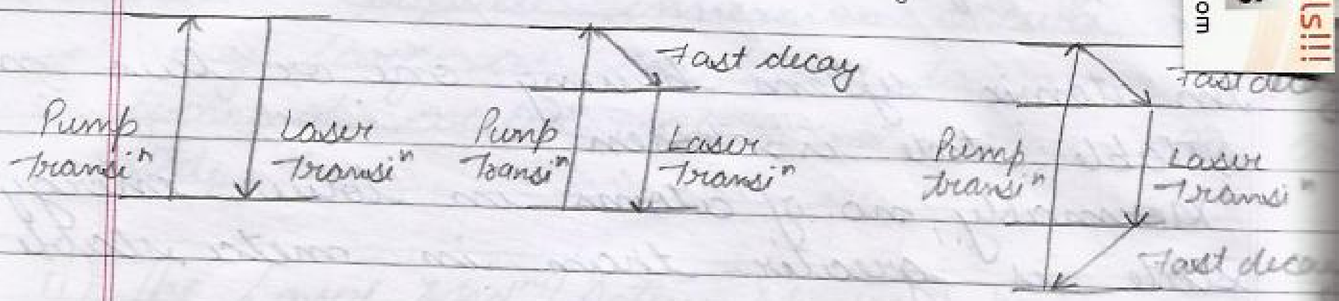
Two Three and Four level systems-

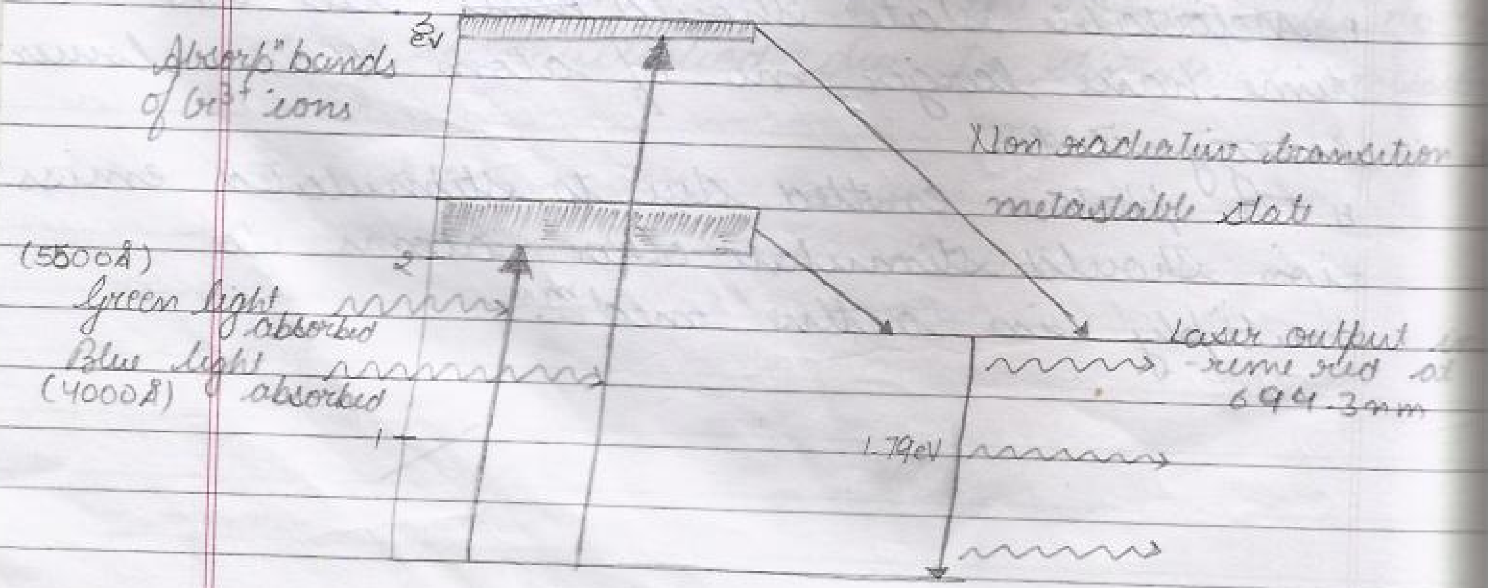


Ruby Laser-

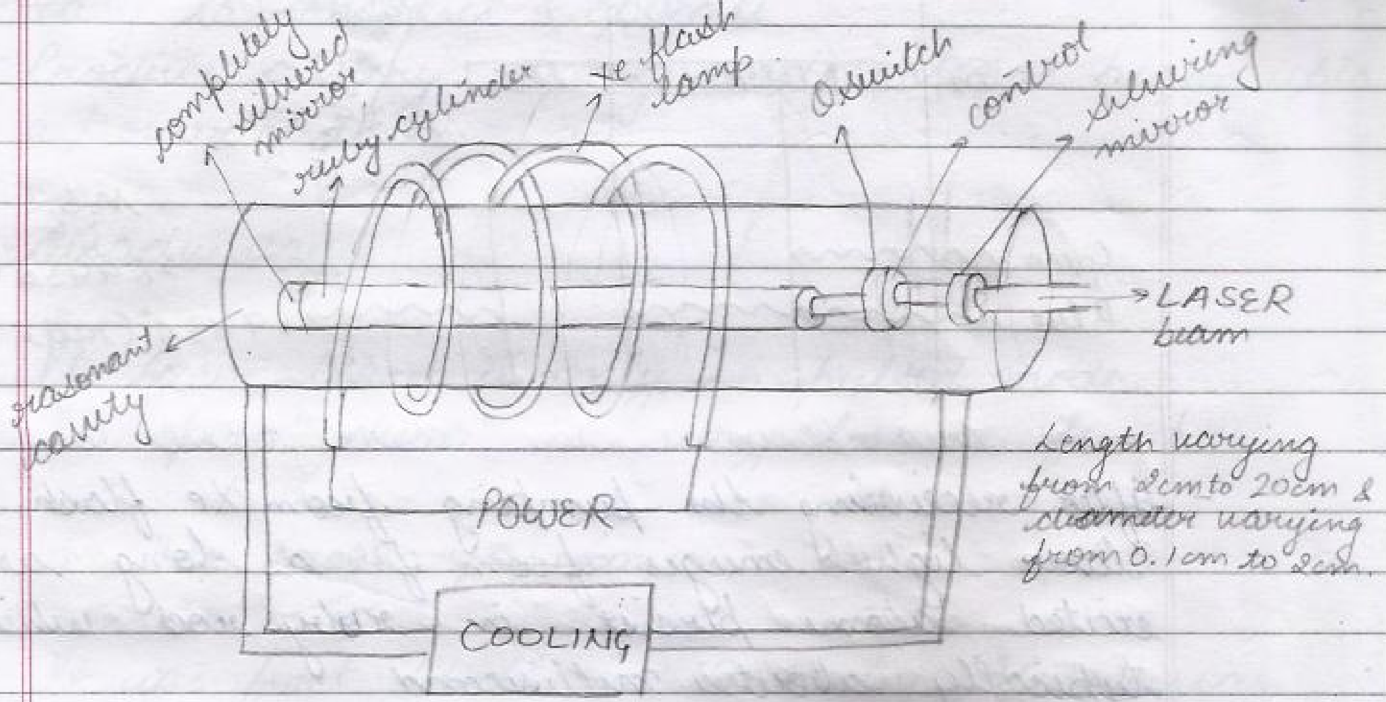
- The 1st laser was ~~chr~~ created in 1961 by T. M
- It is a solid state laser.

Working material

- A rod of ruby is used as active medm
- Ruby is basically Aluminium oxide (Al_2O_3) cry in which small part of Al is replaced with Cr^{3+}
- Cr atom play the active role for laser action a Al_2O_3 atoms remains ~~a~~ inert.
- Cr ions have absorpn bands in blue & green reg
- Ruby rod is taken in the form of cylindrical rod of about 4cm in length & 1cm in diameter
- The end faces of ruby rod are silvered so tha they form the optical rasonator.
- Source of light is Xenon flash lamp.



Working principle of Ruby laser. → It is based on optical pumping



* In this laser, Cr^{3+} ions are active centres which are responsible for laser transition

- The ruby rod is illuminated by intense impul-se of light, which is generated by helical xenon flash lamp.

