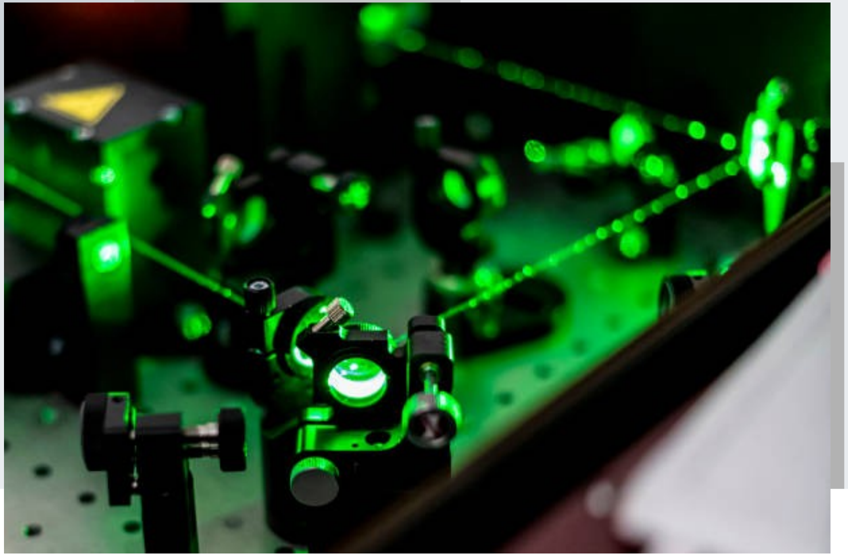
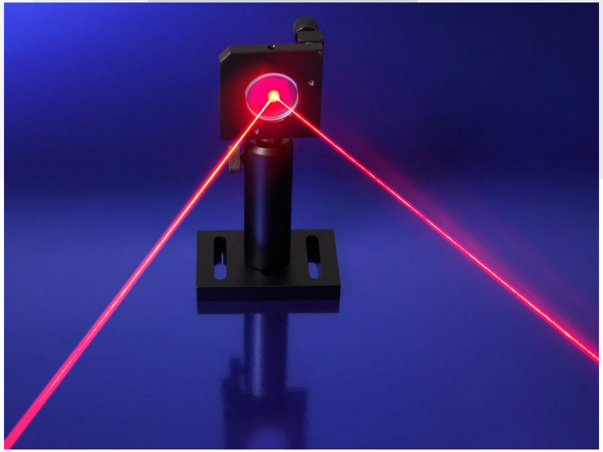
Module – 5

LASERS





Dr. Pankaj Sheoran
SAS

Syllabus

Laser characteristics - spatial and temporal coherence - Einstein coefficients and their significance - Population inversion - two, three and four-level systems - Pumping schemes - threshold gain coefficient - Components of a laser - He-Ne, Nd: YAG and CO_2 lasers and their engineering applications.

Reference Books:

1. W. Silfvast, Laser Fundamentals, 2012, 2nd Edition, Cambridge University Press, India.
2. Principles of Lasers, Orazio Svelto, 5th edition (2009)

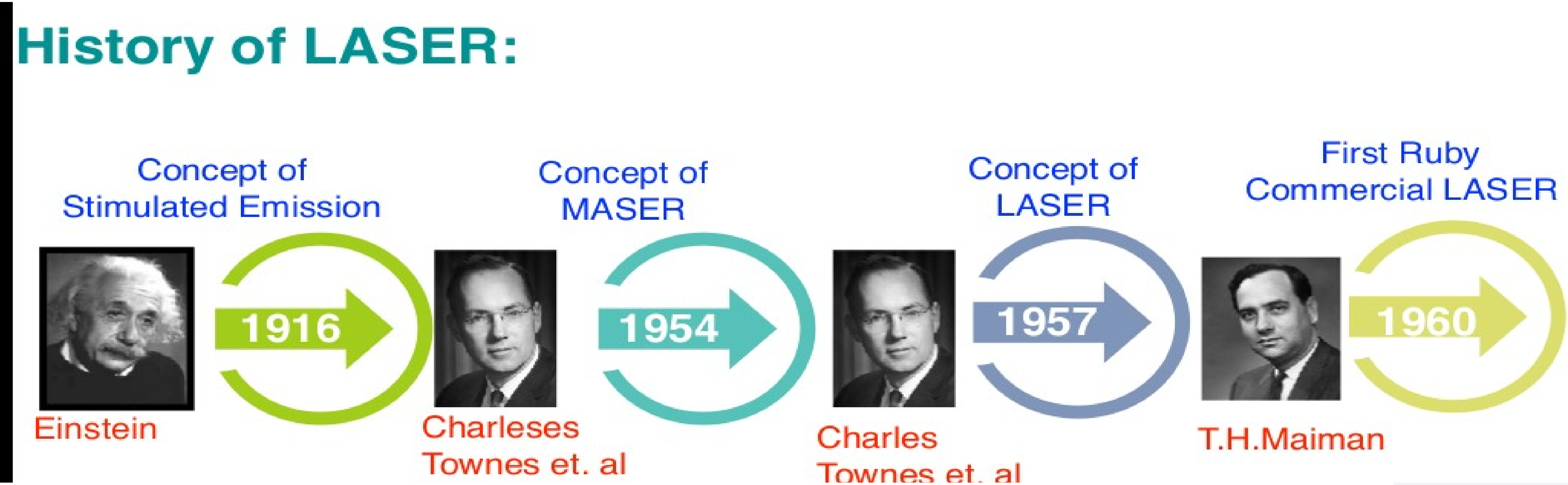
Outline:

Introduction to LASER

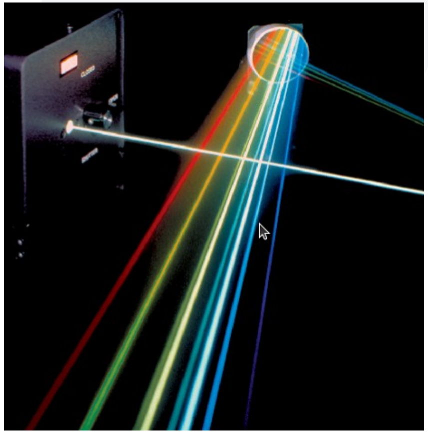
- Properties of Laser Light
- Three basic processes
  - Absorption
  - Spontaneous Emission
  - Stimulated Emission
- Main components of a Laser and Working principle
  - Population Inversion
  - Pumping
  - Light amplification in a laser

INTRODUCTION

LASER stands for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. **Laser** is a device which **emits** *amplified, monochromatic, electromagnetic radiation* ,using the process stimulated emission of atoms and molecules. The emitted light waves are coherent in nature.

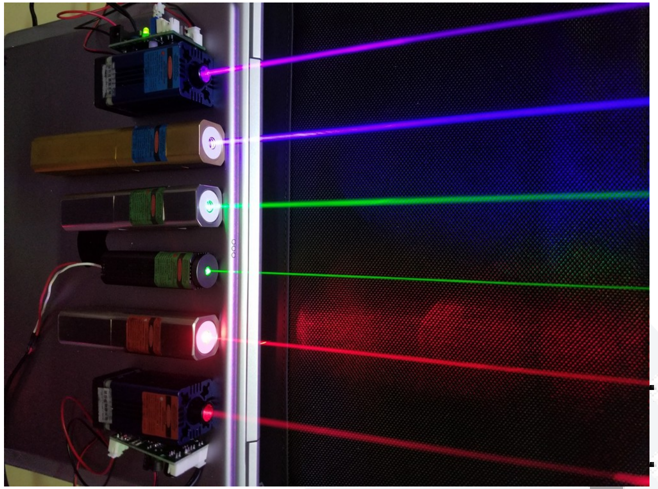


Properties of LASER



- **Monochromatic:** Laser beam is highly monochromatic; the wavelength is single.

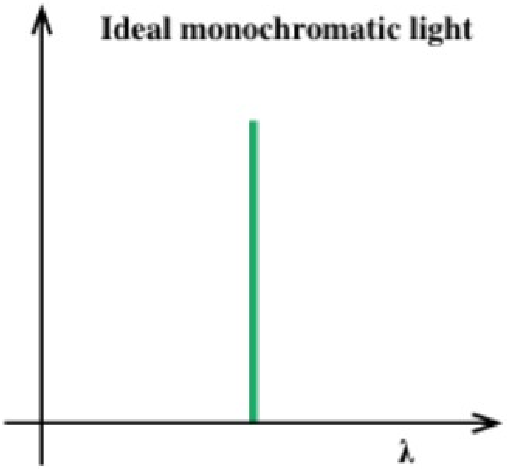
- **Coherence:** In lasers the wave trains of same frequency are in phase, the radiation given out is in mutual agreement not only in phase but also in the direction of emission and polarization.

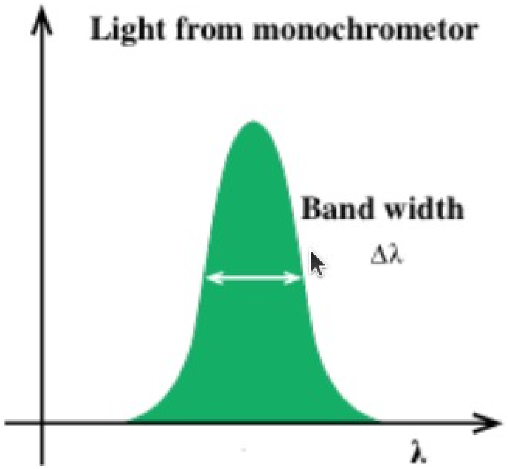


- **Collimated/Directional:** Ordinary light spreads in all directions and its angular spread is 1m/m. But it is found that laser is highly directional and is angular spread is 1mm/m.

- **High Energy/Intense:** due to high directionality, the intensity of laser beam reaching the target is of high intense beam. For example, 1 mill watt power of He-Ne laser appears to be brighter than the sunlight.

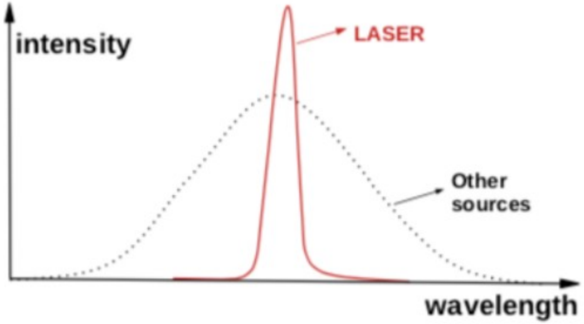
LASER Properties: Monochromaticity





$$\text{Monochromaticity} = \frac{\lambda_o}{\Delta\lambda} = \frac{\nu_0}{\Delta\nu}$$

No light is 100% monochromatic. But the LASER emitted light have higher degree of monochromaticity.



He-Ne Laser
λ0 = 632.5 nm
Δλ = 0.2 nm

Diode Laser
λ0 = 900 nm
Δλ = 10 nm

Concept of Coherence

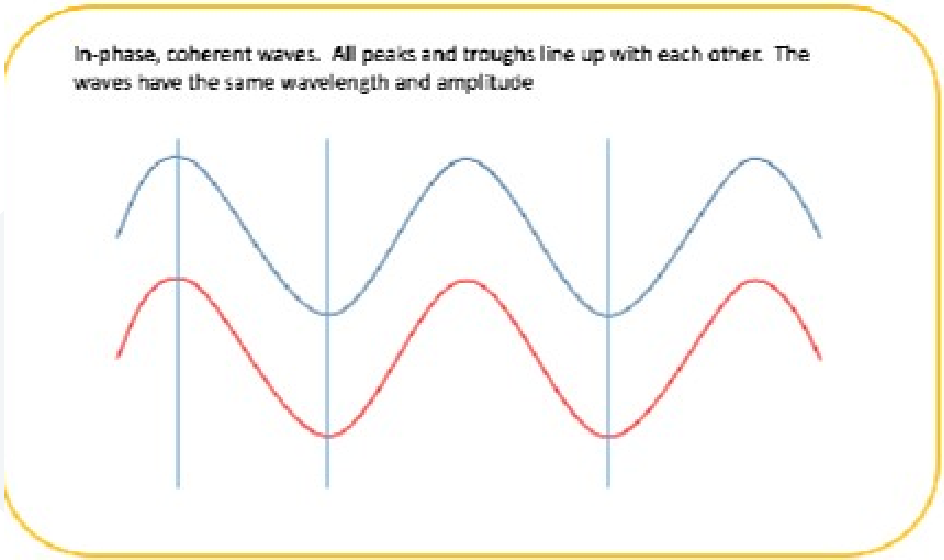
Coherence

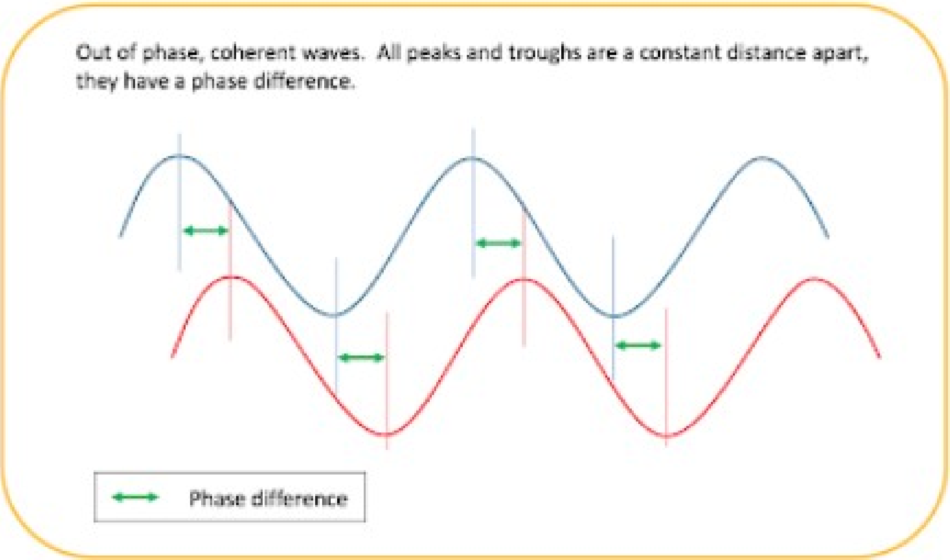
Incoherence

Partial Coherence

Concept of coherence in Lasers

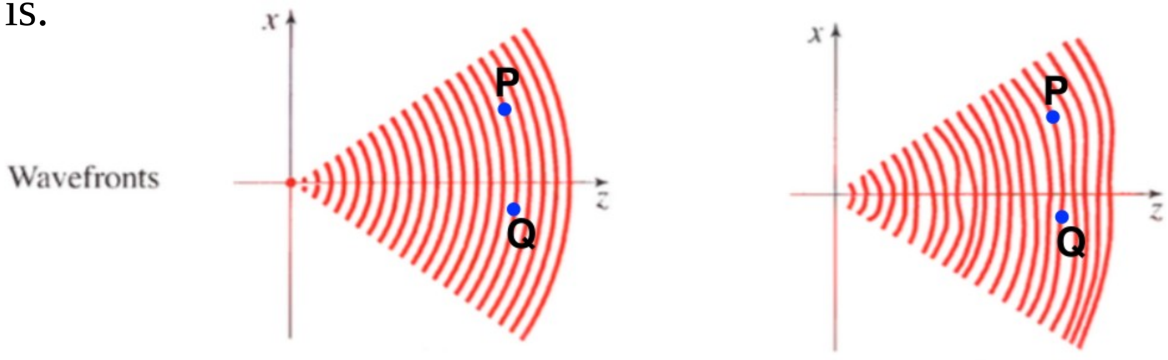
Coherence is a measure of the correlation between the phases measured at different (temporal and spatial) points on a wave or........*Two waves are called coherent if they have the* ***same frequency, and wavelength and have a constant phase difference****.*





Types of coherence

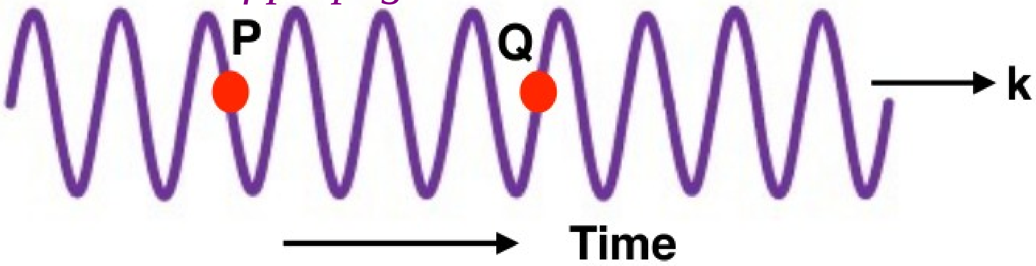
- **Spatial (transverse) coherence:** It is a *measure of the correlation of a light wave's phase at different points transverse to the direction of propagation* - it tells us how uniform the phase of a wavefront is.



