MASER - Discovered before laser
↓ Microwave

→ Bond e⁻s play major role in laser

Bond e⁻? → Outer shell ko chorke, inner shells mein jitne e⁻s hai woho

LASER

→ Signal increase krna

- Stands for Light Amplification By Stimulated Emmision of Radiation.
- Introduced by Dr. Theadore H. Maiman (on 16 may 1960, at Hyges research lab in california.
  → This is principle of laser action

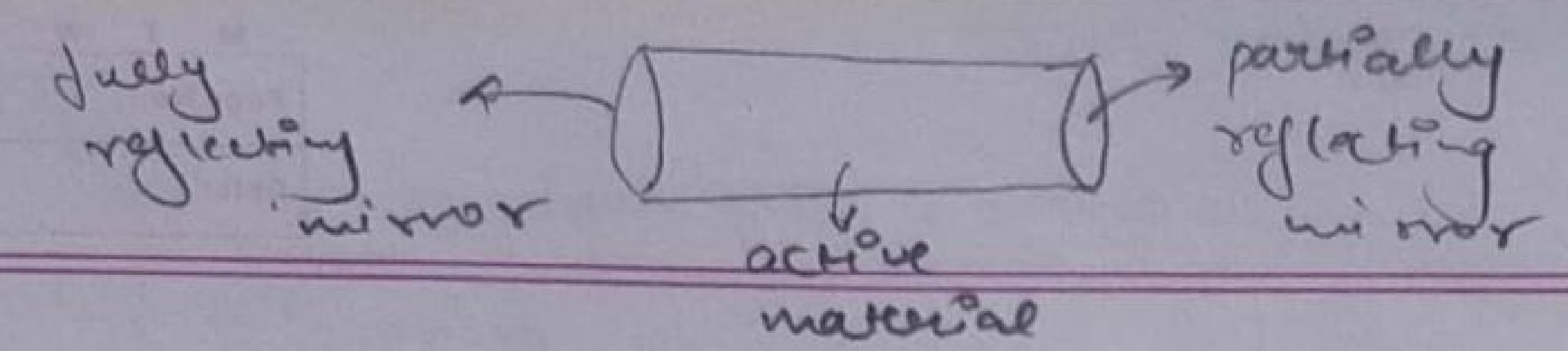
* Properties :-
1. High intensity → harmful for eyes
2. High degree of coherence
3. ~~tr~~ high directionality → Dur tak ja skta
4. low beam divergence → Dur tk bhi light spread nhi hoti.
5. High monochromaticity
- Principle of laser action is stimulated Emission.

* Main components of laser
1. Active material :-
- Materials which is responsible for laser action, eg Ruby
- Active material woh hote jinme generally metastable State present hoti hai.
  helps to acheive population inversion

→ jisme resonance ho

2. Optical resonator :-
  → Jab high intensity ki light hogi tabhi bahar ayegi warna tab tak andar hi resonate hogi.
- Cylindrical tube jisme resonance hota hai active material dwara.
- It consists of 2 mirror in both ends
  1st mirror hamesha 100% fully reflecting mirror hota hai aur 2nd mirror partially reflecting hota hai.
  → taaki light bahar aa ske
  → 10% transperency & 90% reflection hogi.
- Yeh spherical or plane mirror ho skte hai : Quartz & Ruby ke bane hue.

3. Pumping System :- pumping source
  → also called
  → eg: ruby ke bond e⁻ ko yeh source denge Ruby laser mein hota hai.
- To active material ke e⁻ ko energy provide krega woh pumping source ↑
- alag alag type ke pumping source hai → eg. optical pumping source (isme xenon flash lamp & krypton flash lamp use hota), chemical pump source (HCl laser), semiconductor diode laser (isme laser ko hi laser ke pumping source jaisa use krte), Electric discharge method (He-Ne laser)



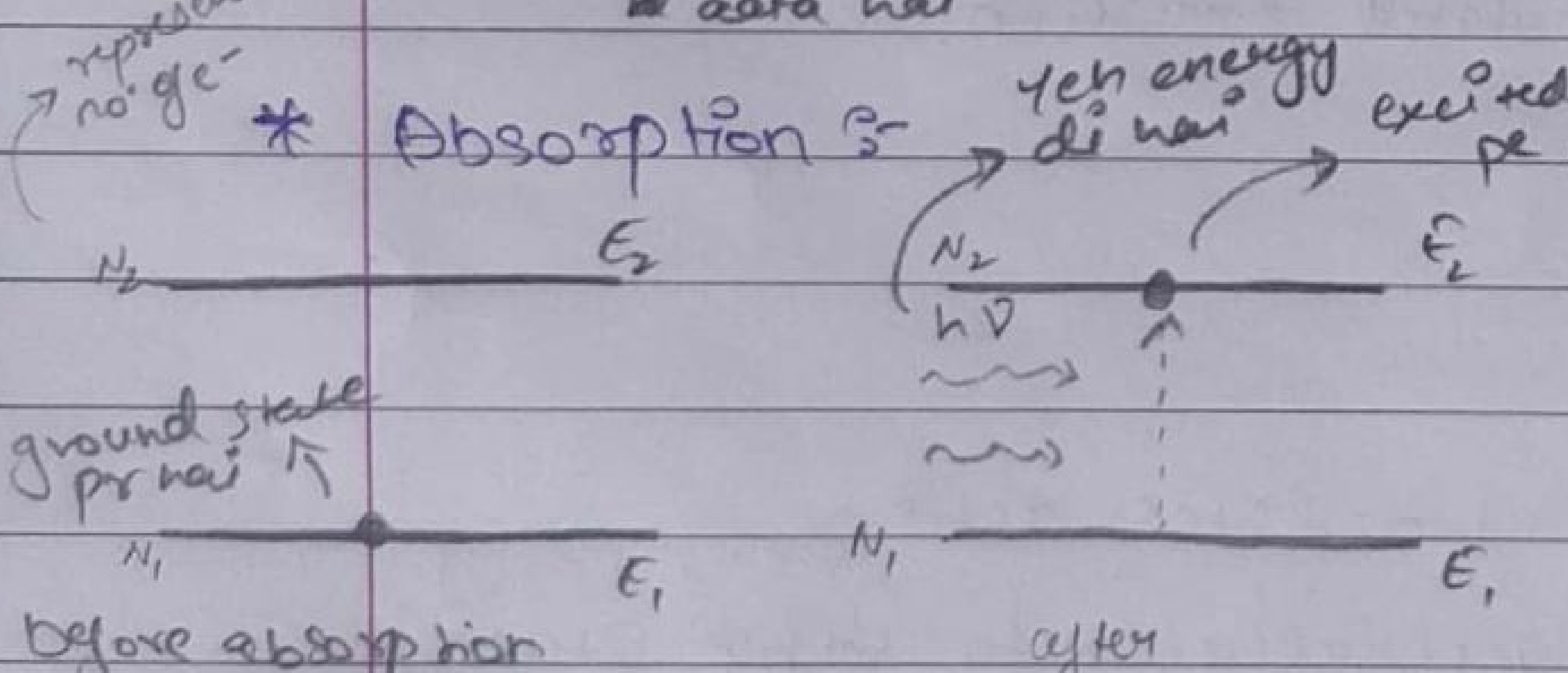
4. Cooling System :- → Xenon flash lamp also.