- The ends of ruby rod are highly silvered to serve as laser mirrors

- When light from Xe flash lamp of $\lambda = 5500\,Å$ (green & blue colour) & $4500\,Å$ is made to fall on ruby rod, then Cr atoms absorb it & goes into excited state E_{21} & E_{22}

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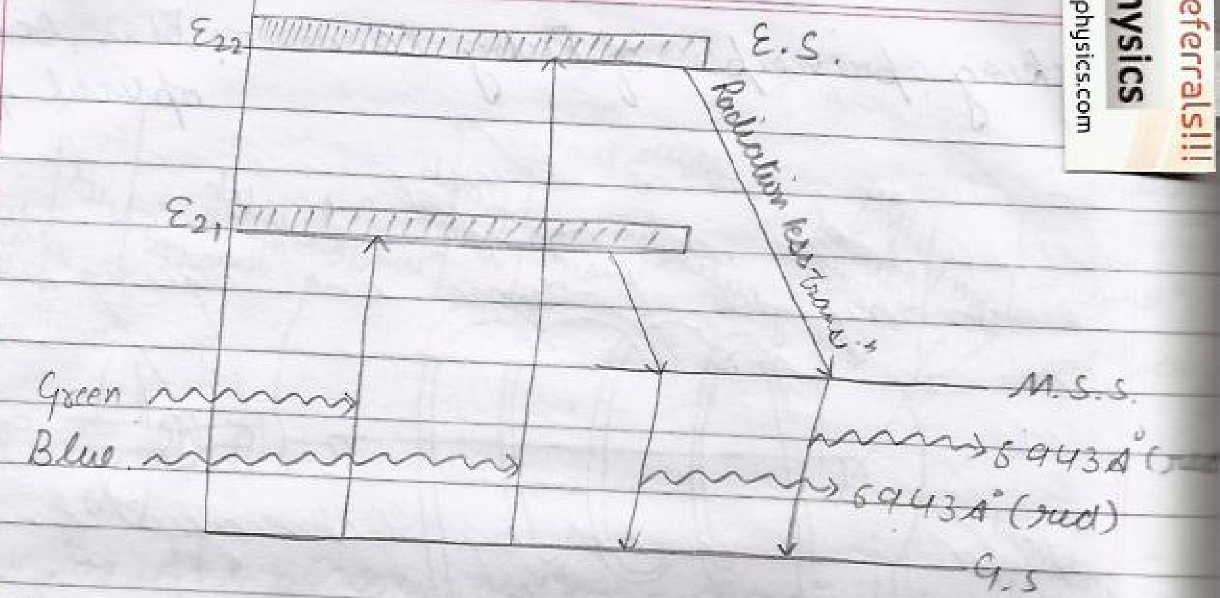


- After receiving the pumping from Xe flash tube laser light emerges ~~from~~ for as long as excited atoms persist in ruby rod which typically about a millisecond

- In order for stimulated emission to exceeds stimu-lated absorpⁿ, more than half of Cr^{3+} ions of ruby rod must be in metastable state.

- The ruby laser works in pulsed mode

- Its output is red light having $\lambda = 694.3\,nm$

Salient features-

- It is a solid state laser.
- Cr^{3+} ions are responsible for laser transition
- It is three level laser.
- Its output is $6943\,Å = 694.3\,nm$
- Its output lies in visible spectrum (red)
- Its output is not continuous but pulsed.