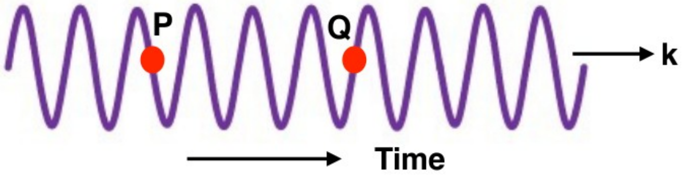
Spatial Coherent

Spatial Incoherent

- **Temporal (longitudinal) coherence:** *It is a measure of the correlation of light wave's phase at different points along the direction of propagation* – it tells us how monochromatic a source is.



<u>Temporal (longitudinal) coherence Length</u>



at time, :t_1

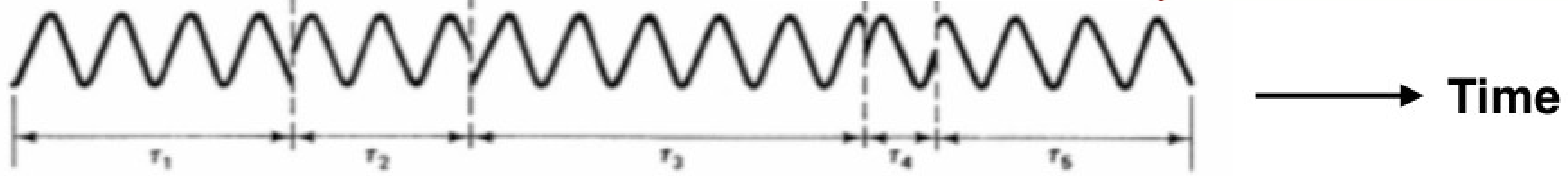
$$P: \ Phase = \Phi_1$$
$$Q: \ Phase = \Phi_2$$

at time, :t_2

$$P: \ Phase = \Phi'_1$$
$$Q: \ Phase = \Phi'_2$$

temporal coherence if

$$\boxed{\phi_1 - \Phi_2 = \phi'_1 - \Phi'_2}$$



Temporal Coherence time $= \tau_c = \dfrac{\tau_1 + \tau_1 + \tau_2 + \tau_3 \ldots + \tau_n}{n}$

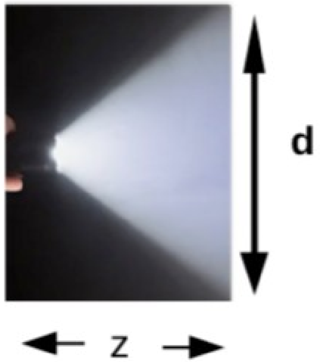
Temporal Coherence length $= L_c = c\tau_c$

Coherence, tells us how monochromatic a source is: For a monochromatic source $\tau_c \to \infty$.

For ordinary light source:	$\tau_c = 10^{-10}\, s$	and	$L_c = 3\, cm$
For LASER source:	$\tau_c = 10^{-3}\, s$	and	$L_c = 300\, km$

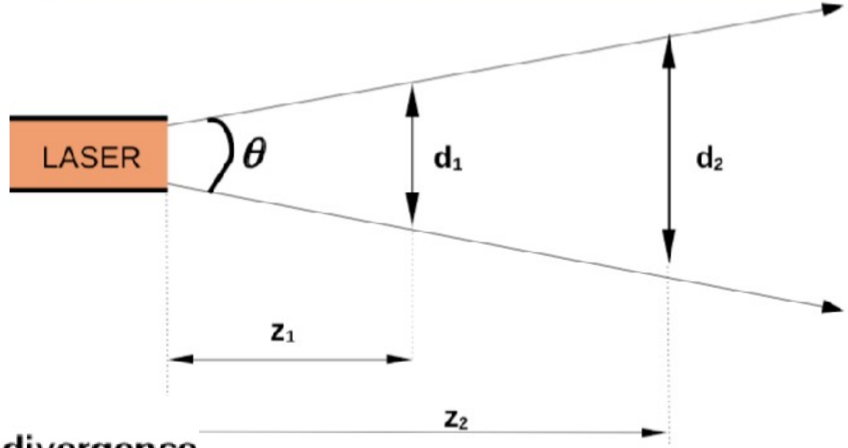
Directionality

LASERs are *highly directional*. A very tight beam, which is strong and concentrated in a particular direction. It can travel for a long distance with a little spread or with a minimum divergence. i.e. **it is related to the how much a light beam diverge or spread.**



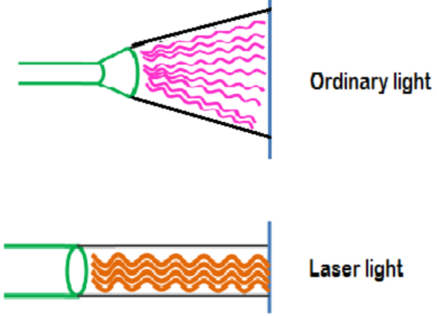
Angle beam divergence

$$\theta = \frac{d}{z}$$



Angle of divergence

$$\theta = \frac{d_2 - d_1}{z_2 - z_1}$$



- Normal Flashlight: Divergence ~ 20^{o}-30^{o}.
- Searchlight: Divergence ~ 8^{o}-10^{o}.
- LASER: Divergence ~ 0.5^{o}-0.6^{o}

High Energy/Intense

It is highly monochromatic and directional. As a result, it is more intense than regular light. The laser beam's power can be maintained across long distances because of its high degree of directionality.

$$\text{Optical Intensity} = I = \frac{P}{A}$$

P= laser power (W)

A= laser spot area (m^2)

Used for Cutting, welding, drilling, military weapons, etc.

To summarize:

Property	Laser	Ordinary light source
Directionality	Collimated (parallel beam)	Non collimated (light emitted in all directions)
Color	Monochromatic (one color) Comment: coherent beam (i.e., ordered in time & space)	Polychromatic (many colors) Comment: non coherent beam (i.e., non ordered)
Power output	Can be high	Medium or low
Temporal	Can produce very short and energetic pulses	Typically long and low-energy pulses
Power density	High; can be focused to a very small spot (of diameter d=lambda)	low; relatively large focal spot

Module – 5

LASERS

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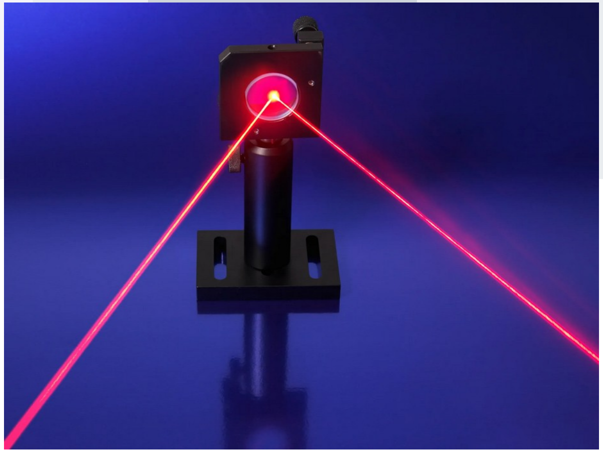
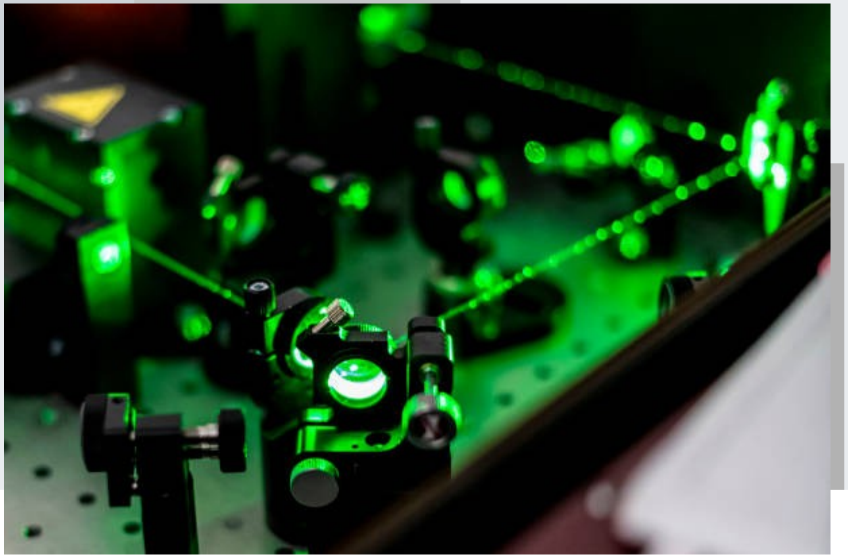




Dr. Pankaj Sheoran
SAS

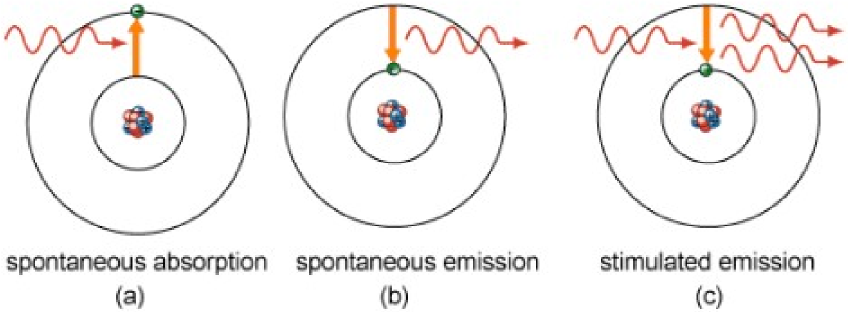
Basic of LASER Physics

3 TYPES OF TRANSITIONS:

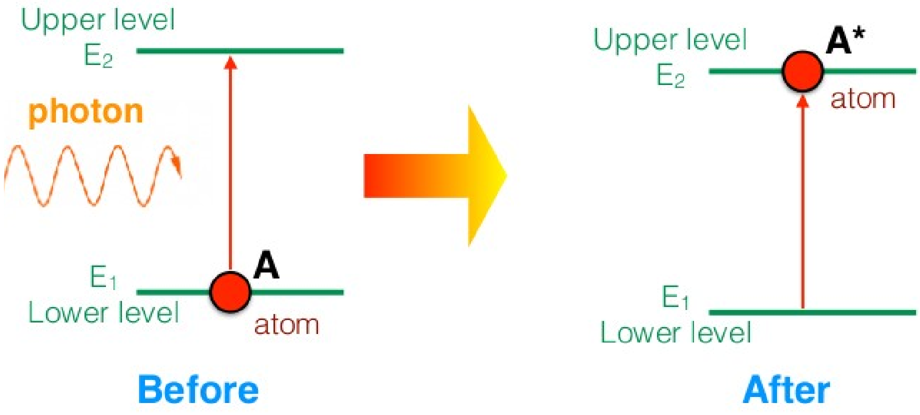
- **Spontaneous Absorption:** When a photon incident on atoms then atoms absorb the energy from the photon and jump from a lower energy state (E1) to a higher energy state (E2).

- **Spontaneous Emission:** The atoms in the excited energy state (E2) undergo a transition to the lower energy level (E1) on its own and gives up the excess energy in the form of a photon.

- **Stimulated Emission:** If a photon with energy $E2-E1=h\nu$ interacts with an atom in the excited energy state(E2), it can trigger the atom to undergo a transition to the lower level (E1) resulting in the emission of another photon. This process is known as stimulated emission. In this process, one photon strikes the photon and one other photon is emitted! A total of two photons comes out at the end.



