

LASER

**Light Amplification by Stimulated
Emission of radiation**

□ Introduction to LASER

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

History

- **LASER**

“Light Amplification by Stimulated Emission of Radiation”

- **MASER (1939 Townes)**

“Microwave Amplification by Stimulated Emission of Radiation”

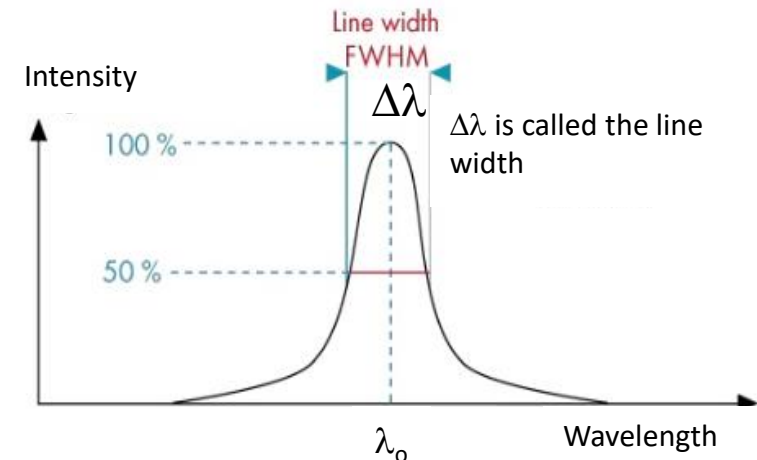
- **Stimulated Emission - Einstein in 1917.**
- **Ruby Crystal LASER - Maiman, California in 1960.**
- **He-Ne LASER - Ali Javan in 1961.**
- **Diode LASER- Hall in 1962.**

□ Characteristics or Properties of Laser Light

- **Monochromaticity**
- **Coherence**
- **Directionality**
- **Intensity**

□ Monochromaticity (Spectral purity)

- No Light source, ordinary or laser emits radiation of absolutely single frequency or wavelength. In other words, no light source is absolutely monochromatic as the energy levels of atoms are not discrete lines.
- In reality energy levels have a finite width ΔE that is a result of interaction of atom with its environment
- A typical value of width of an energy level is $\sim 10^{-7}$ eV
- Due to this fact, every source, even a laser emits light of certain line width, $\Delta\lambda$ (or band width, $\Delta\nu$) at a central wavelength of λ_o (or central frequency ν). So monochromaticity is a relative term.
- **The ratio of central wavelength, λ_o to line width, $\Delta\lambda$ is called degree of monochromaticity.**



i.e. $\text{Monochromaticity} = \frac{\lambda_o}{\Delta\lambda} \dots\dots\dots(1)$

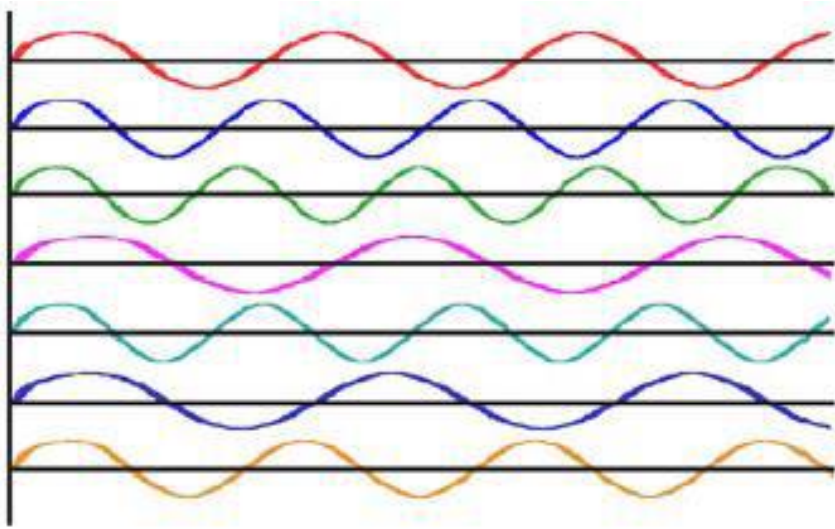
We know that $\lambda = c/\nu$, on differentiating,