- Halogen aur krypton Arc (Kr-Arc) ~~laser~~ lamp kaafi high temp. rkte hai yeh as a pumping source use hote hai laser mein toh inko cool rkhne ke liye cooling system ~~so~~ zaruri hai. → inlet outlet bane hote hai iske liye.
- Generally use liq. nitrogen (N_2) as cooling system.

* Important processes for laser action :-

1. Absorption → energy absorb krke e^- E_1 se E_2 aata hai
2. Population inversion → e^- ki sankhya ka badhna.
3. Spontaneous ~~stimulation~~ emission → energy emit krke e^- E_2 se E_1 ko aata hai
4. Stimulation emission
5. pumping

* Absorption :-



- movement of e^- from ground state (lower) to excited state (upper) when we give it some external energy. It is called absorption (∵ energy absorb krke upar aata hai)

- Rate eq^n of laser :-

$$\left(\frac{dN_1}{dt}\right)_{abs.} = N_1 B_{12} u(\omega)$$

N_1 → N_1 population

B_{12} → 1 se 2 ke taraf shift hogi → [mtlb transition 1 se 2 ke taraf hua]

B_{12} → einstein's coeff. for abs.

$u(\omega)$ → external charge dene ki wajah se

$\left(\frac{dN_1}{dt}\right)_{abs.}$ → time rate bta rha hai ki N_1 population ke saath kya hora.

- absorption is an "induced process". → mtlb karaya jata energy deke, apne aap (spontaneous) nhi hota yeh.

* Population Inversion :-

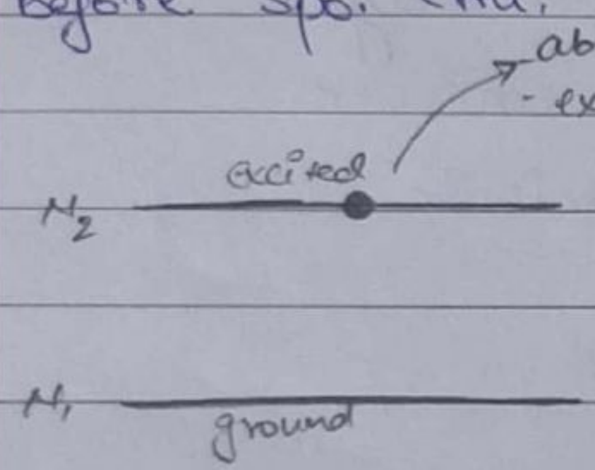
- e^- ki sankhya higher state (i.e. E_2) mein badhna.
- After absorption when population of excited state is higher than ground state this process called <u>population inversion</u>.
- after absorption ⟶ $N_2 > N_1$
- yeh 10^{-8} sec tak hi upar rehta hai.

Imp → - It always follow Boltzman law.

→ e⁻ spontaneously energy emitt krke niche aa jayega

* Spontaneous Emission :-

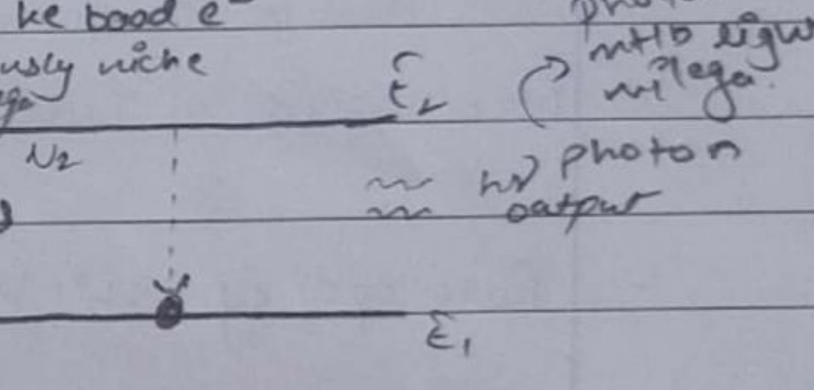
Before Spo. Emi.



- Let kro ~~an~~ absorption ho chuka hai. mtlb ki spo. emi. se pehle apna e⁻ excited state pr hai.

- Jab e⁻ niche aata hai tab yeh ek hν photon output mein deta hai.
- Jo energy emitt krke woh niche woh hν energy hi hogi aur light ka photon banna compulsory hi hai. Jo sirf material ke through possible.

After Spo. Emi.



- Idhar koi bhi external energy provide nhi kr rhe. yeh e⁻ apne aap hi (spontaneously) niche aa jayega after (10^{-8} sec.) → also called avg. life time.