Spontaneous Absorption

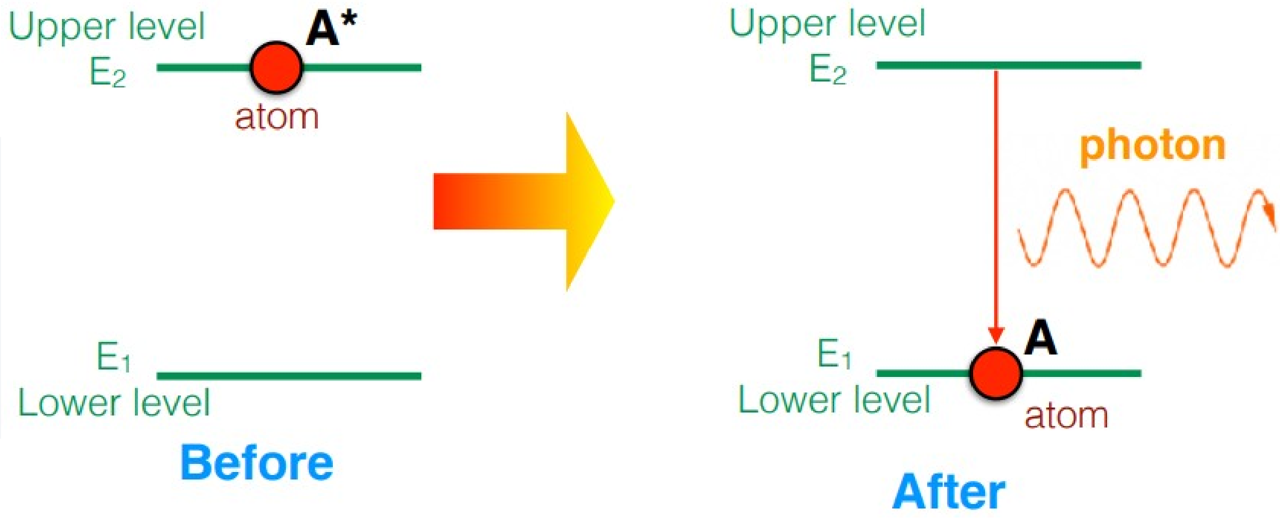


$$A + h\nu \rightarrow A^*$$

Induced/stimulated Absorption

For absorption to occur, the photon must have energy: $E_2 - E_1 = h\nu$

Spontaneous Emission

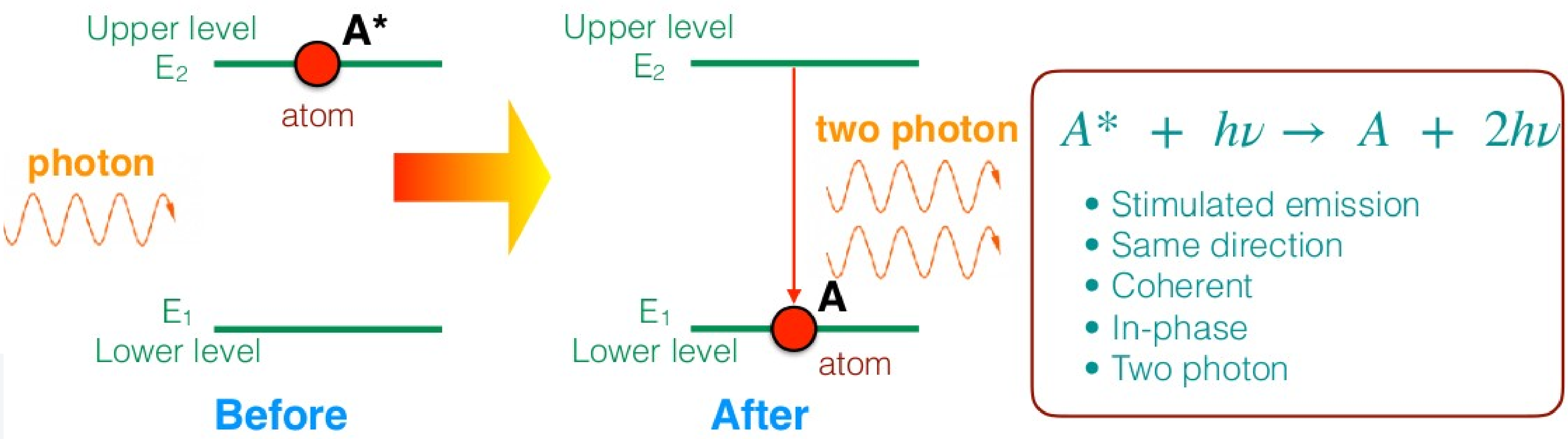


$$A^* \rightarrow A + h\nu$$

- Spontaneous emission
- Random direction
- In-coherent

The emitted photon will have energy: $h\nu = E_2 - E_1$

Stimulated Emission

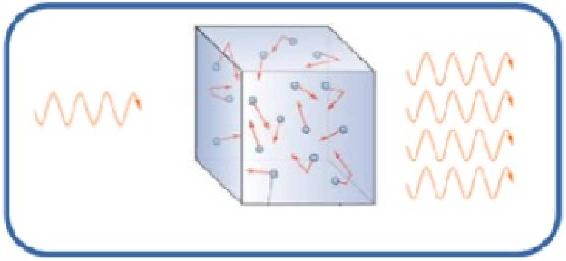


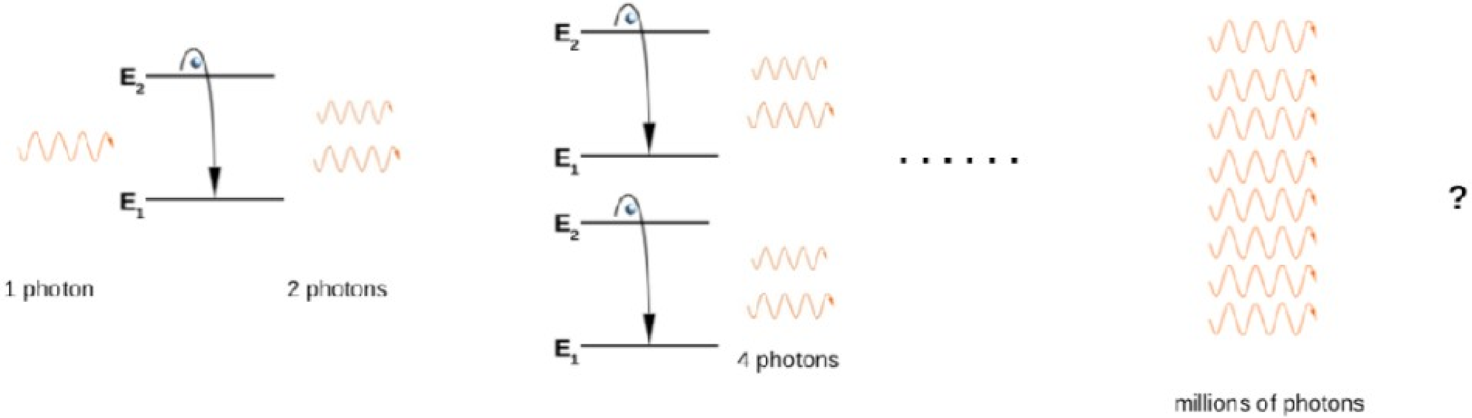
Can we amplify radiation using stimulated emission?

Stimulated Emission leads to Amplification

Take a box of atoms in which larger number of atoms are in the higher energy state (E_2).

Next, shine the box with one photon of energy $h\nu$

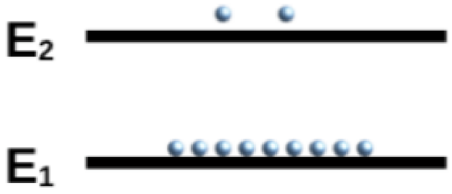




$2^1 \rightarrow 2^2 \rightarrow 2^3 \rightarrow 2^4 \rightarrow \cdots\cdots\cdots \rightarrow 2^N$

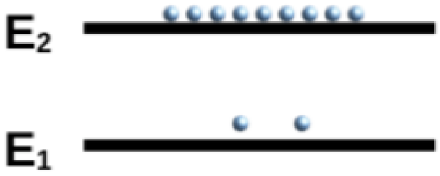
For this to happen, larger number of atoms must be in the higher energy state: **Population inversion!**

Population Inversion



General Scenario

$N_1 > N_2$



Population Inversion

$N_1 < N_2$

Consider two energy levels E_1 and E_2. Let the number of atoms in these levels be N_1 and N_2 respectively. When the number of atoms in the excited state (N_2) are greater than the number of atoms in the lower energy state (N_1), the scenario is called population inversion.

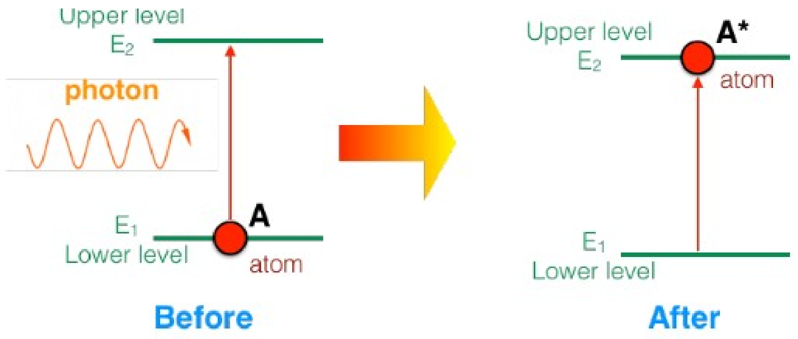
$$\boxed{\frac{N_1}{N_2} = e^{\frac{(E_2 - E_1)}{k_\beta T}}}$$

As $E_2 > E_1$, we have $N_1 > N_2$. Thus, at any finite and positive temperature, the number of atoms in the higher energy level is always less than that in lower energy level. This is equilibrium condition. However, for stimulated emission to dominate over stimulated absorption, we require $N_2 > N_1$.

Einstein Coefficient: Spontaneous Absorption

Energy Difference

$E_2 - E_1 = h\nu$



n_1 ⟶ number of electrons in the state 1

n_2 ⟶ number of electrons in the state 2

$\rho(\nu)$ ⟶ **Photon Density**

So the probability of the transition from E_1 to E_2 is: $P_{12} \propto \rho(\nu)$

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

B_{12} is the Einstein coefficient for absorption

So the no. of atoms absorption from E_1 to E_2 in a time duration Δt is :

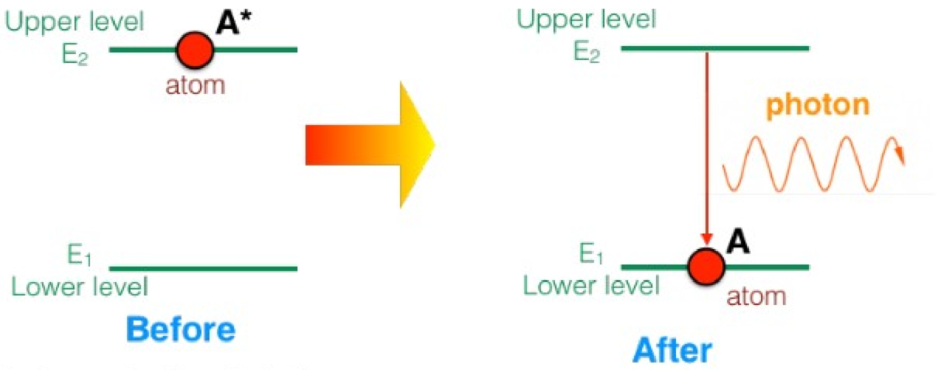
$$\Rightarrow = N_1\, P_{12}\, \Delta t$$

$$\Rightarrow = N_1\, B_{12}\, \rho(\nu)\, \Delta t$$

Einstein Coefficient: Spontaneous Emission

Energy Difference

$$E_2 - E_1 = h\nu$$



n_1 → **number of electrons in the state 1**

n_2 → **number of electrons in the state 2**

$\rho(\nu)$ → **Photon Density**

So the probability of the transition from E_2 to E_1 is:

$$\Rightarrow P_{21} = A_{21}$$

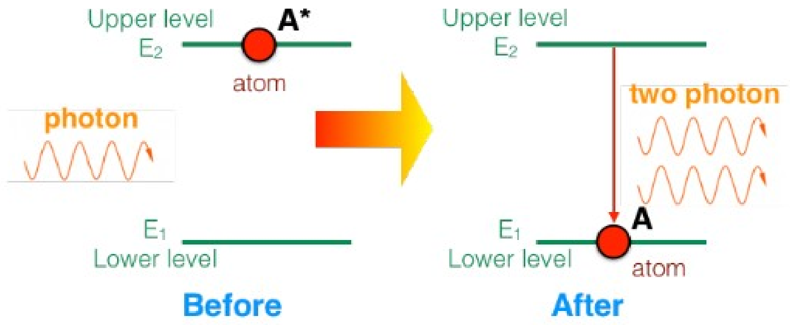
A_{21} is the Einstein coefficient for Spontaneous Emission

So the no. of atoms transition from E_2 to E_1 in a time duration Δt is :

$$\Rightarrow = N_2 \, P_{21} \, \Delta t$$

$$\Rightarrow = N_2 \, A_{21} \, \Delta t$$

Einstein Coefficient: Stimulated Emission



n_1 → number of electrons in the state 1

n_2 → number of electrons in the state 2

$\rho(\nu)$ → Photon Density

So the probability of the transition from E_1 to E_2 is: $P'_{21} \propto \rho(\nu)$

$$\Rightarrow P'_{21} = B_{21}\,\rho(\nu)$$

B_{21} is the Einstein coefficient for Stimulated Emission

A: spontaneous process

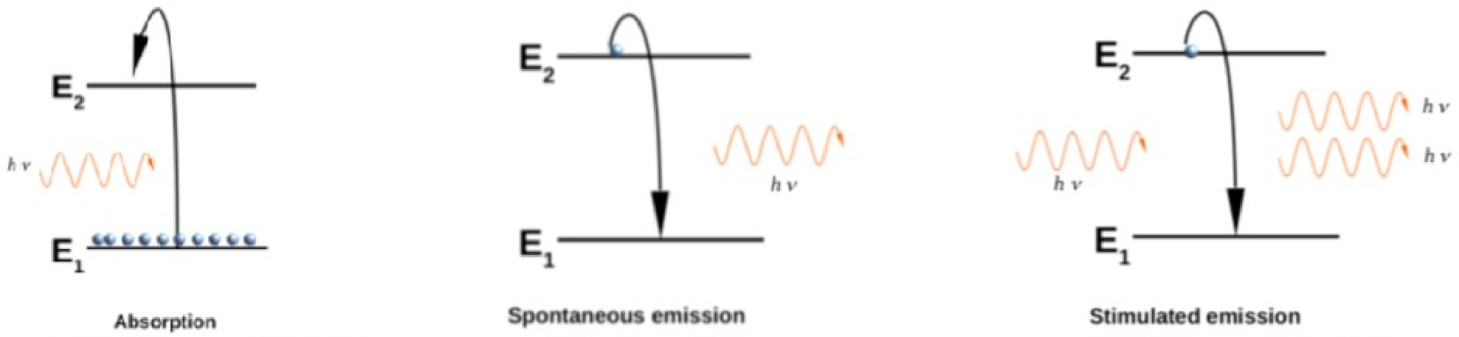
B: stimulated process

So the no. of atoms absorption from E_1 to E_2 in a time duration Δt is :

$$\Rightarrow = N_2\, P'_{21}\;\; \Delta t$$

$$\Rightarrow = N_2\, B_{21}\, \rho(\nu)\; \Delta t$$

Einstein's Coefficient: Derivation



$N_1\ B_{12}\ \rho(\nu)\ \Delta t$ $\quad N_2\ A_{21}\ \Delta t$ $\quad N_2\ B_{21}\ \rho(\nu)\ \Delta t$

In thermal equilibrium:

$\Rightarrow$ No of transition from E_1 to E_2 = No of transition from E_2 to E_1:

$$\Rightarrow N_1\ P_{12} = N_2\ P_{21} + N_2\ P'_{21}$$

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

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

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

Einstein's Coefficient: Derivation cont'd...

$$\Rightarrow \rho(\nu) = \frac{N_2\ A_{21}}{[N_1\ B_{12} - N_2\ B_{21}]}$$

divide both n/d by $B_{12}N_2$

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

At, thermal equilibrium, Boltzmann's statistics

$$\frac{N_1}{N_2} = e^{\frac{(E_2 - E_1)}{k_\beta T}}$$

$$\Rightarrow \rho(\nu) = \frac{A_{21}/B_{12}}{e^{\frac{(E_2 - E_1)}{k_\beta T}} - \frac{B_{21}}{B_{12}}}$$

$$\boxed{\Rightarrow \rho(\nu) = \frac{A_{21}/B_{12}}{e^{\frac{h\nu}{k_\beta T}} - \frac{B_{21}}{B_{12}}}}$$

At, thermal equilibrium, it will also radiate the EM wave according to the Planck's radiation:

$$\rho(\nu) = \frac{8\pi h\nu^3}{c^3}\left[\frac{1}{e^{\frac{h\nu}{k_\beta T}} - 1}\right]$$

on comparison of the both the photon density:

$$\Rightarrow \frac{A_{21}}{B_{12}} = \frac{8\pi h\nu^3}{c^3} \qquad \Rightarrow \frac{B_{21}}{B_{12}} = 1$$

$$\boxed{B_{21} = B_{12} = 1\ \&\ \frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}}$$

Einsteins Coefficient relations

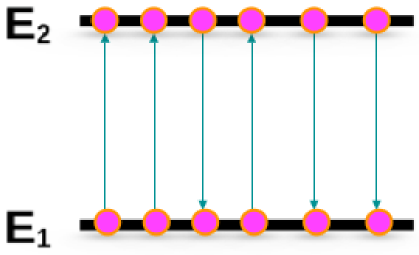
- **"Stimulated emission rate = absorption rate"**
- **Stimulated emission at higher frequency is difficult to achieve**

Significance of Einstein’s Coefficient

- **“Stimulated emission rate = absorption rate”**
- **Stimulated emission at higher frequency is difficult to achieve**