Advantages -

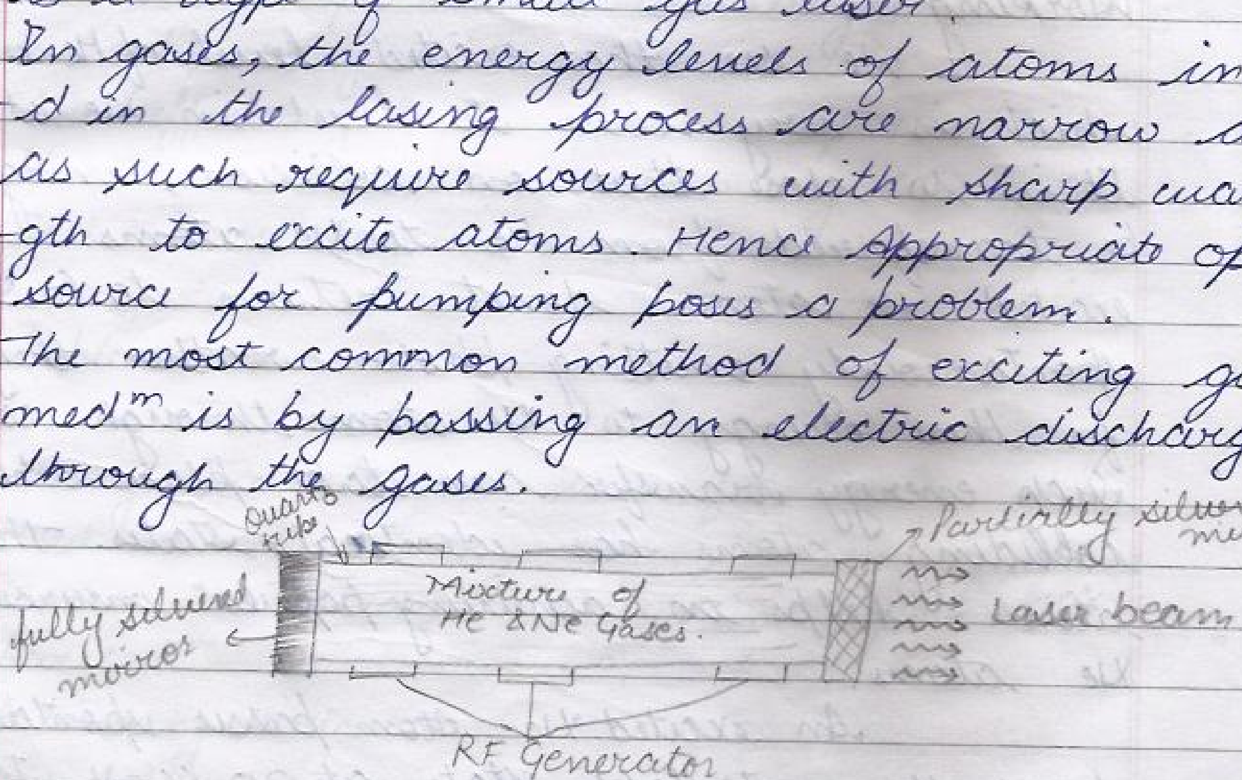
- Easy to construct & operate
- Produce a very strong and intense beam upto a power of 10kW.

Disadvantages

- Its laser beam is only in pulsed mode.
- Its opera^n. dura^n is very less i.e. few hrs.

- He-Ne Laser - Gas Laser

- It was first built in 1961 by Ali Javan.
- A He-Ne laser usually called He-Ne laser, is a type of small gas laser.
- In gases, the energy levels of atoms involved in the lasing process are narrow and as such require sources with sharp wavelength to excite atoms. Hence Appropriate optical source for pumping poses a problem.
- The most common method of exciting gas med^m is by passing an electric discharge through the gases.



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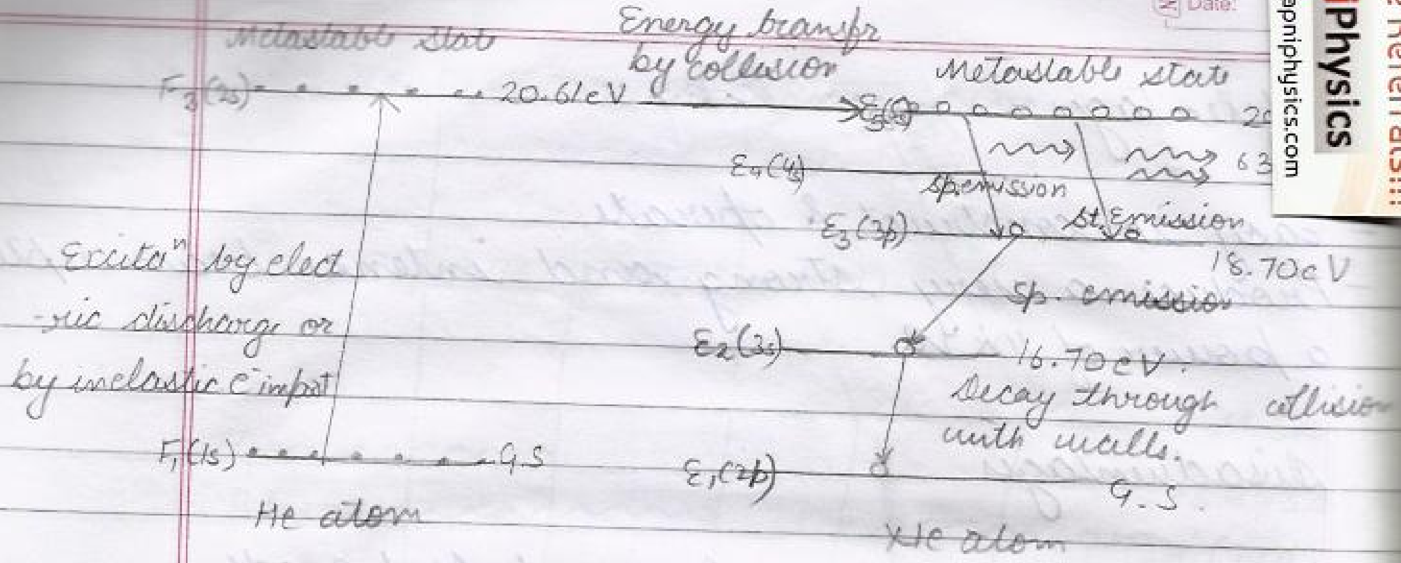