- Mathematical representation.

Jab spontaneous ho toh const. (A) lena hai → transition 2 se 1 ki taraf hora hai → Idhar iss bar energy :: [u(ω)] nhi use kiya

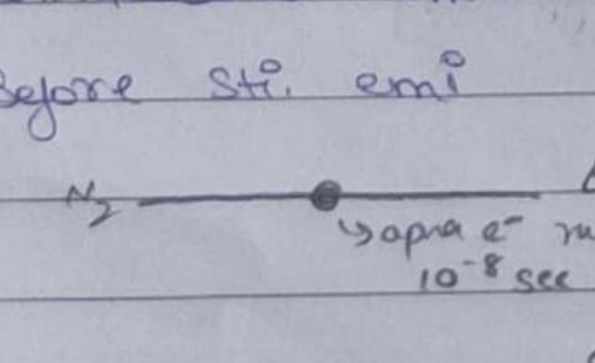
$$\left(\frac{dN_2}{dt}\right)_{spo.} = N_2 A_{21}$$

↳ Time rate emi bta rha hai ki N_2 ke sagth kya hora hai

↳ N_2 ki population

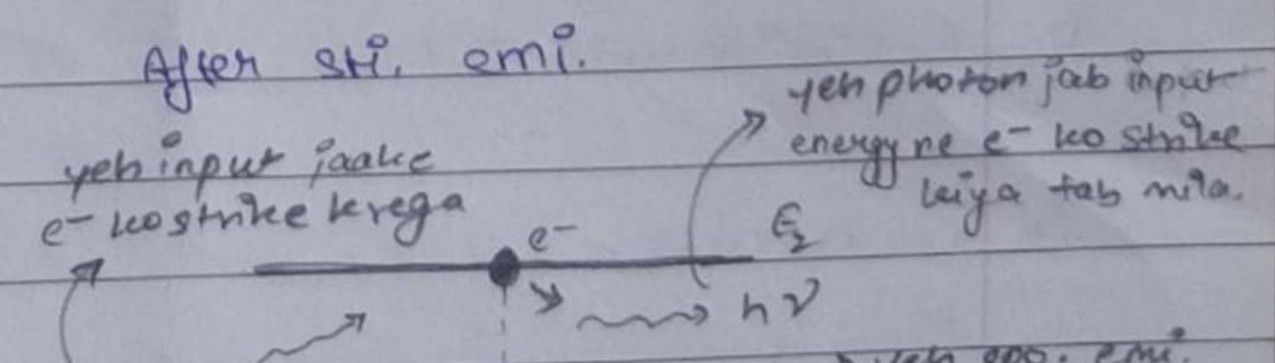
* Stimulated emission :-

Before Sti. emi



- Yaha pe let kerte hai ki apna e⁻ excited state pe hai aur 10^{-8} sec tk hai.

After Sti. emi.



- spo. emi. ki wajah se ek hν photon pehle mila tha
- Isme hum ek external energy denge ie. hν input denge woh e⁻ ko strike krega jiske wajah se

ek aur same property (i.e same wavelength, amplitude, frequency and const. phase hoga) will be coherence houge.
- 2 photons hamesha same direc^n mein emitt houge.
- This above process is called Stimulated emission.
- Also called ~~a~~ induce emission or forced emission.