Population inversion not possible in two level systems

$$B_{21} = B_{12} = 1$$



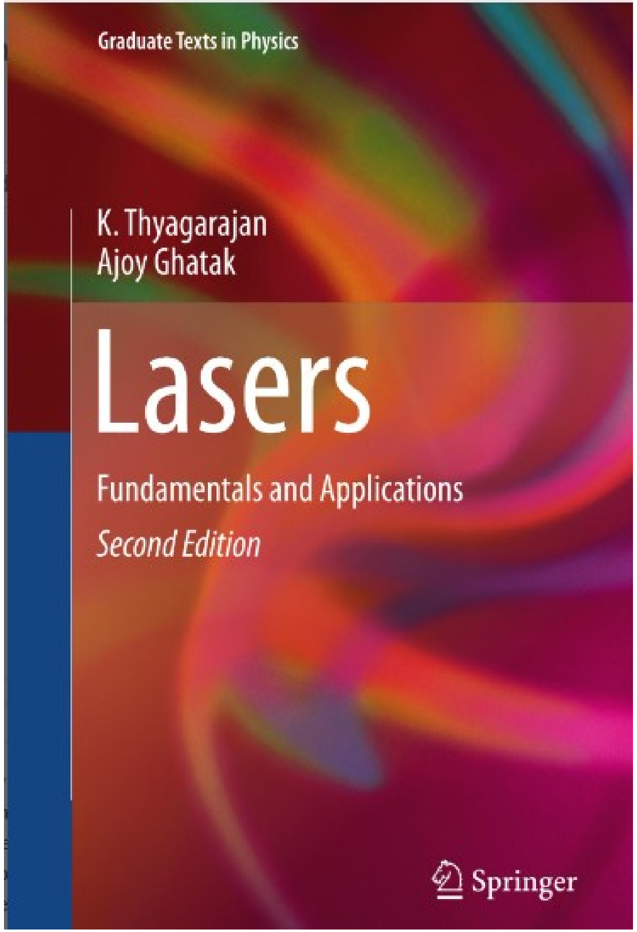
Einstein proved that the rate of stimulated emission is equal to the rate of absorption. Therefore, at best, number of atoms in energy levels in E_1 and E_2 are equal

Also, under thermodynamics equilibrium

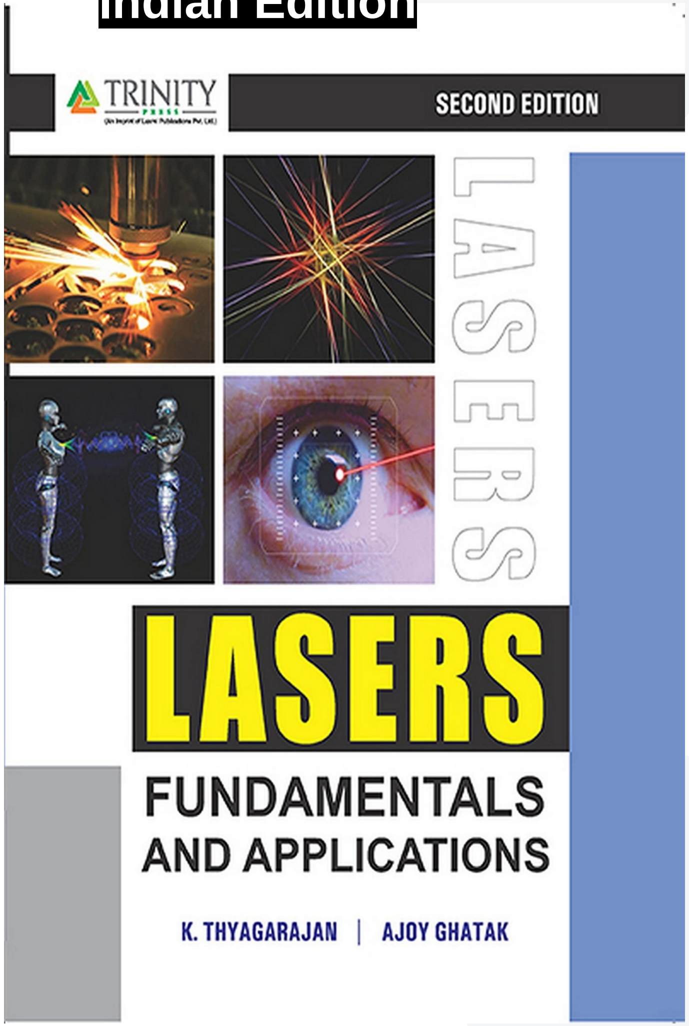
$$\boxed{\frac{N_1}{N_2} = e^{\frac{(E_2 - E_1)}{k_\beta T}}}$$

Laser Rate Equations:

International Edition



Indian Edition



Module – 5

LASERS

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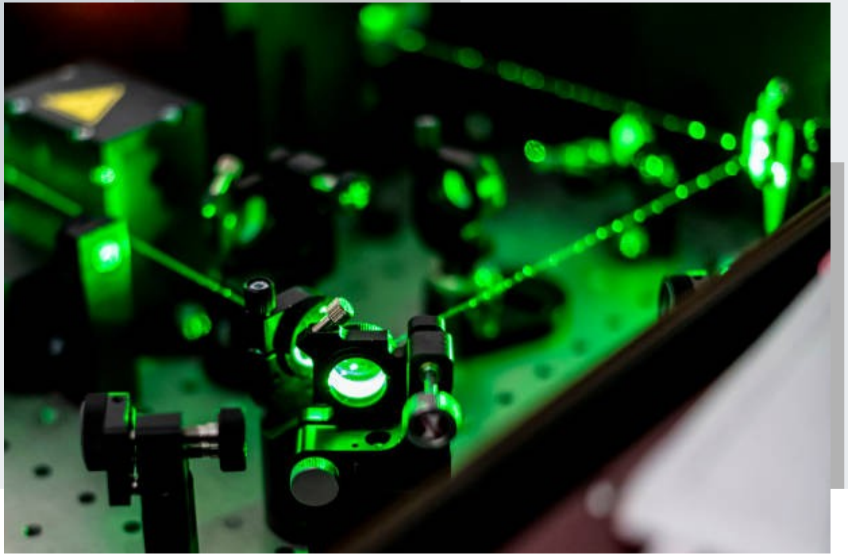
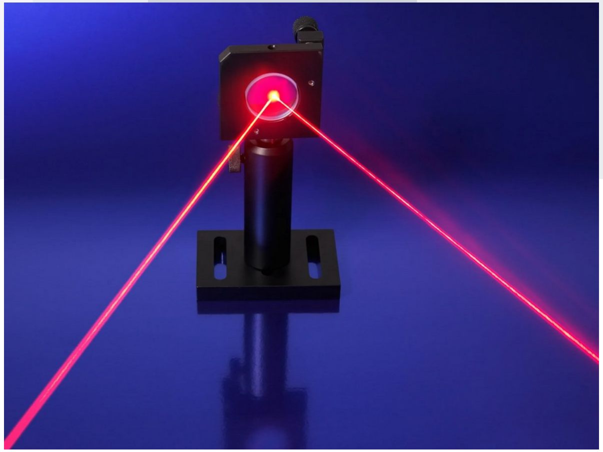




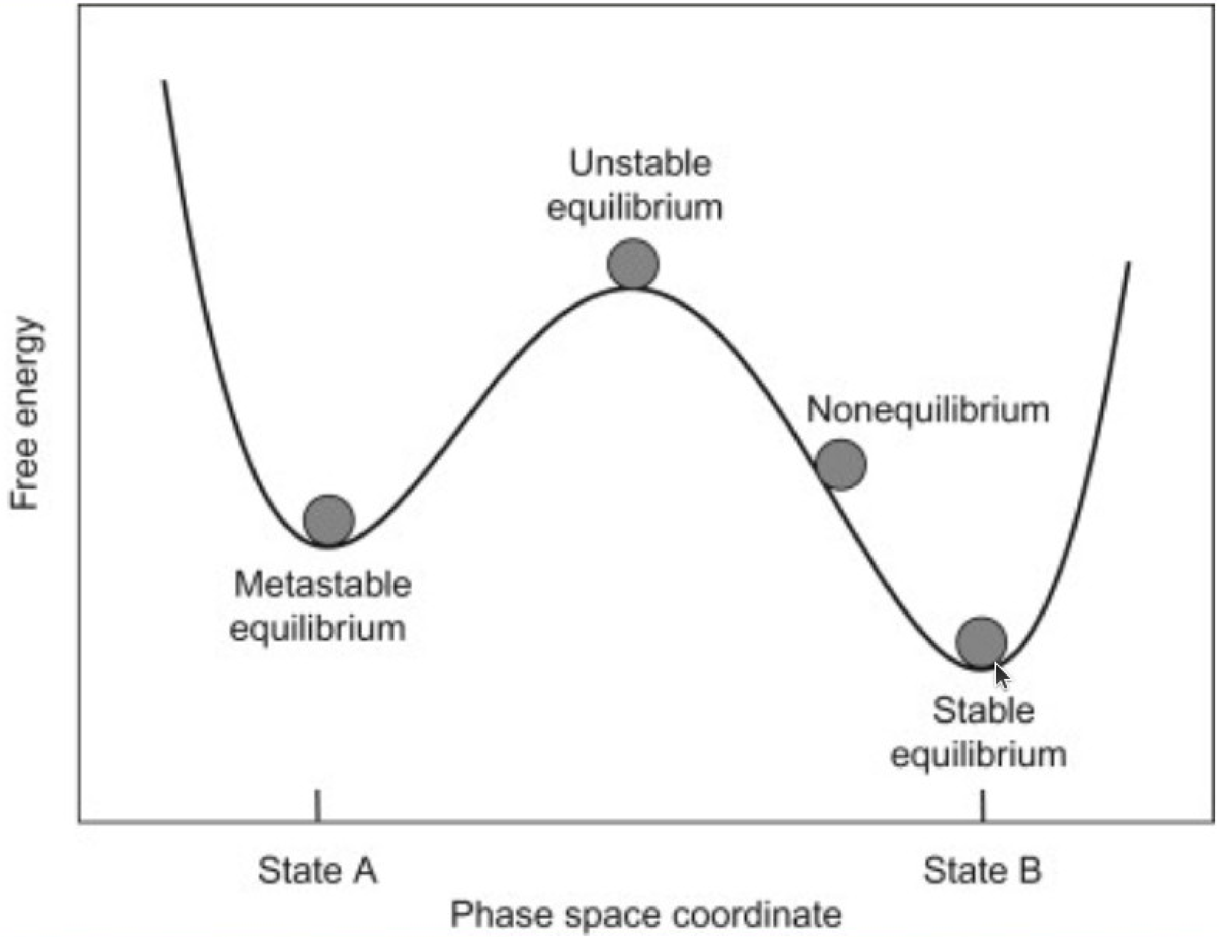
Dr. Pankaj Sheoran
SAS

Basic Physics Behind LASER (Principle)

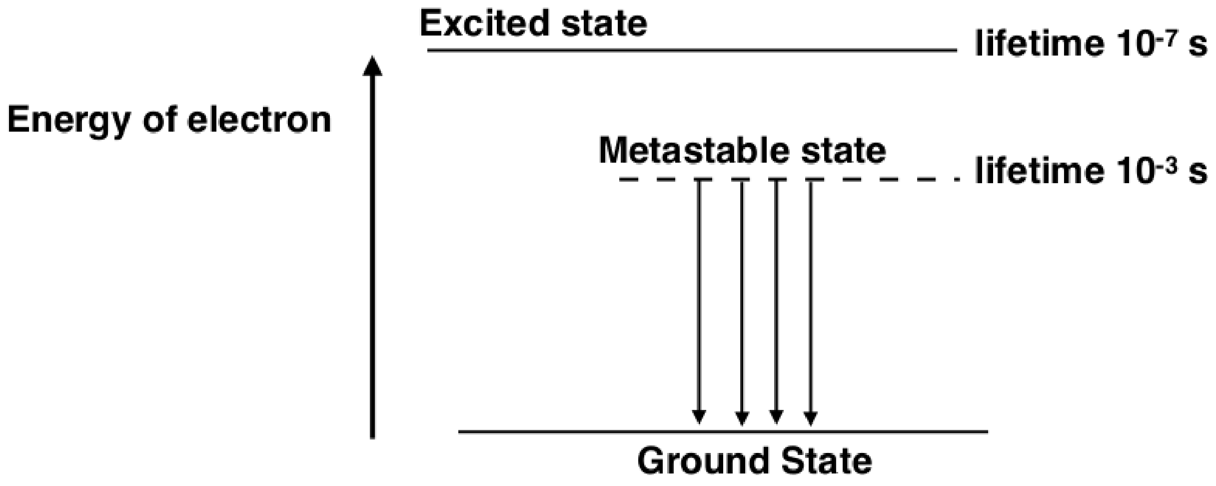
Introduction to LASER

- Properties of Laser Light ✓
- Three basic processes ✓
  - Absorption
  - Spontaneous Emission
  - Stimulated Emission
- Main components of a Laser and Working principle
  - Population Inversion
  - Pumping
  - Light amplification in a laser

Metastable state: Thermodynamics



Metastable state: Energy band diagram

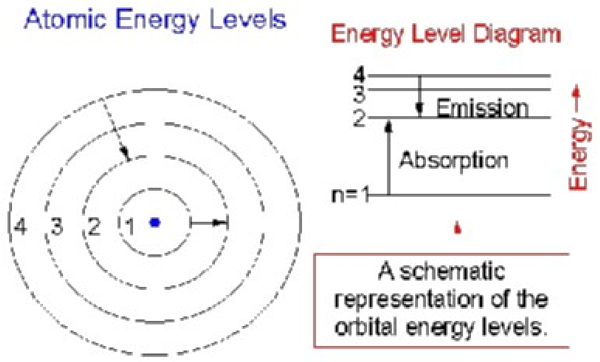


The metastable state is the state which lies between the **ground state and the excited state**. The atom in the ground state absorbs some energy and goes to the excited state. From an excited state, it loses some energy and becomes metastable. The lifetime of the metastable state is $10^{-3}\ s$, which is **higher than** the excited state ($10^{-7}\ s$).

To achieve population inversion, we must have metastable state

Energy Level System

- **Atoms characterized by a large number of energy levels.**
  - Only two, three or four levels are significant to the pumping process.



- **Classified as**
  - Two-level,
  - Three-level and
  - Four –level schemes.

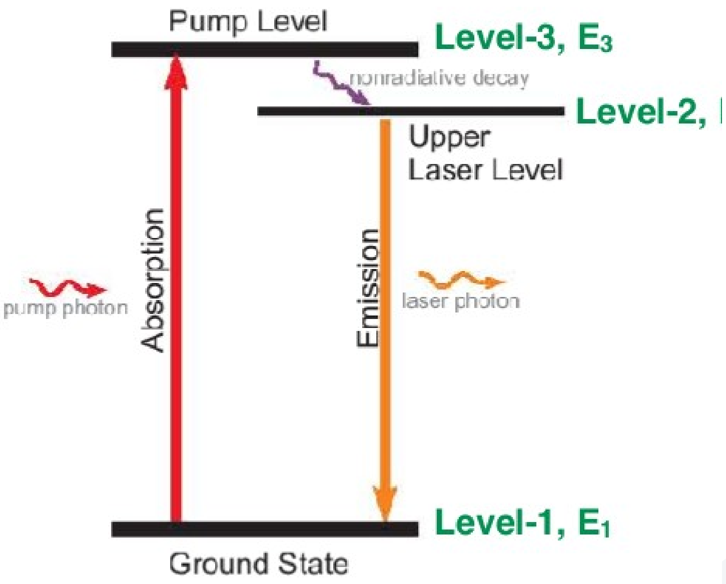
- Two-level scheme will not lead to laser action.
- Three-level and four-level schemes are important and are widely employed.

Three Level System

- **Athree level scheme;** Lower level is either the ground state or a level whose separation from the ground state is small compared to kT.