In this laser system, quartz tube is fille[d] with He & Ne gases in 10:1 ratio at pressure o[f] 0.1mm of Hg. This mixture act as active m[edium]. He is pumped to excited state of 20.61 eV by electric discharge.

Working-

We see that excited level of He is 20[.61 eV] which is very close to level in Ne at 20.[66 eV]. It is so close that on collision, energy c[an] be transferred from He to Ne atoms. Th[e] excited He atoms donot return to G.S. by spontaneously emitting photon rather they tra[ns]-fer there energy to Ne atoms through collisio[n]. Such energy transfer can take place when th[e] colliding atoms has identical states. Thus He atoms helps in acheiving popula^n inversion [in] Ne atoms.

An excited Ne atom passes spontaneousl[y] from the metastable state at 20.66 eV to exci[ted] state at 18.70 eV by emitting photon of 6328 Å. This photon travels through the gas mixtu[re]

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||el to the axis of tube and stimulates the surrounding Xe atoms present in metastable state. This way we get other photons that are in phase with stimulating photons. These photons are reflected forth and back by silvered ends and no. of photons get amplified through stimulated emission every time. Finally a portion of these intensified photons passes through partially silvered end.

Salient features-

- Uses four level pumping scheme.
- The active centres are Ne atoms.
- Electrical discharge is pumping agent.
- Its usual operational wavelength is 632.8 nm in red portion of visible spectrum
- Low efficiency & low power output
- Operates in continuous working CW mode.
- It is most common inexpensive laser.

Applications -

- Many industrial & scientific uses
- Used in laboratory demonstrations of optics
- Narrow red beam is used in supermarkets to read bar code
- Measuring distances
- Guided smart weapons.
- In Holography in producing 3D images of objects

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- Diode Laser: Semiconductor laser.
- A semiconductor laser is specially f pn-junc^n device which emits coherent ligh when it is forward bias.

- In conventional solid state or gas laser, d atomic energy levels are involved where a semiconductor lasers, the transitions are ass -ed with energy bands

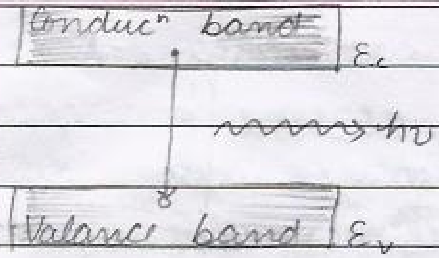
- In semiconductor laser, popula^n inversion m that there must be a region of device in which large density of free e^-s in bottom e level of conduc^n band and large density of holes in top energy level of valance band -s is obtained with high doping concentra^n

Principle - The energy band structure of a semic -ductor consists of a valance band & a conduc band separated by energy gap E_g. The conduc band consists of e^-s & valance band contain holes & e^-s. When e^- from conduc^n band jump into a hole in valance band, the excess en E_g is given out in the form of photon.