we get, $\Delta\lambda = -\frac{c}{\nu^2} \Delta\nu$

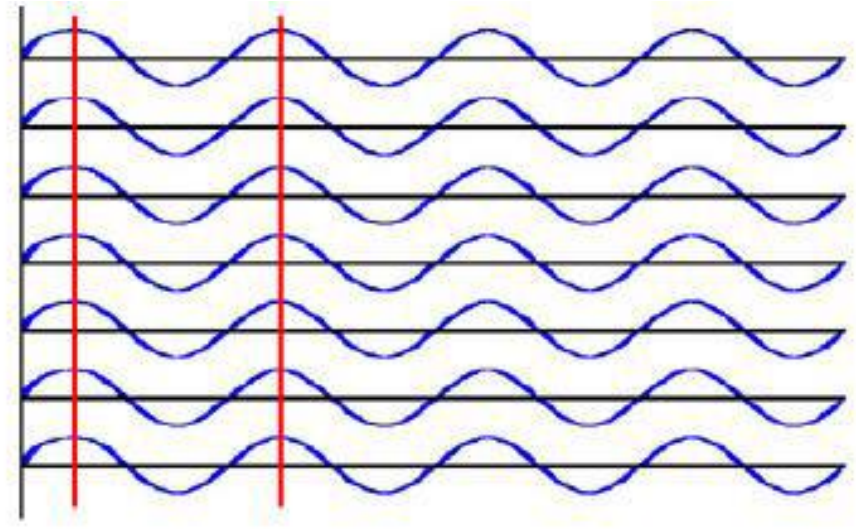
On putting value of $\Delta\lambda$ and λ in equation (1)

we get, $\text{Monochromaticity} = \frac{\nu}{\Delta\nu}$

□ Coherence



Incoherent light waves

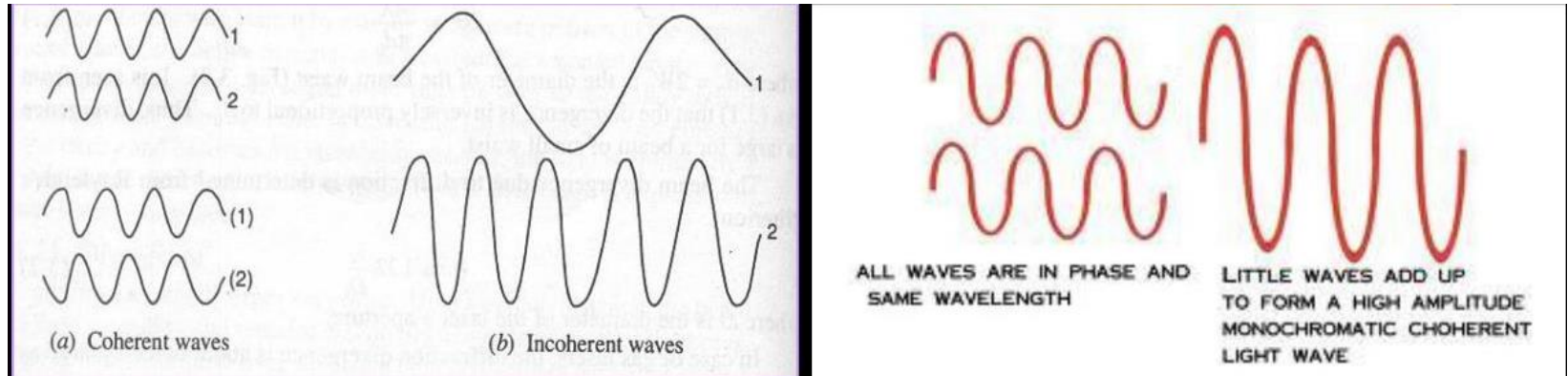


Coherent light waves

- **Laser light is a resultant of number of identical photons which are in phase, hence exhibiting higher degree of coherence**