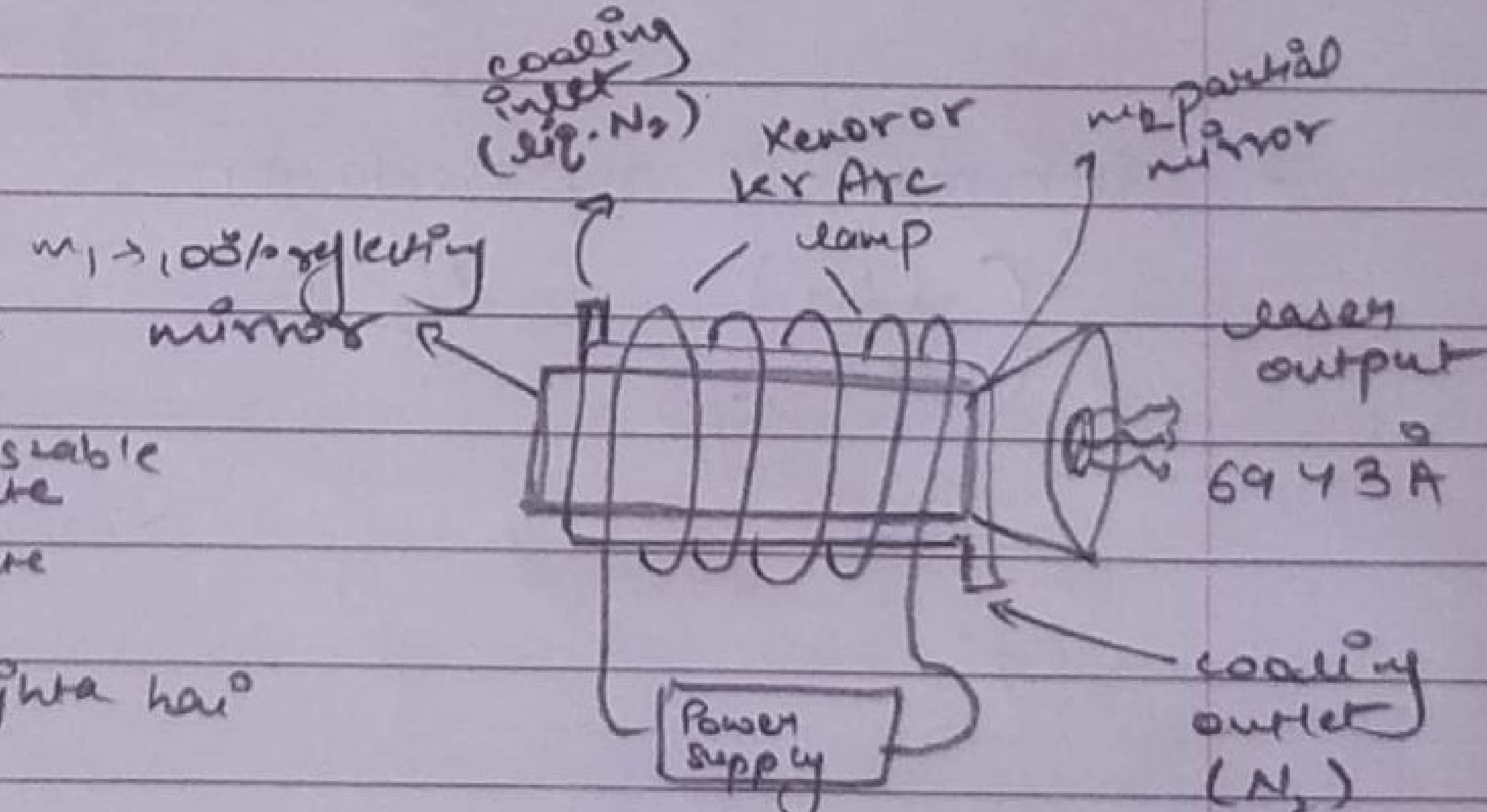
- Rate eq^n of Sti. emi. :-

$$\left(\frac{dN_2}{dt}\right) = N_2 B_{21} (u(\omega))$$

(B → input diya; B use kiya)
(u(ω) → energy bhi di hai, yeh use kiya)
(21 → Transition 2 se 1 ki taraf hora.)

* Pumping :-
- Helps in acheiving population inversion.
- Pumping source ke duara ki gyi process ~~ko pun~~ called pumping process.
- External energy ko provide kr krne ki process called pumping ....