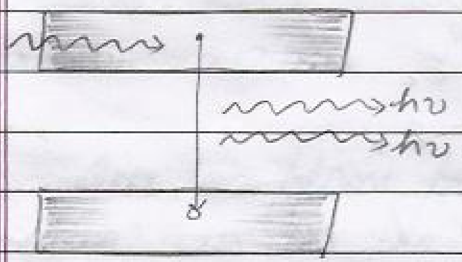
Thus e^--hole recombina^n is basic mechan responsible for ~~emition~~ emission of light

The wavelength of light is given by rel^n

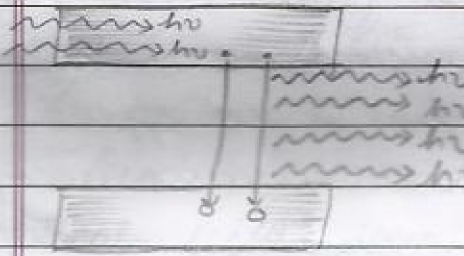
$$\lambda = \frac{hc}{E_g}$$



e^- hole recombina^n or spontaneous emission [LED forma^n]



e^- hole recombina^n or stimulated emission [LASER forma^n]

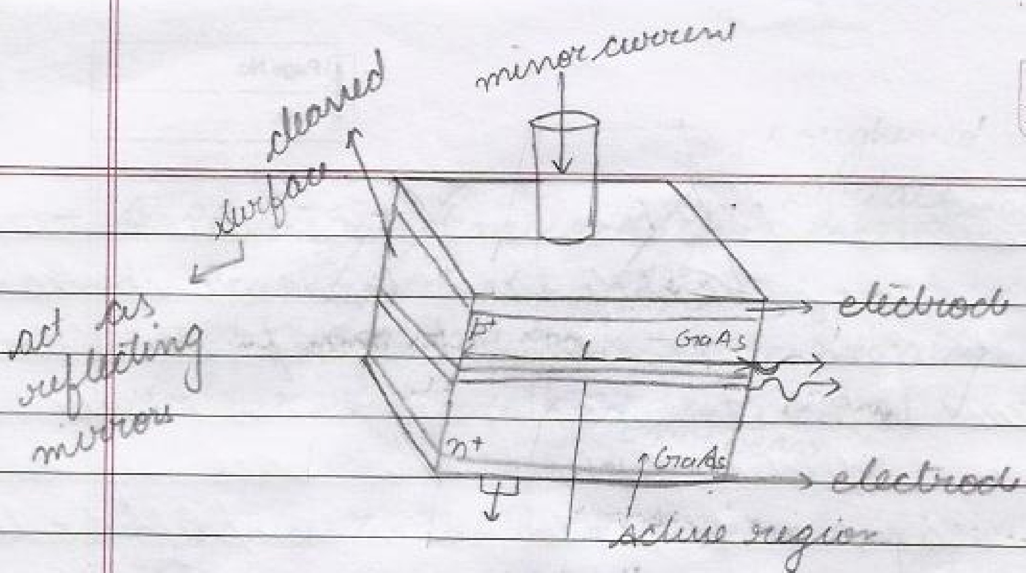


Light Amplifica^n due to polished surfaces (Resonators) (LASER)

Working -

In forward biased p-n junc^n of LED, the higher energy level (conduc^n band) is more populated than the lower energy level (valance band), which is primary requirement for population inversion.

When a photon of energy $h\nu = E_g$ impinges the device, while it is still in excited state due to applied bias, the system immidiately stimulated to make its transition to valance band & gives an additional photon of energy $h\nu$ which is in phase with incident photon.



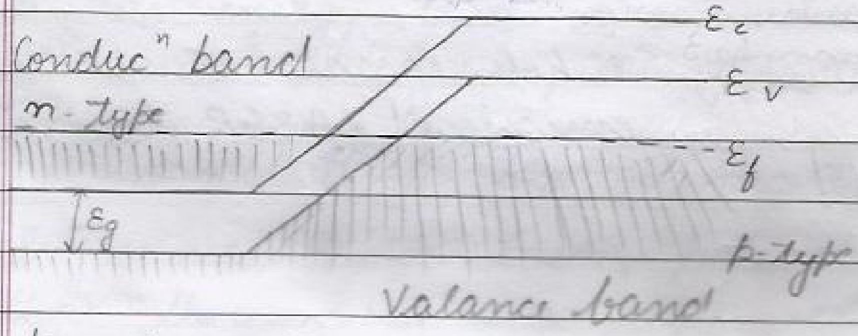


fig.- Band structure near a semiconductor
pn junc^n when forward bias is not applied