Coherence

- Light waves are coherent if they are in phase with each other.
- Maintain crest to crest and trough to trough correspondence



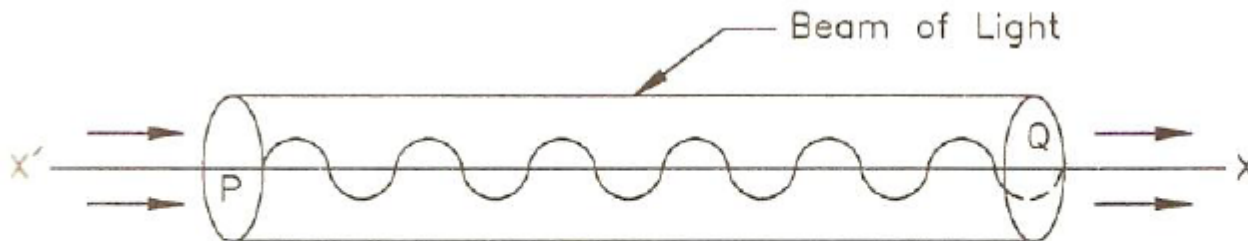
Two conditions necessary for coherence:

- They must start with the same phase at same position
- Wavelengths must be same otherwise they will drift out of phase, crest of higher frequency wave will arrive ahead of the crests of lower frequency wave

Two classes of coherence:

Temporal coherence:

- Temporal coherence is a measure of the correlation between the phases of a light wave at different points along the direction of propagation. Temporal coherence tells us how monochromatic a source is.
- If the phase difference measured at a single point in space at beginning and end of a time interval Δt remain predictable and constant, then waves are said to have temporal coherence in the time interval.
- The maximum value of the time interval in which waves maintain constant and have predictable phase difference is known as coherence time, τ_c . Greater is τ_c , higher are the waves temporally coherent



The beam is said to possess temporal coherence if the phase difference of the waves crossing P and Q at any instant remains constant

- The temporal coherence also refers to the relative phase or coherence of waves at two separate locations along the direction of propagation of the waves.
- The maximum separation between two points along the direction of propagation of waves which maintain constant phase difference is known as temporal coherence length, L_c

Thus,

$$L_c = c \tau_c$$

where c is velocity of light.

- Coherence time, τ_c is reciprocal of band width, $\Delta\nu$

Therefore,

$$L_c = c / \Delta\nu$$

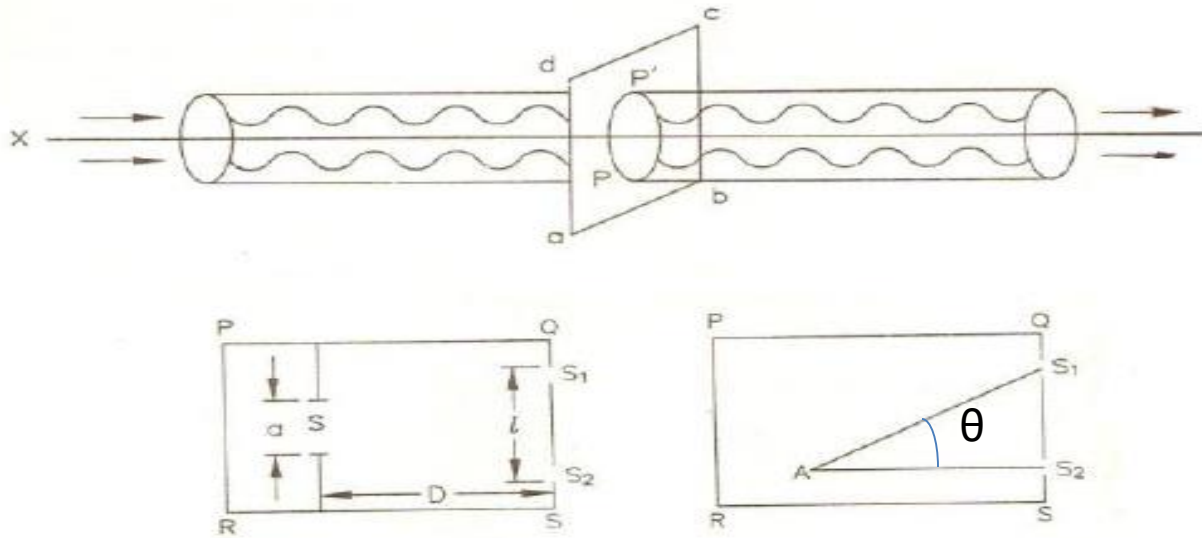
- In terms of line width, $\Delta\lambda$ and wavelength, λ ,