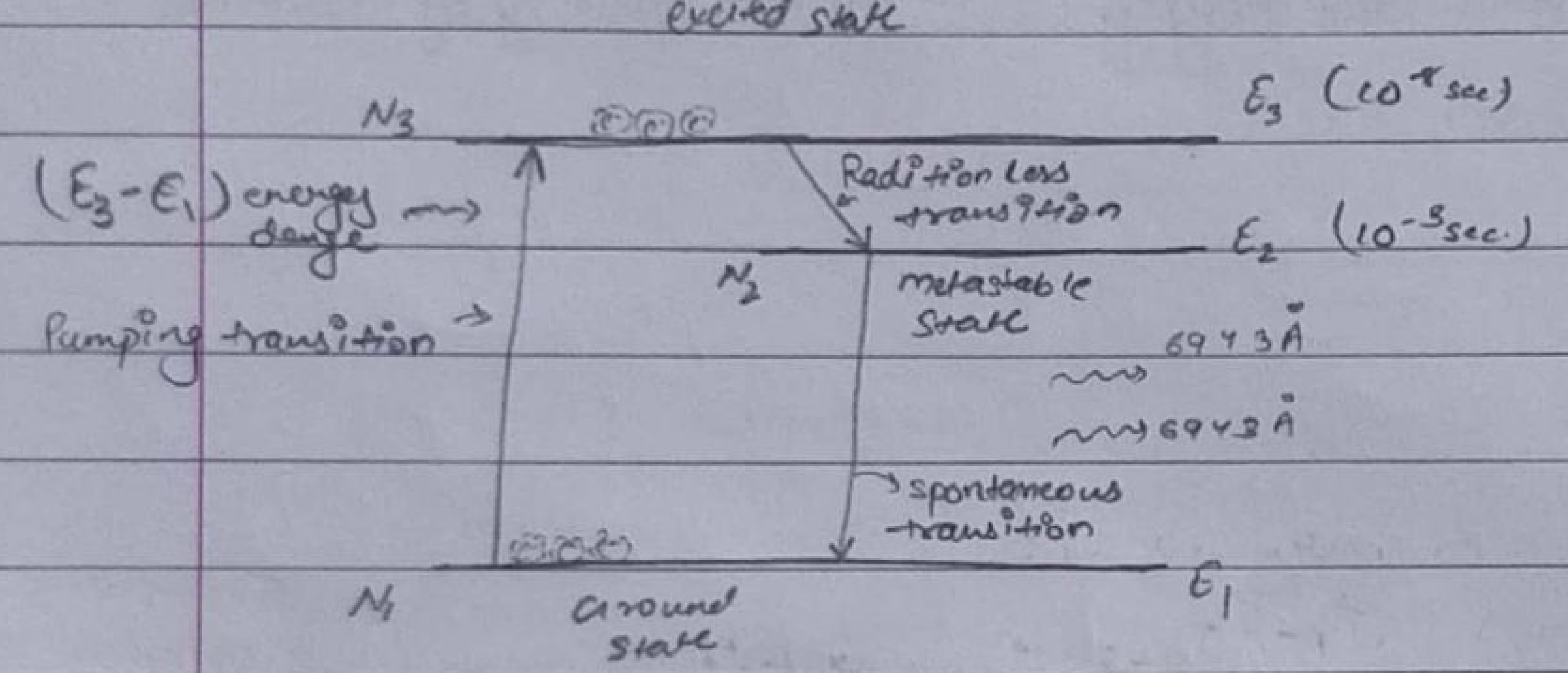
* Ruby Laser

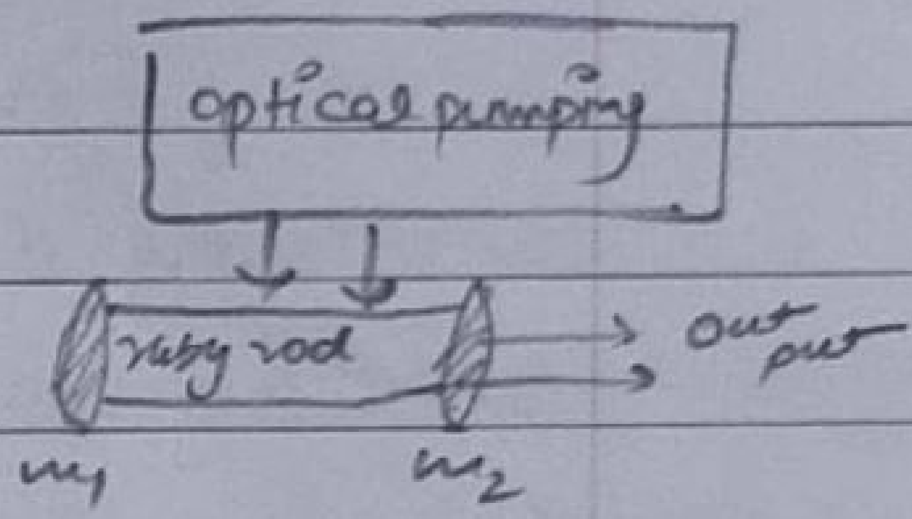


- Properties of Ruby laser :-
1. Solid state laser
2. 3 level laser (→ 3 energy level hote hai) → excited state / metastable state / ground state
3. Output wavelength = 6943 Å
4. Pulsed laser output → Jalta bujhta hai
5. External cooling req. (N2 or water cooling used)
6. Active material → Al_2O_3
7. ~~Eff~~ low efficiency.
8. Cost (high cost)

* Construction
1. Ruby parameters :→ length upto 30 cm & diameter upto 2.5 cm
2. Optical cavity :- Resonating made of 2 mirrors
   m_1 → 100% reflecting ; m_2 → partially reflecting
3. energy Pump source :- optical pumping, flash ~~ton~~ lamp, Xenon
4. Active material :- Al_2O_3 (Ruby crystal) with 0.5% of Cr_2O_3
5. Cooling system :- liquid N_2 cooling.

* Working of Ruby laser





absorption
- In normal state, e^- are at ground state ∴ population inversion of $N_1 > N_3$
now we provide energy ($E_3 - E_1$) (→ iske barabar energy denge.) (↳ kam denge to upar nhi jayega.) using Xenon lamp taaki e^- excited state pr jaa paye. Optical pumping source se energy denge.

population inversion
- extited state mein jaane ke baad $N_3 > N_1$ ho jayega. yeh process zaruri hai tabhi pr e^- niche ayega aur photon milega humko.

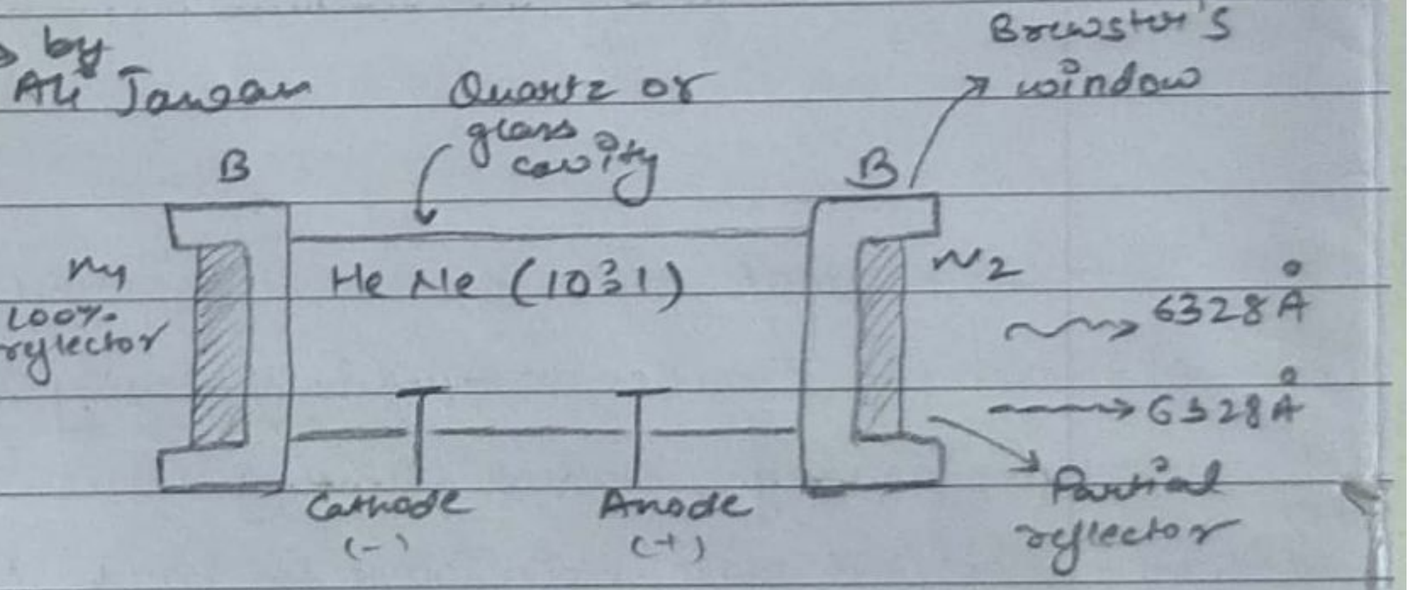
spontaneous emission
- E_3 level pr yeh 10^{-8} sec rukte hai fir uske baad woh E_2 level pr niche ata hai pr photon release nhi hota bss heat ke form mein energy nikalti (↳ kyuki utna energy gap nhi hai) ∴ it is called radiationless transition.
- Jab e^- E_3 se E_2 pr ayega toh woh E_2 pr bhi thodi der rukega i.e 10^{-3} sec. woh metastable state hai fir e^- E_2 se E_1 spontaneously ayega jiski wajah se photon emitt hoga.
  idhar 2 baar spontaneous emi. hora → E_3 se E_2 (no photon emitt) ; (E_2 se E_1) (Photon isme se niklega)

stimulated emi.
- Spontaneous emission ki wajah se 1 photon mil rha hai but energy hum continous dete hai isliye idhar stimulated emission hota jiski wajah se e^- jaake dusre ko strike krta hai jisse ek aur photon milta hai.
  this stimulated transition is laser transition issi se laser milta hai. Process is repeated agai and again because photons lagatar ~~...~~ move kr re hai aur reflect hore hai.
  This result in amplified strong laser beam.
- laser output → 6943 Å
- It drawback :- Isme 3 milliseconds ka gap hota hai jiski wajah se humko emission pulse form mein milta hai continous laser output nhi milta.