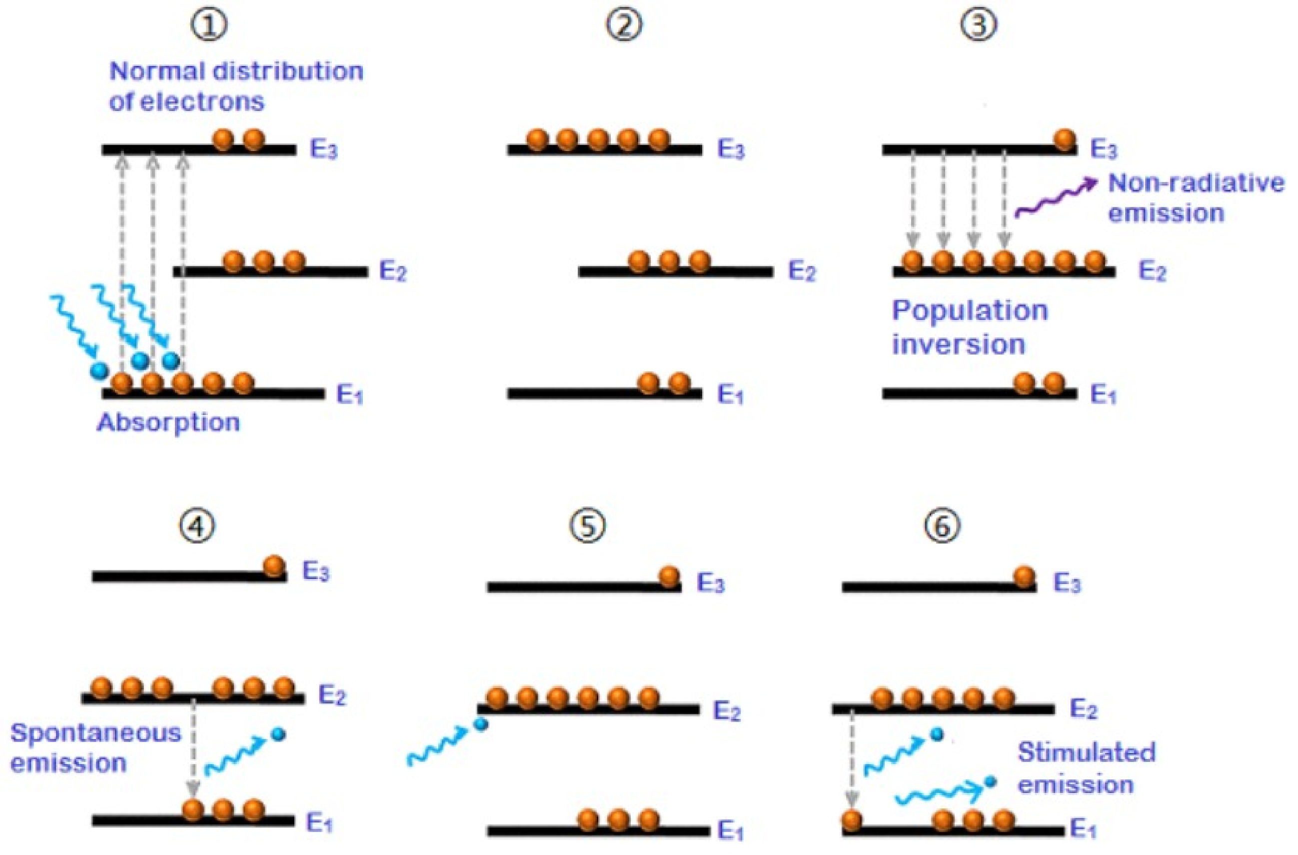
E_2 – A metastablelevel

- Atoms accumulate at level E_2
- Build-up of atoms at E_2 continues because of pumping process.
- Population N_2 at E_2 exceeds the population N_1 at E_1 and
  - ➢ **P.I. is attained.**



❖ **A photon of $h\nu(=E_2-E_1)$ can induce stimulated emission and laser action.** **level 2 is a meta-stable state**

Population Inversion: Three Level System



Disadvantage of Three Level System

- **Major disadvantage of a three level scheme ⇒ it requires very high pump powers.**

  - Terminal level of the laser transition is the ground state.

- As the ground state is heavily populated, large pumping power is to be used to depopulate the ground level to the required extent ($N_2 > N_1$)

- **Three level scheme can produce light only in Pulses.**

  - Once stimulated emission commences, the metastable state E_2 gets depopulated very rapidly and the population of the ground state increases quickly. As a result the population inversion ends. One has to wait till the population inversion is again established.

  - **Three level lasers operate in Pulsed Mode.**

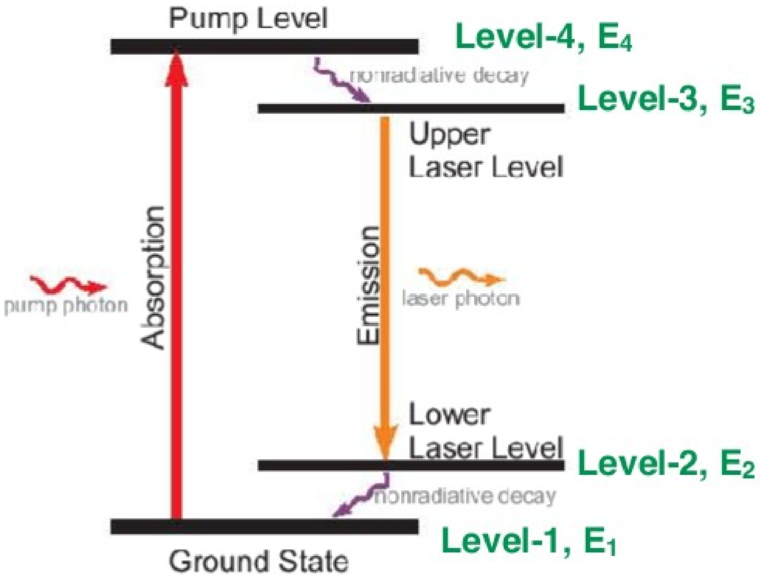
Four Level System

In Four level scheme, the terminal laser level E_2 is well above the ground level such that $(E_2 - E_1) >> kT$.

- It guarantees that the thermal equilibrium population of E_2 level is negligible.

E_3 - a metastable level

- Laser transition takes the atoms to the level E_2
- Atoms lose the rest of their excess energy & finally reach the ground state E_1.
- Atoms are once again available for excitation.



Four Level System

- ***In contrast to three level scheme, the lower laser transition level in four level scheme is not the ground state and is virtually vacant.***

  - It requires less pumping energy than does a three level laser. This is the major advantage of this scheme.

- ***Further, the lifetime of the lower laser transition level E_2 is much shorter, hence atoms in level E_2 quickly drop to the ground state.***

  - This steady depletion of E_2 level helps sustain the population inversion by avoiding an accumulation of atoms in the lower lasing level.

- Four level lasers can operate in **Continuous Wave mode.**

❑ **Most of the working lasers are based on Four Level Scheme**

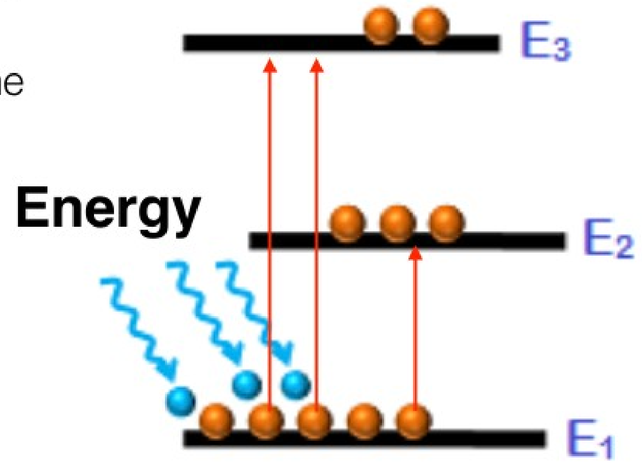
Basic Physics Behind LASER (Principle)

Introduction to LASER

- Properties of Laser Light ✓
- Three basic processes ✓
  - Absorption
  - Spontaneous Emission
  - Stimulated Emission
- Main components of a Laser and Working principle
  - Population Inversion ✓
  - Pumping
  - Light amplification in a laser

Pumping

Pumping is a process of energy transfer from an external source to atoms to achieve population inversion. The source that supplies energy to the laser medium is called pump source



- **Optical Pumping**
- **Electrical Pumping**
- **Chemical Pumping**

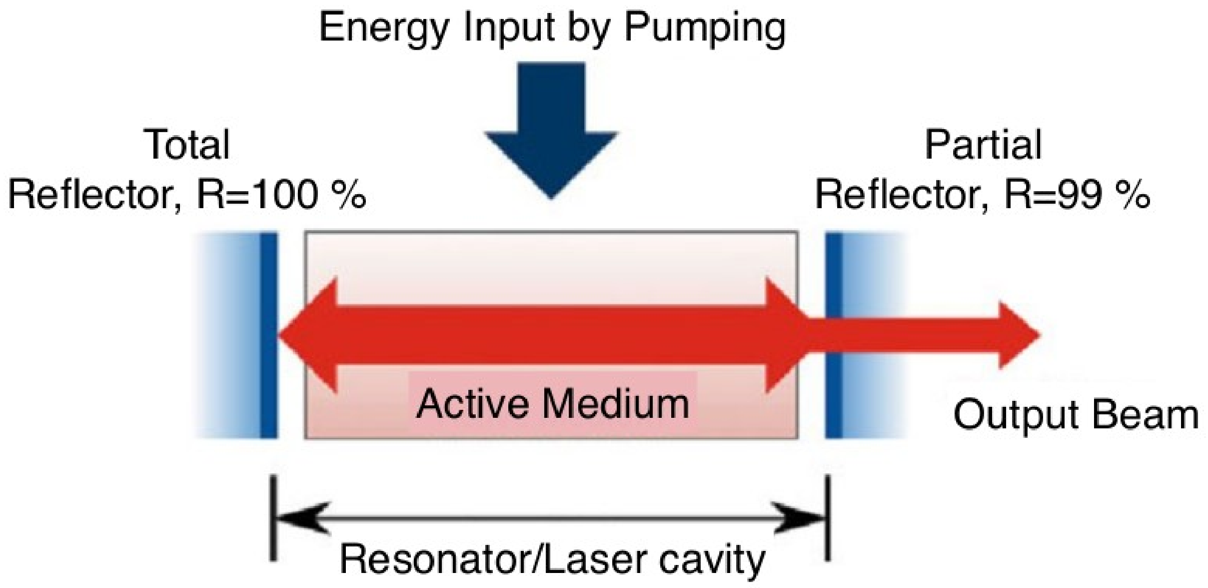
Types of Pumping

Optical Pumping: In this method, a strong **light source** such as gaseous discharge, flash lamp, or arc lamp is used. The light emitted from such sources excites atoms. This type of pumping is used in solid-state lasers like ruby laser and Nd-YAG laser. In a ruby laser, xenon flash lamp is used as a pumping source.

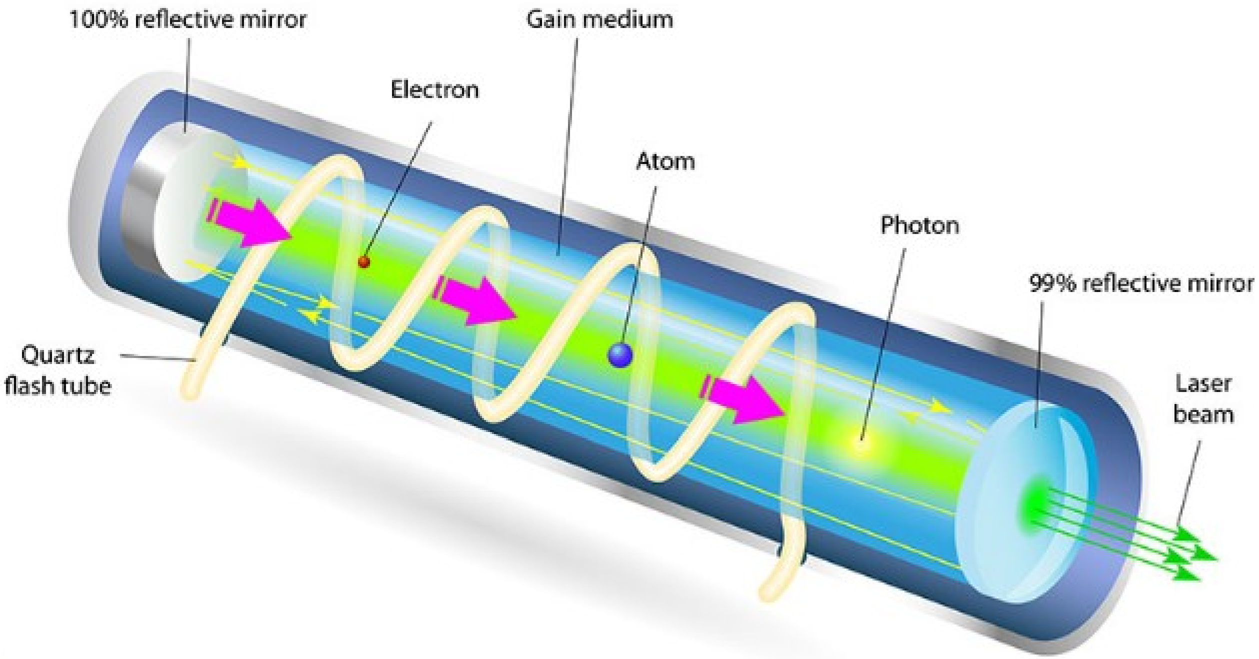
Electrical Pumping: In this method, electrons are produced in an **electrical discharge tube**. These electrons are accelerated to high velocities by a strong electrical field. These accelerated electrons collide with the gas atoms, and energy from the electrons is transferred to the gas atoms. This excites the atoms to higher energy levels. This method of pumping is used in gas lasers like argon and CO_2 Laser

Chemical pumping: In this process, population inversion is achieved by using a suitable chemical reaction. If an atom or a molecule is produced through some chemical reaction and remains in an excited state at the time of production, then it can be used for pumping. For example, in the reaction $A + B \longrightarrow AB^*$, where AB^* is the excited vibrational state of the AB molecule. The chemical pumping method is used in Hydrogen Fluoride and Deuterium Fluoride LASER