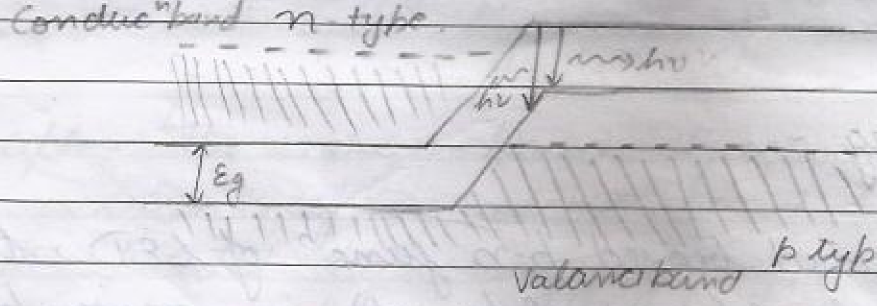
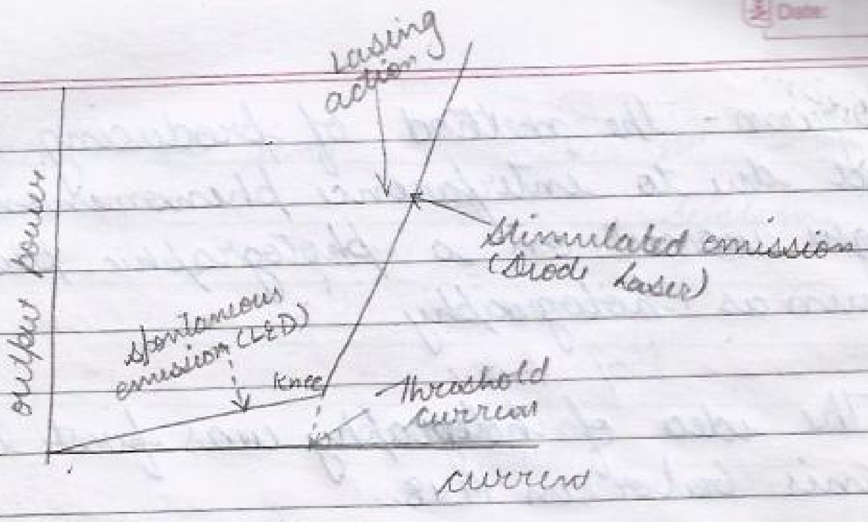


fig.- Band structure when forward bias is present

When a forward bias ~~current~~ is applied, a
current flows. Initially at low current there
spontaneous emission in all directions. Furth
as bias is increased, a threshold current is
-ed at which stimulated emission occurs.

output power from a diode laser as a func^n of input current →



Due to plane polished surfaces, the stimulated radia^n in the plane ⊥ to deple^n layer builts up to multiple reflections in the cavity formed by these surfaces and a highly directional coherent radia^n is ~~seen~~ emitted

Diode lasers are low power lasers used as optical light source in optical communica^n.

Advantages-

Very high efficiency (40%)
High reliability
Very long life time
Very cheap price
Small vol^m & small weight
Highly compact
Operates at low power.
Small size
Portable

Hologram - The method of producing 3-D object due to interfarence phenomenon of light waves on a photographic plate is known as holography.

The idea of holography was first developed by Dennis Gabor in 1948.

When an object is photographed by camera, a 2D image of 3D object is made. Here only amplitude of light wave is recorded on photographic film. In holography both phase & amplitude of light waves are recorded in film. The resulting photograph is called hologram. The image is produced by process reconstruction

Photography	Holography
I 2D image of 3D object	I 3D image of 3D object
II The quality of depth is missing	II It provides depth perception also
III. Each region contains seperate & individual part of original object	III. Each part contains information about entire object
IV. In it, radiated energy is recorded & phase relationship of wave arriving from different direction & distances is lost	IV. In it phase relationship is recorded by using technique of interfarence of light waves.
V. Ordinary light can be used	VI. Laser beam should be used

VI. It is based on lens systems	VI. It is a lensless systems