* Application of Ruby laser :-
- In welding
- In LIDAR (Light Detection and Ranging)
- In labs for study & research
- In display decoration
- In holography
- In tattoo removal.
- In treatment of retina
- to test quality of materials

* He-Ne laser (gas laser) → by Ali Javan

- Characteristics of He Ne laser
1. It is gas laser
2. 4 level laser
3. Active medium He with Ne
4. High efficiency
5. Continous laser o/p (6328Å)
6. Electric pumping is used
7. No external cooling req. (optical pumping use nhi kiya ∴ zyada near nhi hogi)

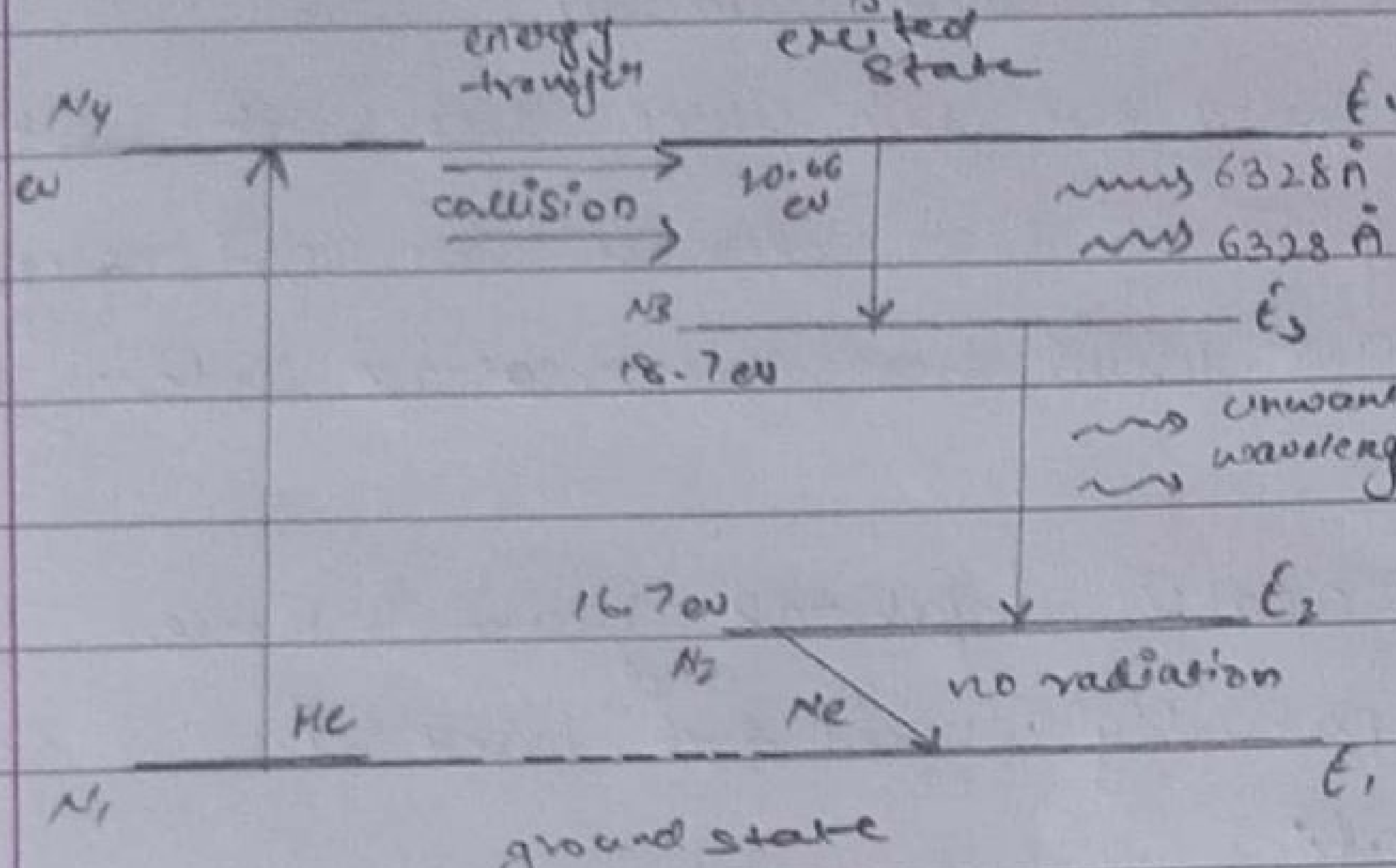


* Construction :-
1. General parameters :- Tube length upto 80 cm ; diameter ~~upto~~ 1.5 cm (reflecting khokhla tube)
2. Optical cavity / Resonator :- has 2 mirror (plane or spherical) that are 100% & partial reflector. Optical cavity is quartz cavity or glass cavity.
3. Active medium :- Helium & Neon gas in ratio 10:1
4. Brewster's window :-
- It is a substrate act to eliminate unwanted wavelengths
5. Energy pump source :- Electrical pumping is used. ~~the~~ Cathode and anode terminals are in gas discharge tube.

→ He-Ne laser mein 4 energy levels hoti hai jaise jaise emission hoga alag alag wavelength ki light emitt hogi pr humko ek particular wavelength light chaiye ~~to~~ baaki nhi toh usse baaki unnecessary light ko rokne ke liye brewster window use hoti hai.