Components of Laser: Construction

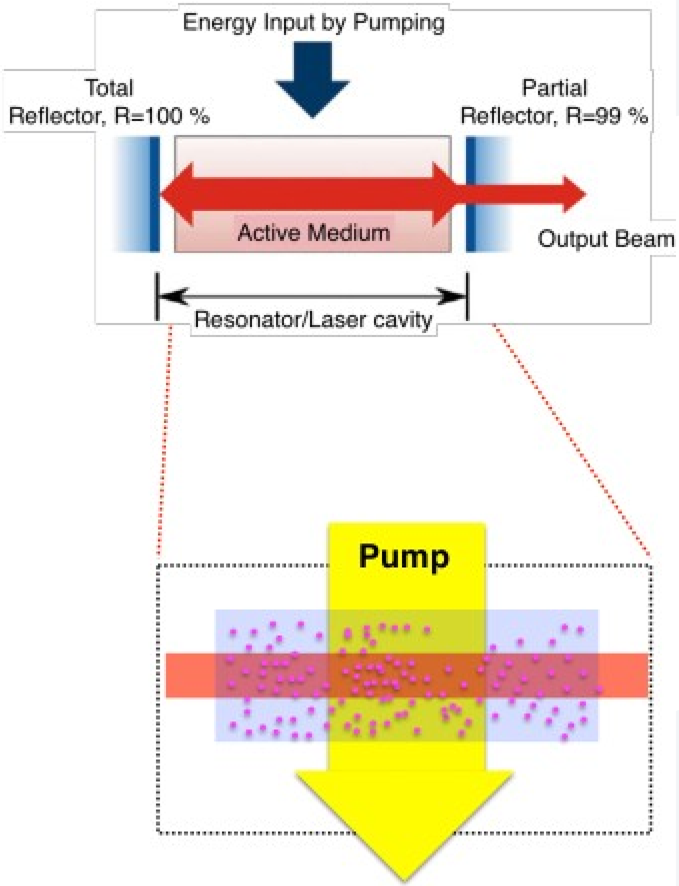


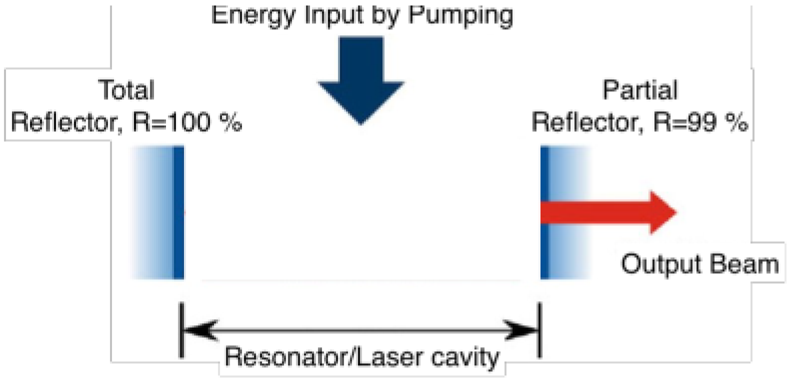
- **Active Medium (gain medium or lasing medium)**
- **Pumping energy source**
- **Resonance cavity (optical resonator)**



- **Active Medium (gain medium or lasing medium)**
- **Pumping energy source**
- **Resonance cavity (optical resonator)**

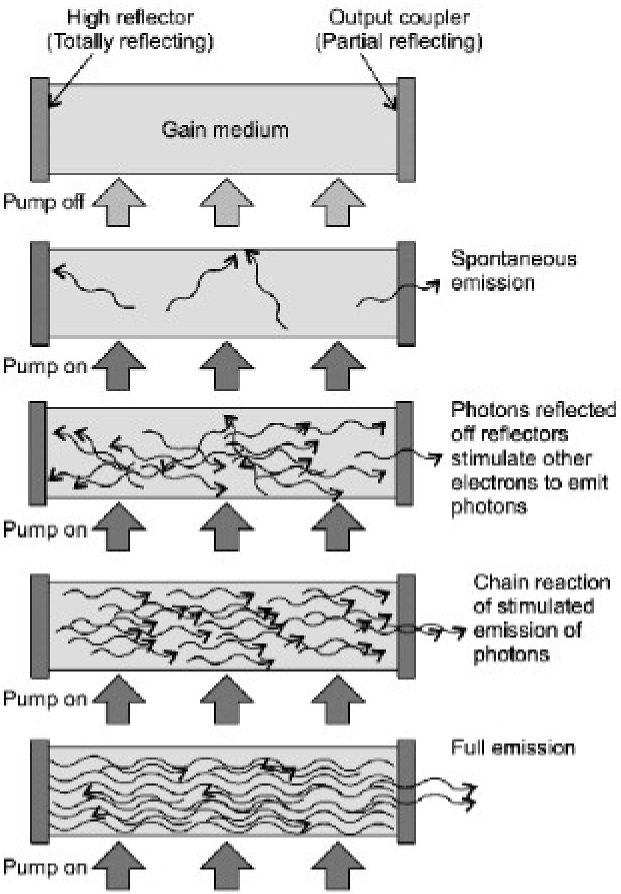
- It is the material in which the laser action takes place.
- Active medium contain a collection of atoms that can be excited state.
- Using external source (radiation, electrical or chemical), these atoms can be excited to higher energy level. The atoms later relax to a meta-stable state as a result **population inversion can be achieved in this medium**.
- The active medium may be solid crystals such as ruby or Nd:YAG, liquid dyes, gases like CO_2 or Helium / Neon, or semiconductors.

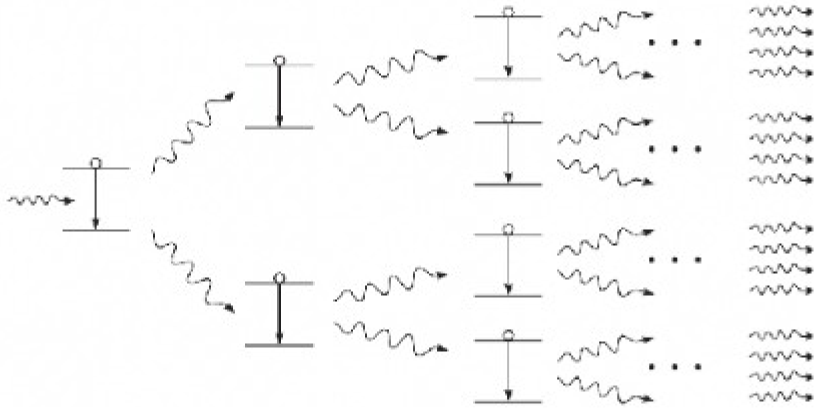




- It n simple words, it consists of two parallel mirrors placed around the gain medium.
- Among the two mirrors, one is highly reflective (100% reflective) and the other is partially transmissive (99% reflective).
- Light generated in the medium by spontaneous emission is reflected by the mirrors back into the medium, where it may is amplified by stimulated emission.
- The light may reflect from the mirrors and thus pass through the gain medium hundreds of times before exiting the cavity.
- The design and alignment of the mirrors with respect to the medium is crucial for determining the exact operating wavelength and other attributes of the laser system.

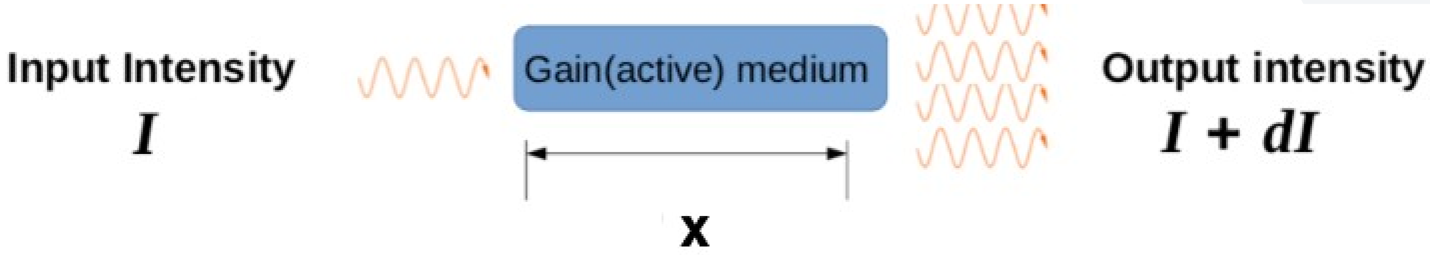
Generation of LASER





1. Pumping
2. Population Inversion
3. First few spontaneous emissions
4. Stimulated emission
5. Absorption of the off-axis photons
6. Back-and-forth oscillations of the photons in the laser cavity
7. The chain reaction of stimulated emission
8. Avalanche multiplication of the photon
9. Outburst of the laser through the partially reflecting mirror

Optical Gain / Gain Coefficient



The rate of change in intensity by the stimulated inversion is directly proportional to the difference between the no of atoms in the two energy levels, N_1 and N_2.

$$\Rightarrow \frac{dI}{dt} \propto N_2 - N_1 \Rightarrow \frac{dI}{dt} = I\,(N_2 B_{21} - N_1 B_{12}) h\nu$$

$$\Rightarrow I = I_0\, e^{\beta t}$$ This is the total stimulated Intensity at a given time t

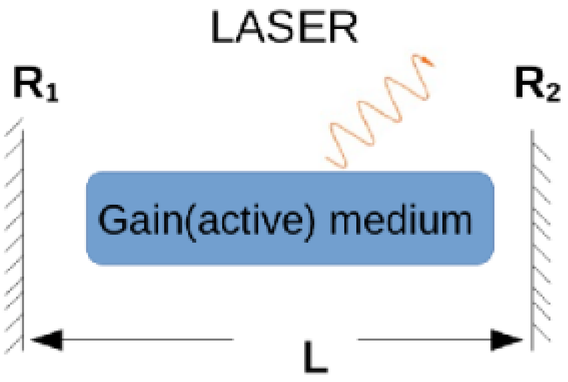
$$\Rightarrow I = I_0\, e^{\frac{\beta x}{c}} \Rightarrow I = I_0\, e^{\gamma x}$$

$$\gamma = (N_2 B_{21} - N_1 B_{12}) \frac{h\nu}{c} \Rightarrow \boxed{\gamma = (N_2 - N_1) \frac{Bh\nu}{c}}$$

optical gain or gain coefficient

$$\Rightarrow I = I_0 \, e^{\gamma x}$$

$$\Rightarrow \boxed{\gamma = (N_2 - N_1)\frac{B h\nu}{c}}$$



However, in practical, we have several sources of losses from the reflectivity error, Absorption of photon by other parts of cavity, Scattering, diffraction, non-radiative decays etc

$\Rightarrow$ If we couple all the losses and call them as α together with the losses from the mirror R1 and R2. Then the Intensity of the radiation after one complete round trip will be

$$\Rightarrow I = I_0 \, e^{(\gamma-\alpha)x} \times R_1 \, R_2 \qquad \Rightarrow I = I_0 \, R_1 \, R_2 \, e^{(\gamma-\alpha)x}$$

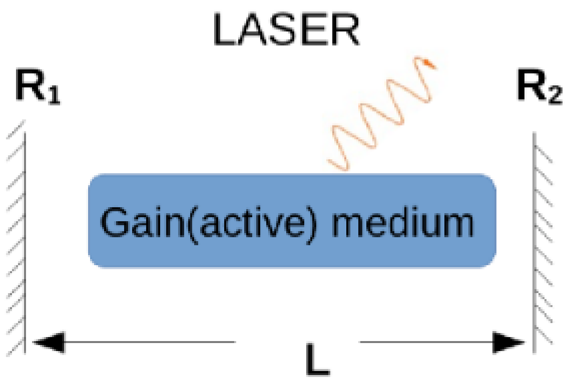
$$\Rightarrow I = I_0 \, R_1 \, R_2 \, e^{2(\gamma-\alpha)L} \qquad \Rightarrow \frac{I}{I_0} = R_1 \, R_2 \, e^{2(\gamma-\alpha)L}$$

$$\Rightarrow \frac{I}{I_0} = R_1 R_2 e^{2(\gamma-\alpha)L}$$

$$\Rightarrow G = \frac{I}{I_0} = R_1 R_2 e^{2(\gamma-\alpha)L}$$

G is the threshold gain of the medium:

- if G > 1 Laser will be there
- if G < 1 No lasing



in steady state condition, $I=I_0$

$$\Rightarrow R_1 R_2 e^{2(\gamma-\alpha)L} = 1$$

$$\boxed{\gamma_{th} = \alpha + \frac{1}{2L} ln(\frac{1}{R_1 R_2})}$$

is called **threshold gain coefficient**

Threshold gain coefficient is the gain required to just balance the total losses such as absorption and scattering in the gain medium, and transmission through the mirrors

So far, we have talked about:

Introduction to LASER

- Properties of Laser Light ✓
- Three basic processes ✓
  - Absorption
  - Spontaneous Emission
  - Stimulated Emission
- Main components of a Laser and Working principle
  - Population Inversion ✓
  - Pumping ✓
  - Light amplification in a laser ✓
  - Types of laser

Based on their gain medium/active Medium, lasers are broadly divided into four categories

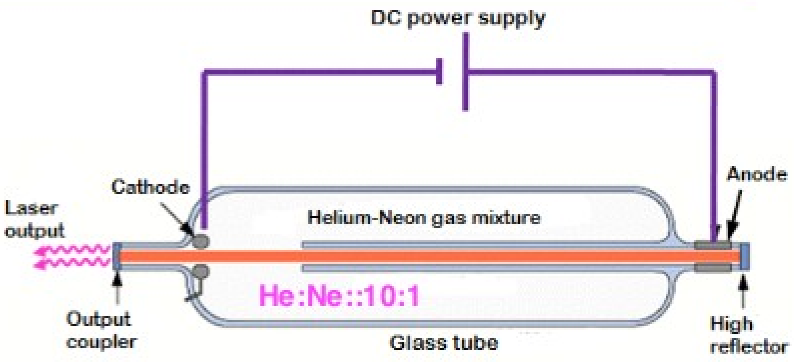
- Gas Lasers. ✓
- Solid-State Lasers. ✓
- Liquid Lasers (Dye Lasers) ✗
- Semiconductor Lasers (Laser Diodes) ✗

Solid State lasers	:	Ruby laser, Nd:YAG laser, Nd:Glass laser
Gas lasers	:	He-Ne laser, CO_2 laser, Argon laser
Liquid/Dye lasers	:	Polymethene dye, Courmarine dye, Rhodamine laser
Semiconductor laser	:	GaAs laser, InP laser

He-Ne LASER

Constructions:

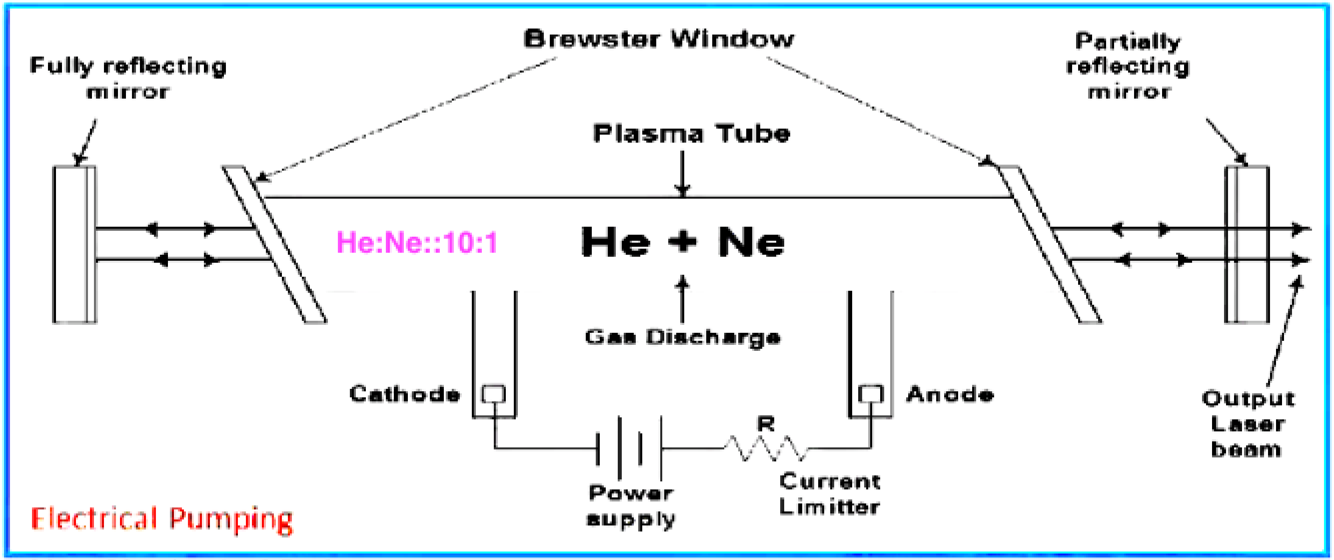
- The first continuous wave (CW) laser, was built-in 1961 by Ali Javan, Bennett, and Herriott at Bell Laboratories.
- Operates on electrical pumping method
- He-Ne mixture of gas as active medium
- Laser generals at of 632.8 nm (visible-Red)