Coherence length,

$$L_c = \lambda^2 / \Delta\lambda$$

□ Spatial Coherence

- Light is said to possess spatial coherence if the phase difference of the waves crossing the two points lying on a plane perpendicular to the direction of propagation of the beam is time-independent.
- This type of coherence is also called as transverse or lateral coherence. It is measure of minimum separation across the wave from where two waves remain coherent.
- Spatial coherence describes the ability for two points in space, in the extent of a wave to interfere, when averaged over time.
- More precisely, the spatial coherence is the cross correlation between two points in a wave for all times.
- If a wave has only one value of amplitude over an infinite length, it is perfectly spatially coherent.



The beam is said to possess spatial coherence if the phase difference of the waves crossing P and P' at any instant remains constant

- In the figure, S is a source and S_1 and S_2 are two slits of separation, l . If interference occurs for $l_{max} = l_w$, then this separation, l_w between sources S_1 and S_2 is called the spatial coherence length of the source.

The condition for coherence of S_1 and S_2 is

$$\frac{\lambda}{a} > \frac{l}{D} \quad \text{or} \quad l < \frac{\lambda}{a/D}$$

Since, $\frac{a}{D} = \theta$, angle subtended by width of slit S . Thus, we get

$$l_w = \frac{\lambda}{\theta}$$

□ Directionality

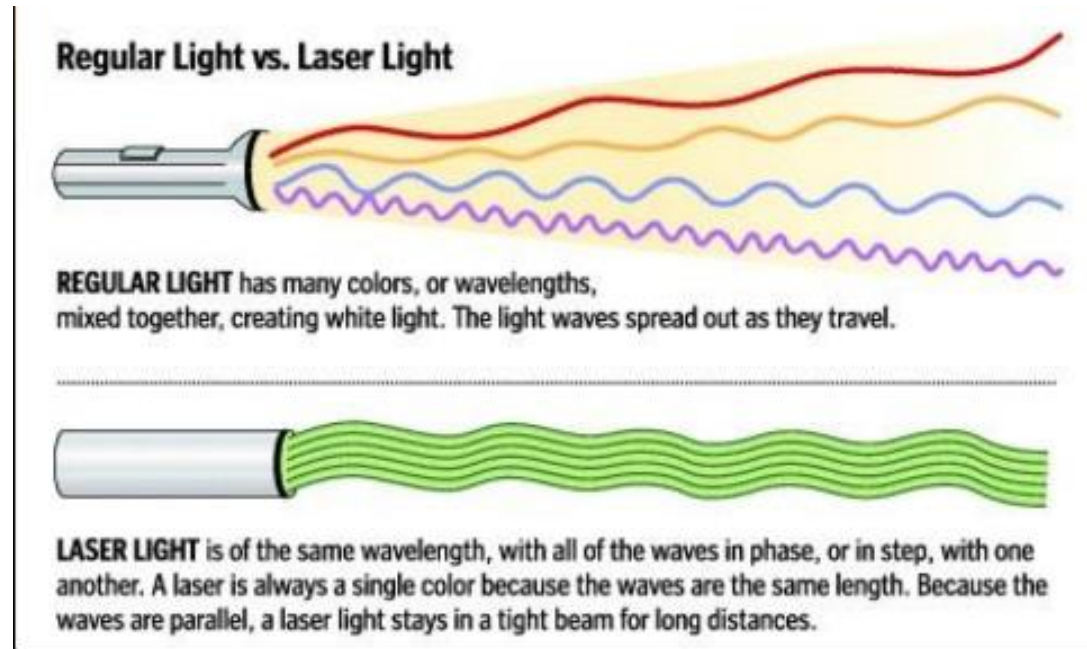
- Conventional light sources emit light in all the directions
- Laser emit light only in one direction(along cavity axis)