* Working of He-Ne laser :-

Normal diagram



Imp. pts to remember

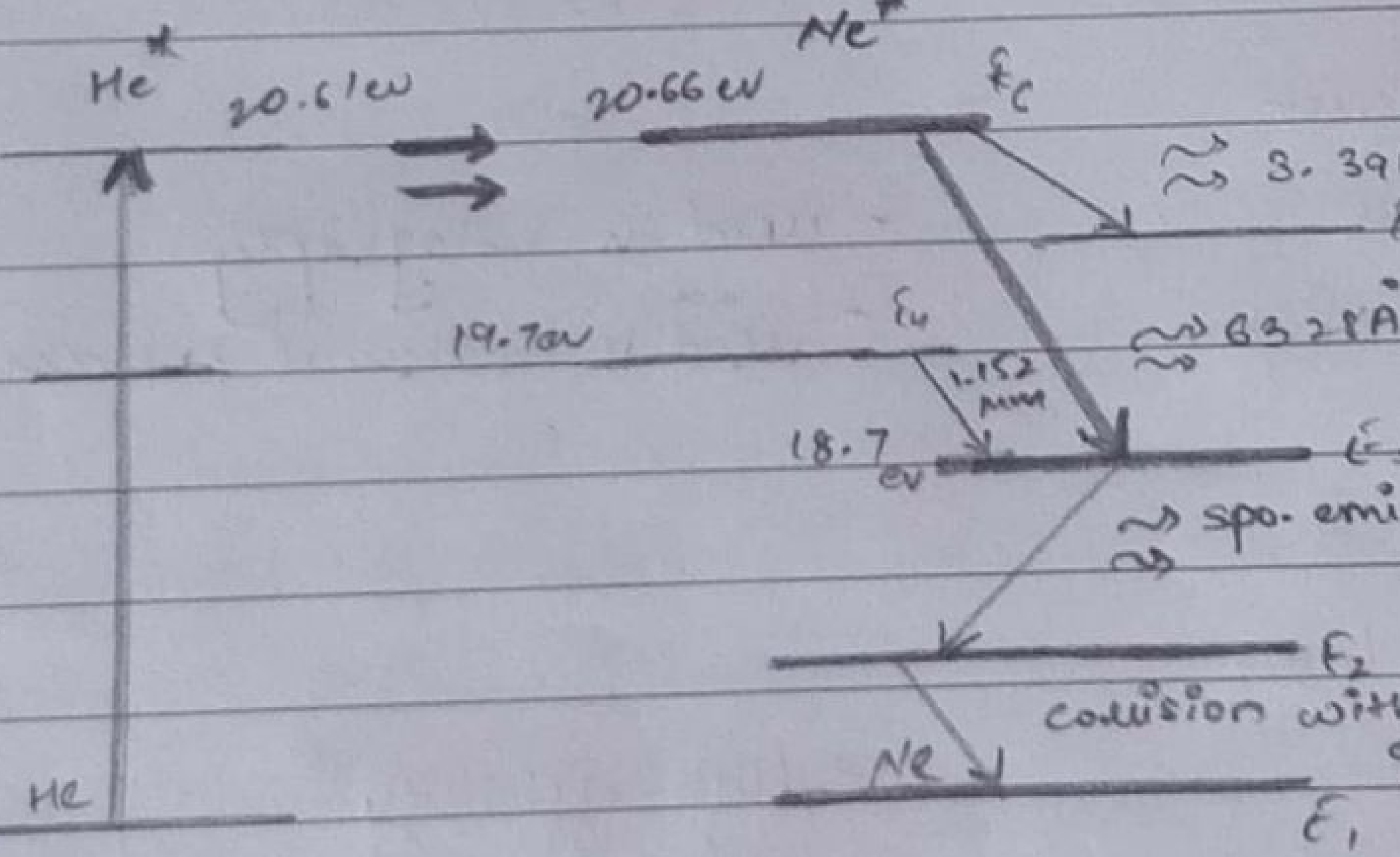
- lighter but more in amount → mass of He → 4 amu
- heavier but less in amount → mass of Ne → 20.1 amu (→ 5 times of He)

laser o/p → 6328 Å (20.66 eV to 18.7 eV)

excited hone se pehle → $e + He \rightarrow He^*$ (→ iska matlb excited ho chuka hai)

discharge se e^- diya He ko: $He^* + Ne \rightarrow Ne^*$

Better diagram



→ Idhar 6 energy state hai toh iska matlb yeh nhi ki yeh 6 level laser hai.
- Major 4 hi level hote hai pr inke beech chote-chote energy bands hote hai too low gap pr.

- In normal state (→ electrical discharge, pumping use krte hai), helium and neon atoms are at ground state but when a discharge passes then He atoms pehle excited hote hai aur excited state pr pahuchte hai kyunki unka ~~amount~~ amount zyada hota hai aur lighter bhi hote hai. e discharge e^- He aur Ne dono ko strike krega pr pehle He atom upar jayega.
- He atom ka lifetime 10^{-4} s hai isliye woh upar zyada der tk rehta hai as compare to Ne atom jiska life time 10^{-8} s hota hai. toh jab neon atom thodi der ke baad upar excited state pr jata hai toh ~~woh~~ excited He usko strike krta hai aur apni energy Ne ko deta hai so that ~~He~~ Ne be excite ho jata hai.
- Since Ne ka life-time kam hai toh woh niche bhi pehle ayenge to joh energy woh niche leke ayenge th humko spo. emi & sti. emi milega.
- E_4 se E_3 pr jo transition hoga i.e. 20.66 eV to 18.7 eV to humko

Imp → issi region se laser output milta hai i.e. 6328 Å. (→ red in color.)