The helium-neon laser consists of three essential components:

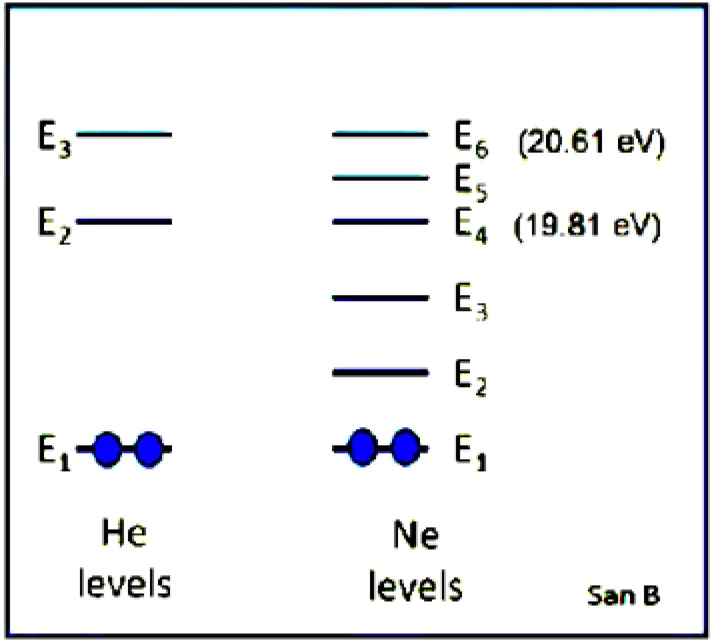
- **Pump source (high voltage power supply)**
- **Gain medium (laser glass tube or discharge glass tube)**
- **Resonating cavity**
- **High voltage power supply**

Working principle:

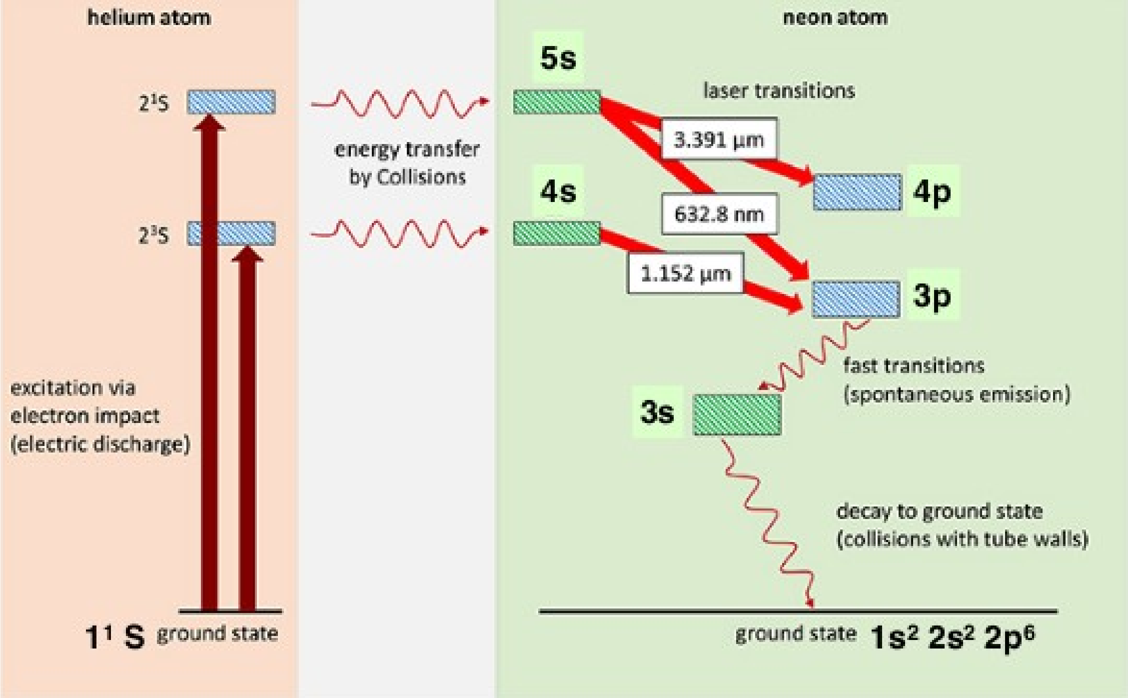


The partial pressure of helium is 1 mbar whereas that of neon is 0.1mbar. The population inversion is achieved by exciting Neon atoms. Only helium atoms help in exciting neon atoms. A high voltage of about 10 kV is applied to the mixture gas. Brewster windows are used to have polarised light. The glass tube is used to absorb the shorter/other wavelengths of photons that are generated in this process.

Role of Helium:



- The helium atoms are lighter. So more readily excitable than neon atoms.
- Helium atoms in excited energy levels E_2 and E_3 collide with the Neon atoms in the ground level. Neon atoms are excited to energy levels E_4 and E_6 and Helium atoms come back to the ground state.
- **The neon atoms are much heavier and could not be pumped efficiently without Helium atoms.**
- **The role of Helium atoms is to excite Neon atoms and cause population inversion.**



5s → 4p transition	Generates a laser beam of wavelength 33900 A^0 (3.39 µm)
5s → 3p transition	Generates a laser beam of wavelength 6328 A^0
4s → 3p transition	Generates a laser beam of wavelength 11500 A^0 (1.15 µm)

Advantages of Helium-Neon laser:

- Helium-neon laser emits laser light in the visible portion of the spectrum.
- High stability-No extra cold system required
- Low-cost
- Operates without damage at higher temperatures.

Disadvantages of Helium-Neon laser:

- Low efficiency
- Low-gain
- Helium-neon lasers are limited to low-power tasks

Applications of Helium-Neon laser:

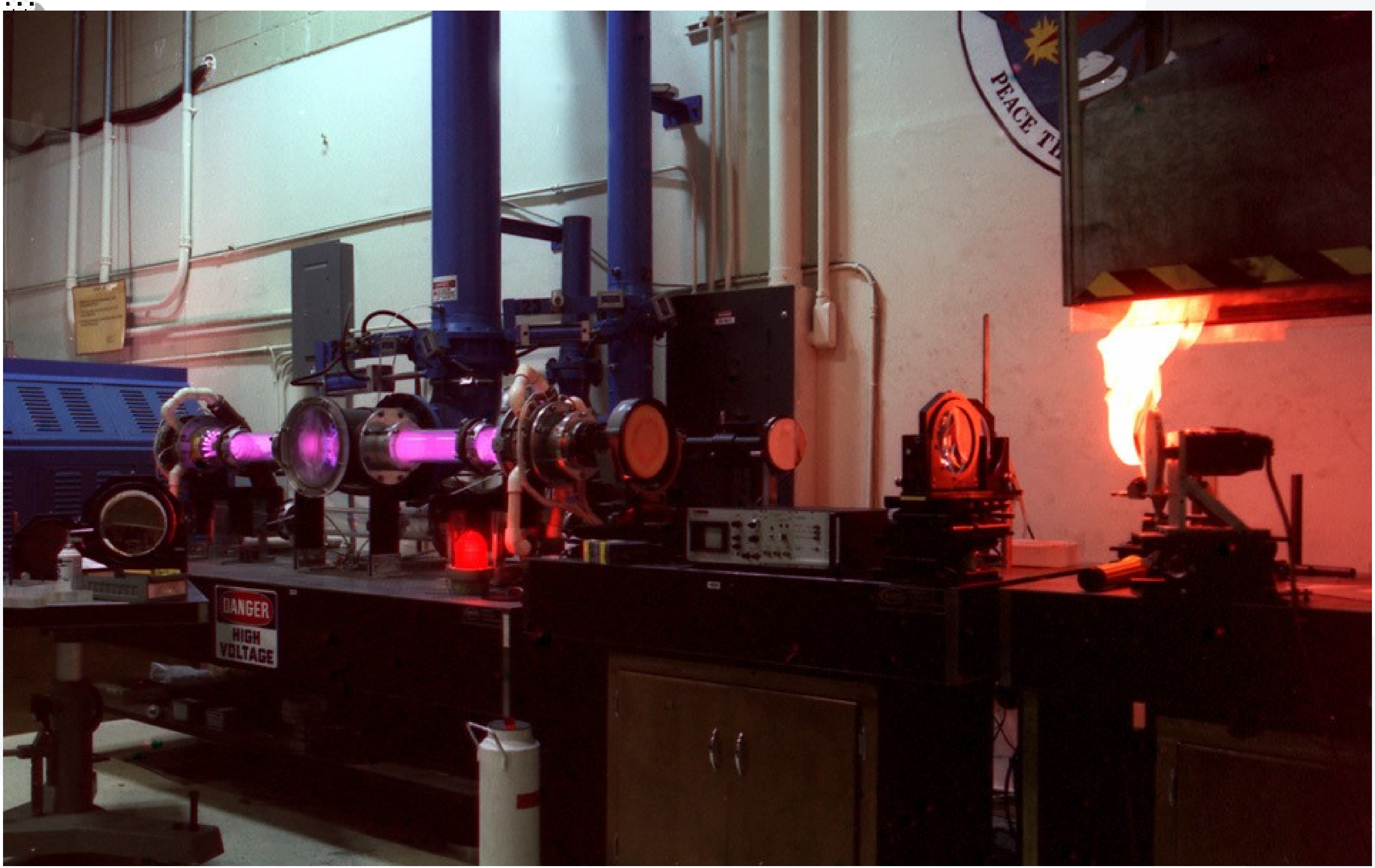
- Helium-neon lasers are used in industries.
- Helium-neon lasers are used in scientific instruments.
- Helium-neon lasers are used in college/university laboratories.

Module – 5

CO_2 LASERS

Cont'd...

Dr. Pankaj Sheoran
SAS


PEACE
DANGER
HIGH VOLTAGE

CO_2 LASER

- It is a **molecular gas laser**.
- It was **invented** by **Chandra Kumar Naranbhai Patel** of Bell Labs in 1964.
- The **output** of this laser is **continuous**.
- The **transition takes place between the vibrational states of** CO_2 **molecules.**
- It is a **four level laser** and it **operates at 10.6 µm** in the far **IR region.**

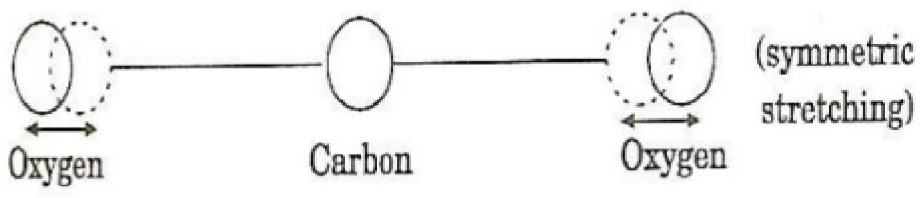
C. K. N. Patel

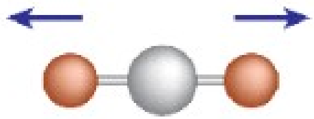
Born	2 July 1938 (age 84) Baramati, Bombay Presidency, British India
Nationality	Indian/American
Alma mater	College of Engineering, Pune (B.E.) Stanford University (M.S.) Stanford University (PhD)
Awards	Stuart Ballantine Medal (1968) IEEE Medal of Honor (1989)
	Scientific career
Fields	Electrical engineering
Institutions	University of California, Los Angeles

CO_2 Molecule

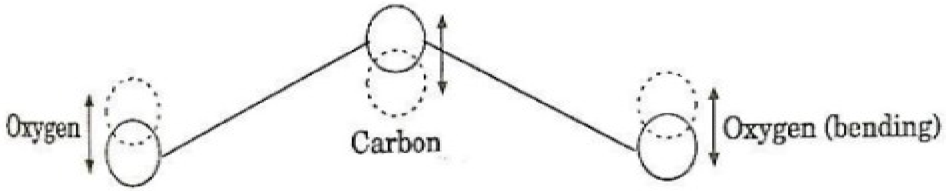
A carbon dioxide molecule has a carbon atom at the center with two oxygen atoms attached, one at both sides. Such a molecule exhibits three independent modes of vibrations. They are

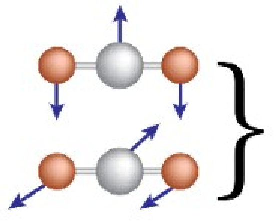
- **Symmetric stretching mode:** In this mode of vibration, carbon atoms are at rest and both oxygen atoms vibrate simultaneously along the axis of the molecule departing or approaching the fixed carbon atoms.



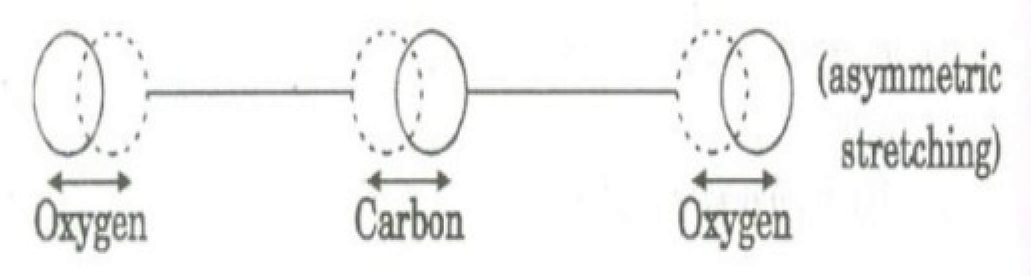


- **Bending mode:** In this mode of vibration, oxygen atoms and carbon atoms vibrate perpendicular to molecular axis.



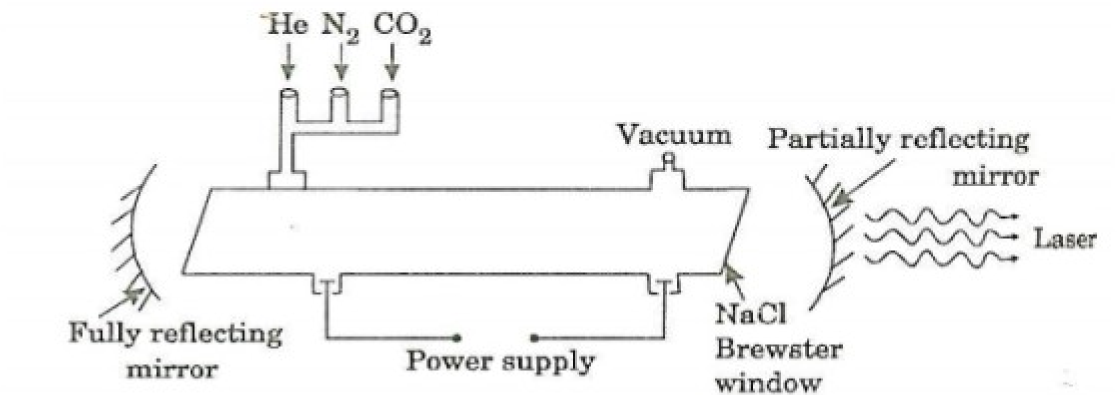


- **Asymmetric stretching mode:** In this mode of vibration, oxygen atoms and carbon atoms vibrate asymmetrically, i.e., oxygen atoms move in one direction while carbon atoms in the other direction.



Principle:

The **active medium is a gas mixture of CO2, N2 and He**. The *laser transition takes place between the vibrational states of CO2molecules*.