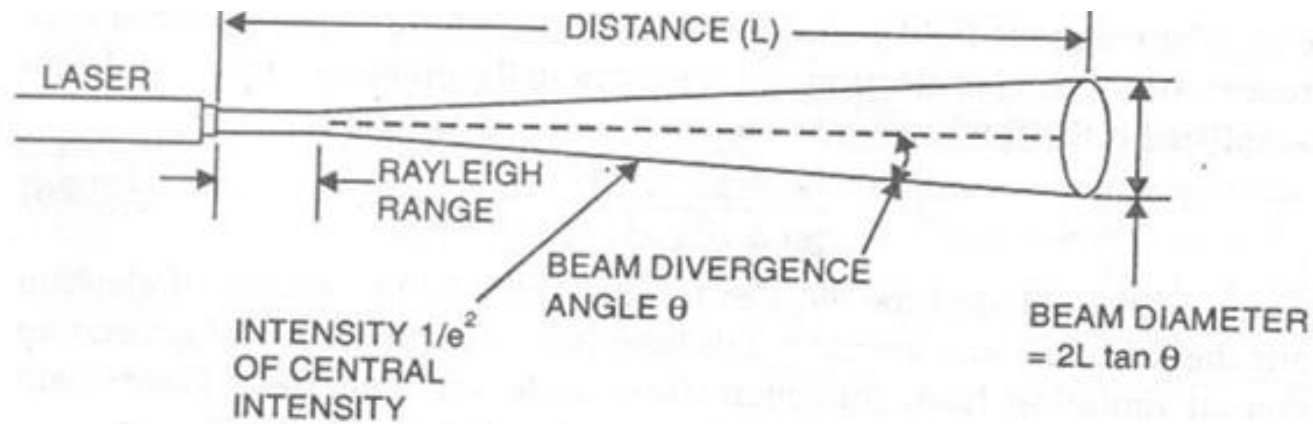
➤ **Directionality of a laser beam is expressed in terms of ⇒**

“Beam divergence”

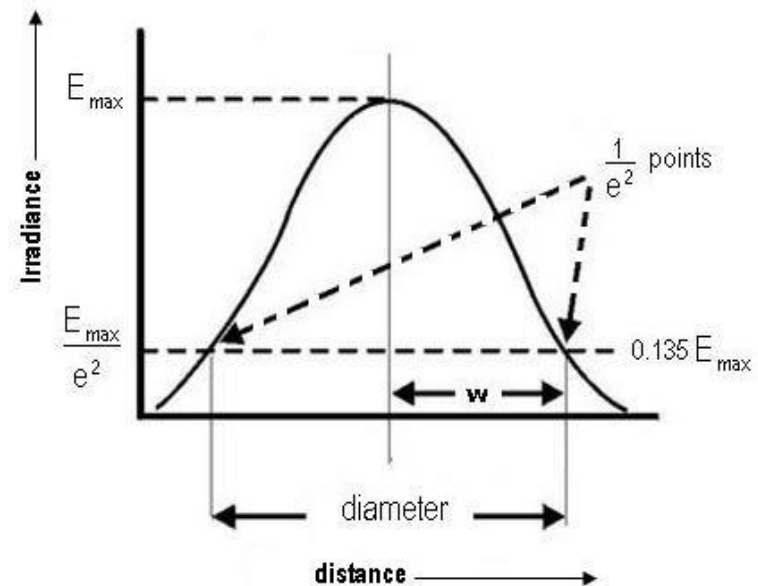
Beam Divergence:

- Light beam from a laser diverges very little
- Up to certain distance, beam remains a bundle of parallel rays; distance from the laser over which the light rays remain parallel is called ⇒ **“Rayleigh range”**
- The laser beam diverges beyond **Rayleigh range**.