E_3 se E_2

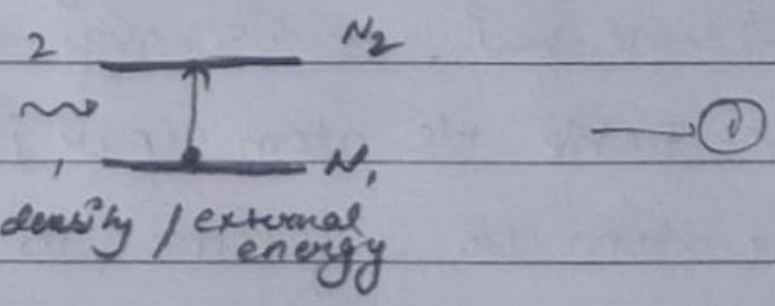
- age transition hone pr bhi wavelengths milti hai pr woh unecesary hoti hai toh Brewster's window kaam aata hai.
- E_2 se E_1 rapid transition hota hai toh usme bss heat milti hai.
- Helium koi laser output nhi deta because woh apni energy Neon ko transfer krta hai aur khud bss heat release krke wo niche aa jata hai.
- Yeh saari process tab tk chalti hai jabtak beam intense nhi ho jaati aur woh partially silvered ends laser ki form mein nikal nhi jati.

* Application of He Ne laser.
  - Used in labs experiments
  - Used in optical communication
  - used in medical field
  - used in holography
  - used in material processing

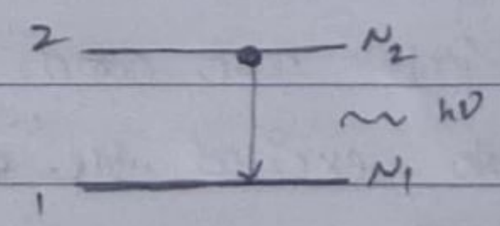
* Advantages of He-Ne laser
  - 4 level laser
  - Continous laser output
  - No cooling req.
  - High efficiency
  - less expensive
  - High stability of frequency

* Relation b/w Einstein's coeff. A & B. → Jab external energy dene hai then we use B coeff.
  (energy nhi dete then we use coeff. A)

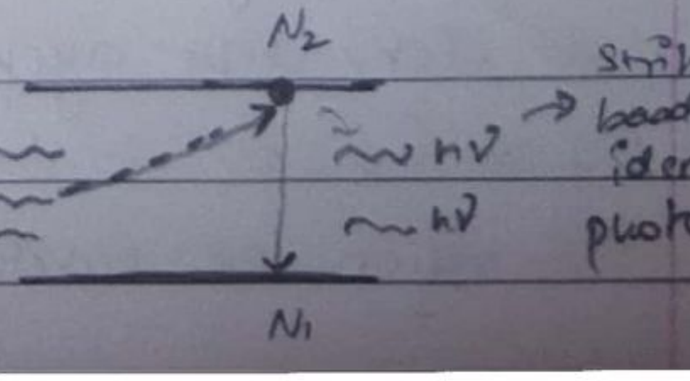
- Rate eqn for absorption
  $\left(\frac{dN_1}{dt}\right)_{abs} = N_1 B_{12} u(\omega)$ — (1)
  (N_1 → population of ground state; B_{12} → transition const.; $u(\omega)$ → energy density / external energy)

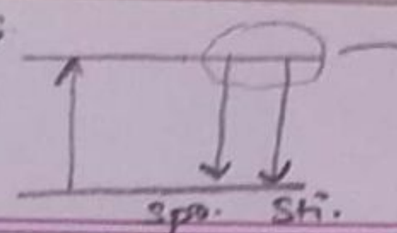


- Rate eqn for spo. emi.
  $\left(\frac{dN_2}{dt}\right)_{spo.} = N_2 A_{21}$ — (2)
  (A_{21} → external energy nhi di)



- Rate eqn for sti. emi. (↳ also called induced emission)
  $\left(\frac{dN_2}{dt}\right)_{sti} = N_2 B_{21} u(\omega)$ — (3)
  ($u(\omega)$ → conti. energy di)





- we know that jab 2 energy levels hoi toh thodi time ke baad thermal equil^m ki condition achieve hone lgegi.

after thermal equil^m condition :-

no of upward transition = total no of downward transition

i.e. absorption = sti spo. emi + sti emi

$$\left(\frac{dN_1}{dt}\right)_{abs} = \left(\frac{dN_2}{dt}\right)_{spo} + \left(\frac{dN_2}{dt}\right)_{sti}$$

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

$$u(\omega)\,[N_1 B_{12} - N_2 B_{21}] = N_2 A_{21}$$

$$u(\omega) = \frac{N_2 A_{21}}{N_1 B_{12} - N_2 B_{21}} = \frac{A_{21}}{\frac{N_1 B_{12}}{N_2} - B_{21}} \longrightarrow (4)$$

from Boltzmann distribution law

$$N = N_0 e^{-E/kT}$$

Hence $N_1 = N_0 e^{-E_1/kT}$ and $N_2 = N_0 e^{-E_2/kT}$

Now, putting values of N_1 & N_2 in eq^n (4) (yeh eq^n = planck's radiation law jaisi eq^n banni hai toh usko taran similar banane ke liye kuch changes krenge.)

$E = h\nu$ → pichle padha tha

$$u(\omega) = \frac{A_{21}}{e^{(E_2 - E_1)/kT}\,(B_{12}) - B_{21}}$$

$$\text{So, } u(\omega) = \frac{A_{21}}{B_{12}\left[e^{h\nu/kT} - B_{21}/B_{12}\right]} \longrightarrow (5)$$

we k.t planck's radiation law is

$$u(\omega) = \frac{8\pi h\nu^3}{c^3}\left[\frac{1}{e^{h\nu/kT} - 1}\right] \longrightarrow (6)$$

By comparing eq^n 5 and 6 we get,

remember $\boxed{\frac{A_{21}}{B_{12}} = \frac{8\pi h\nu^3}{c^3}}$ — (7) & $\frac{B_{21}}{B_{12}} = 1$ or $\boxed{B_{21} = B_{12}}$ — (8)

eq^n (7) and (8) are representing relation b/w coeff. A & B.

- upward transition coeff. ka ya fir downward wala ki value same hoti hai.
- agar dono mein se koi ek transition pta hai toh dusra predict kr skte hai.