Construction:

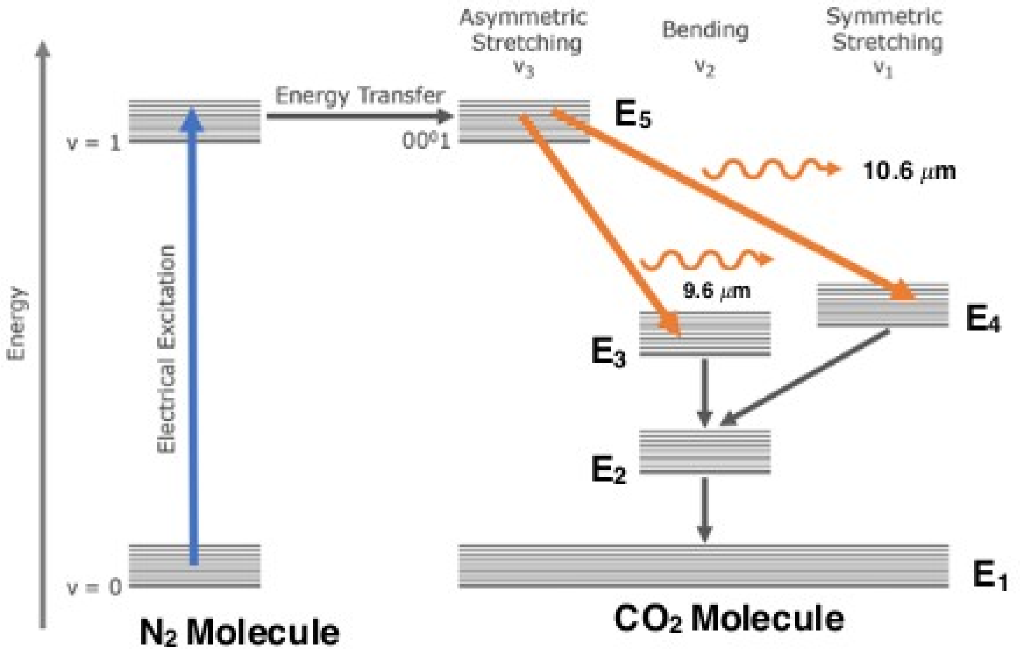
- It consists of a quartz tube 5 m long and 2.5 cm in the diameter. This discharge tube is filled with gaseous mixture of CO2(active medium), helium and nitrogen with suitable partial pressures.
- The terminals of the discharge tubes are connected to a D.C power supply. The ends of the discharge tube are fitted with NaCl Brewster windows so that the laser light generated will be polarized.
- Two concave mirrors one fully reflecting and the other partially form an optical resonator.

Working Principle:

$$N_2 + e^* = N_2^* + e$$

$$\downarrow$$

$$N_2^* + CO_2 = CO_2^* + N_2$$



Transition E5 to E4 :

- This will produce a laser beam of wavelength 10.6 μm

Transition E5 to E3

- This transition will produce a laser beam of wavelength 9.6μm.
- Normally 10.6 μm transition is more intense than a 9.6 μm transition.
- The power output from this laser is 10kW.

Characteristics:

1. **Type:** It is a molecular gas laser.
2. **Active medium:** A mixture of CO_2 , N_2 and helium or water vapour is used as active medium
3. **Pumping method:** Electrical discharge method is used for Pumping action
4. **Optical resonator:** Two concave mirrors form a resonant cavity
5. **Power output:** The power output from this laser is about 10kW.
6. **Nature of output:** The nature of output may be continuous wave or pulsed wave.
7. **Wavelength of output:** The wavelength of output is 0.6μm and 10.6μm.

Advantages:

1. The construction of CO_2 laser is simple
2. The output of this laser is continuous.
3. It has high efficiency
4. It has very high output power.
5. The output power can be increased by extending the length of the gas tube.

Disadvantages:

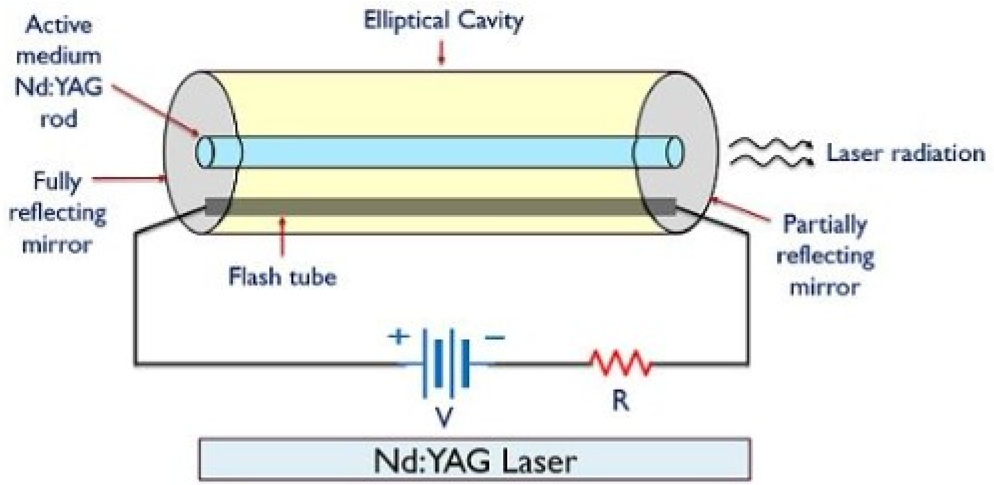
1. The contamination of oxygen by carbon monoxide will have some effect on laser action
2. The operating temperature plays an important role in determining the output power of laser.
3. The corrosion may occur at the reflecting plates.
4. Accidental exposure may damage our eyes, since it is invisible (infra red region) to our eyes.

Applications:

1. High power CO2 laser finds applications in material processing, welding, drilling, cutting soldering etc.
2. The low atmospheric attenuation (10.6μm makes CO2 laser suitable for open air communication.
3. It is used for remote sensing
4. It is used for treatment of liver and lung diseases.
5. It is mostly used in neuro surgery and general surgery.
6. It is used to perform microsurgery and bloodless operations.

Nd: YAG laser

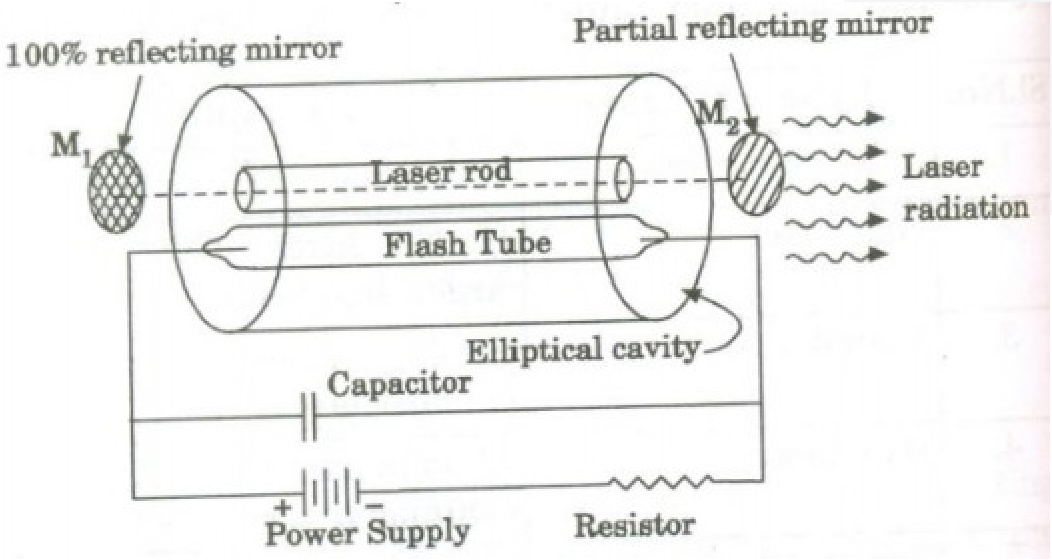
- Nd: YAG laser is a **neodymium based laser**. **Nd stands for Neodymium** (rare earth element) and **YAG stands for Yttrium Aluminum Garnet** (Y3Al5 O12) .
- It is a **four level solid state laser**.



Principle:

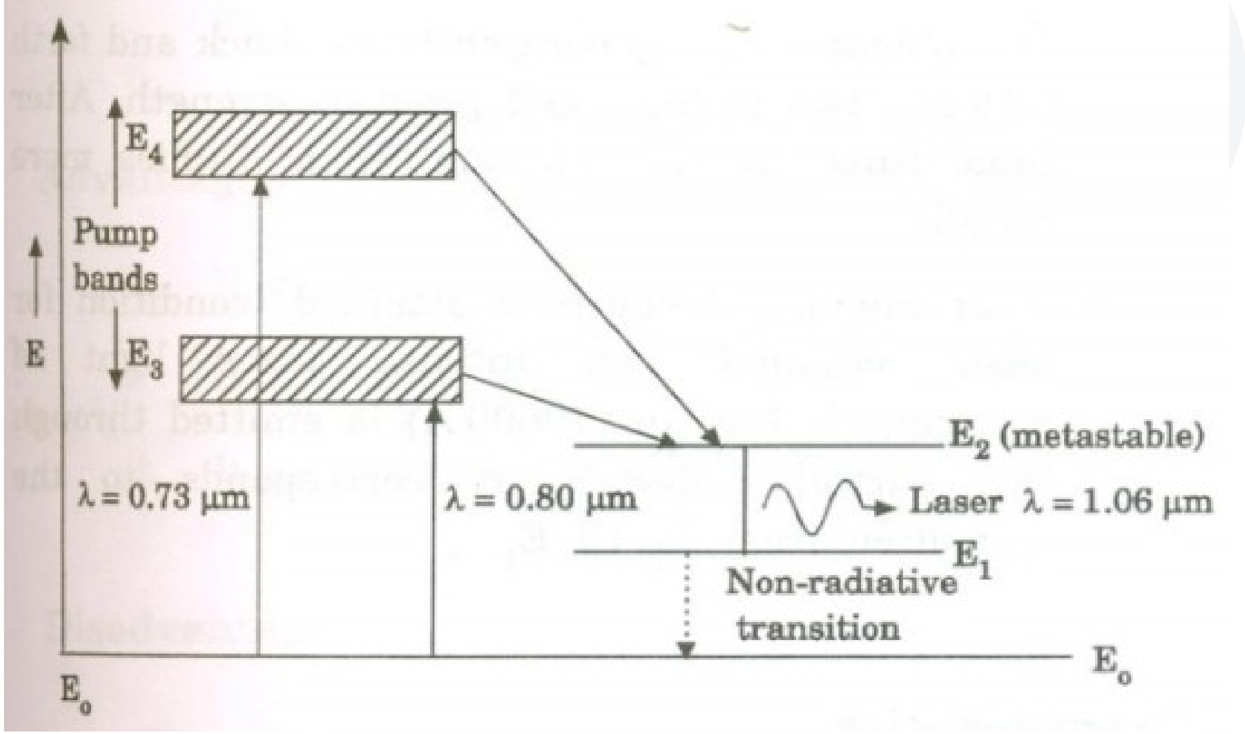
- The active medium Nd: YAG rod is optically pumped by Krypton flash tubes.
- The Neodymium ions (Nd^{3+}) are raised to excited levels.
- During the transition from meta stable state to ground state, a laser beam of wavelength 1.064μm is emitted.

Construction:



- A small amount of Yttrium ions (Y3+) is replaced by Neodymium (Nd3+) in the active element of Nd: YAG crystal.
- This active element is cut into a cylindrical rod.
- The ends of the cylindrical rod are highly polished and they are made optically flat and parallel.
- This cylindrical rod (laser rod) and a pumping source (flash tube) are placed inside a highly (reflecting) elliptical reflector cavity.
- The optical resonator is formed by using two external reflecting mirrors. One mirror (M1) is 100% reflecting, while the other mirror (M2) is partially reflecting.

Working Principle:



- When the krypton flash lamp is switched on, by the absorption of light radiation of wavelength 0.73μm and 0.8μm, the Neodymium(Nd3+) atoms are raised from ground level E0 to upper levels E3and E4 (Pump bands).
- The Neodymium ions atoms make a transition from these energy levels E2 by non-radiative transition. E2 is a metastable state.
- The Neodymium ions are collected in the level E2 and the population inversion is achieved between E2 and E1.
- An ion makes a spontaneous transition from E2 to E1, emitting a photon of energy $h\nu$. This emitted photon will trigger a chain of stimulated photons between E2 and E1.
- The photons thus generated travel back and forth between two mirrors and grow in strength. After some time, the photon number multiplies more rapidly.

- After enough strength is attained (condition for laser being satisfied), an intense laser light of wavelength 1.06μm is emitted through the partial reflector. It corresponds to the transition from E2to E1.

Characteristics:

1. **Type:** It is a four level solid state laser.
2. **Active medium:** The active medium is Nd: YAG laser.
3. **Pumping method:** Optical pumping is employed for pumping action.
4. **Pumping source:** Xenon or Krypton flash tube is used as pumping source.
5. **Optical resonator:** Two ends of Nd: YAG rod is polished with silver (one end is fully silvered and the other is partially silvered) are used as optical resonator.
6. **Power output:** The power output is approximately 70 watt.
7. **Nature of output:** The nature of output is pulsed or continuous beam of light.
8. **Wavelength of the output:** The wavelength of the output beam is 1.06μm(infra-red).

Advantages:

1. It has high energy output.
2. It has very high repetition rate operation
3. It is much easy to achieve population inversion.

Disadvantages:

The electron energy level structure of Nd^{3+} in YAG is complicated.

Applications:

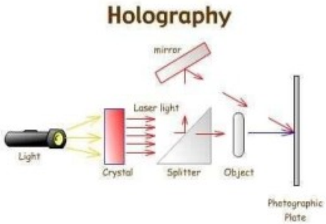
1. It finds many applications in range finders and illuminators.
2. It is widely used in engineering applications such as resistor, trimming scribing, micro machining operations as well as welding, drilling etc.
3. It finds many medical applications such as endoscopy, urology, neurosurgery, ENT, gynecology, dermatology, dental surgery and general surgery.

Application of Laser in Engineering

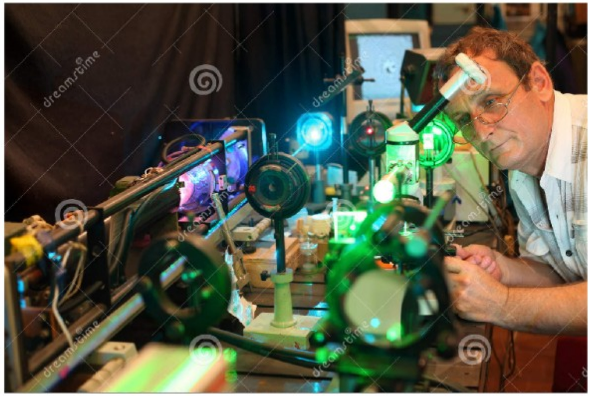
In Military.

Laser communication:

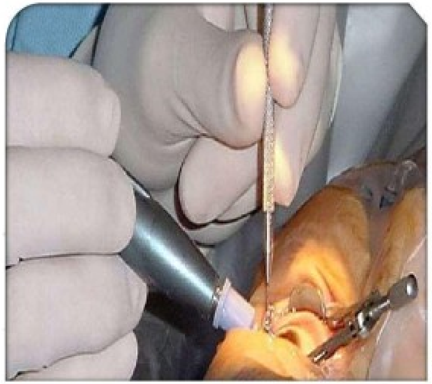
Data Storage

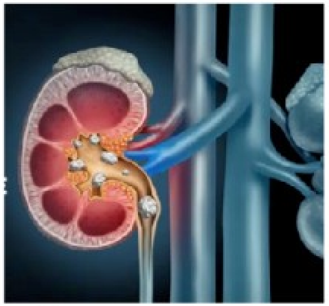


In Scientific Research and Development



IN MEDICAL:





Kidney stone breaking

IN INDUSTRY:

WELDING & CUTTING OF METAL