- Divergence angle is measured from the center of the beam to the edge of the beam
 - Edge: Location in the beam where intensity decrease to $1/e^2$ of that at the center
- Twice the angle of divergence is known as **full angle beam divergence** $\Rightarrow$
 - $\Rightarrow$ measure of how much the beam will spread as it travels through the space



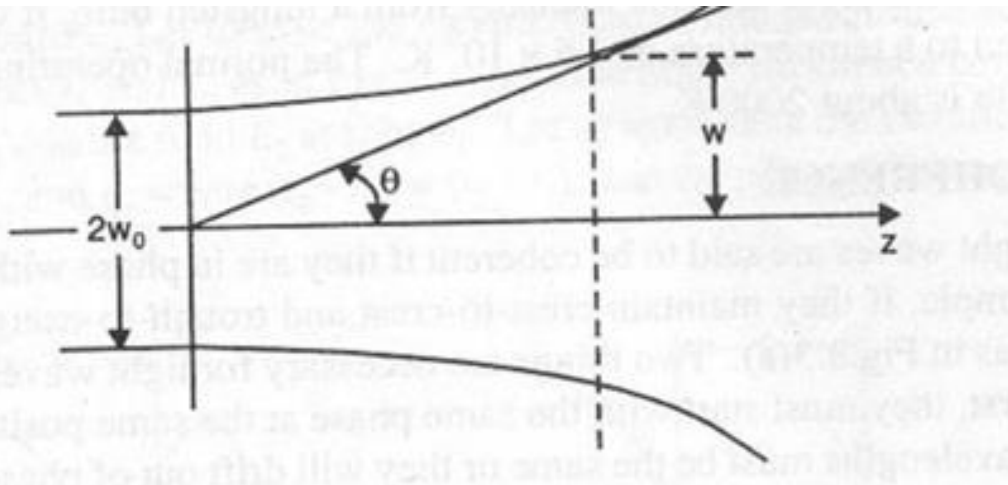
Two parameters which cause the beam divergence:

1. Size of the beam waist
2. Diffraction

Full angle beam divergence is given by

$$2\theta = \frac{4\lambda}{\pi d_0}$$

Where $d_0 = 2w_0$ is the diameter of the beam



- Divergence is inversely proportional to ' d_0 '
- Large for a beam of small beam waist

Beam waist and divergence of laser beam

Intensity

- An ordinary source of light (assuming a spherical wave front) follows inverse square law for intensity and its intensity is given by

$$I = \frac{P}{4\pi r^2}$$

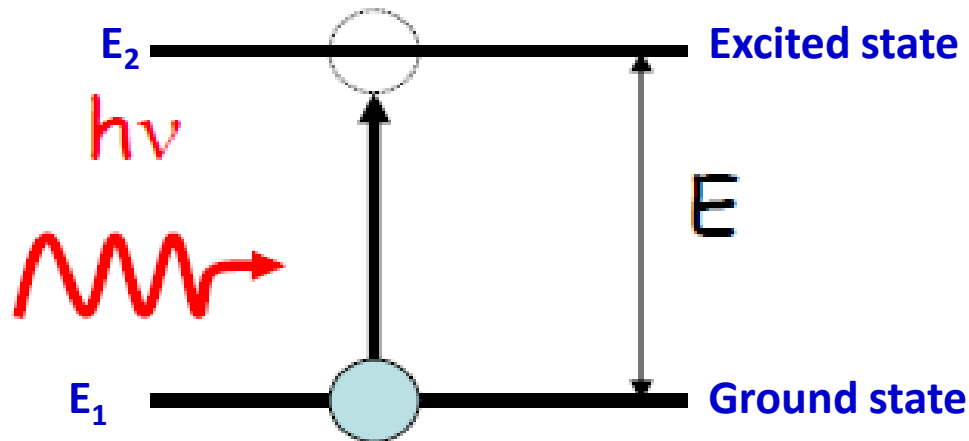
- Where P is the power of the source and r is the distance of the observation point from the source.
- For a Laser, Intensity is calculated by dividing power of the laser beam with the area of laser spot in terms of the diameter or radius of the spot.
- E.g. to find the intensity of a laser beam of 10 mW power and having a beam diameter of 1.3 mm, we use the formula

$$I = \frac{P}{A}$$

Where A is the area of laser beam spot which is given by πr^2 or $\pi d^2/4$ in this case. Thus Intensity of the beam will be 7.5 kW/m²

□ Stimulated Absorption

absorption

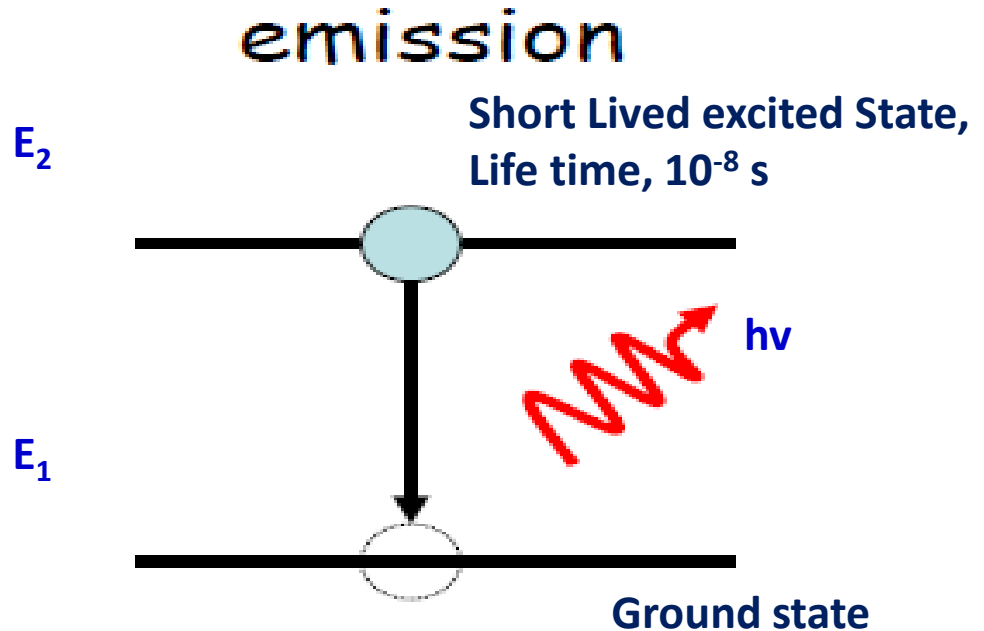


- E_1 = Ground state
- E_2 = Excited State
- $E = h\nu$ (Photon Energy)

- According to Bohr's atomic model, atomic system is characterized by discrete energy level.
- When atoms absorb or release energy it transit upward or downward.
- Lower level E_1 & Excited level E_2
- So, $h\nu = E_2 - E_1$
- The rate of absorption depends on no. of atoms N_1 present in E_1 & spectral energy density $u(\nu)$ of radiation
- So, $P_{12} \propto N_1 u(\nu)$
- $P_{12} = B_{12} N_1 u(\nu)$

□ Spontaneous Emission

- E_1 = Ground State
- E_2 = Excited State
- $E = E_2 - E_1$
= ΔE
= $h\nu$



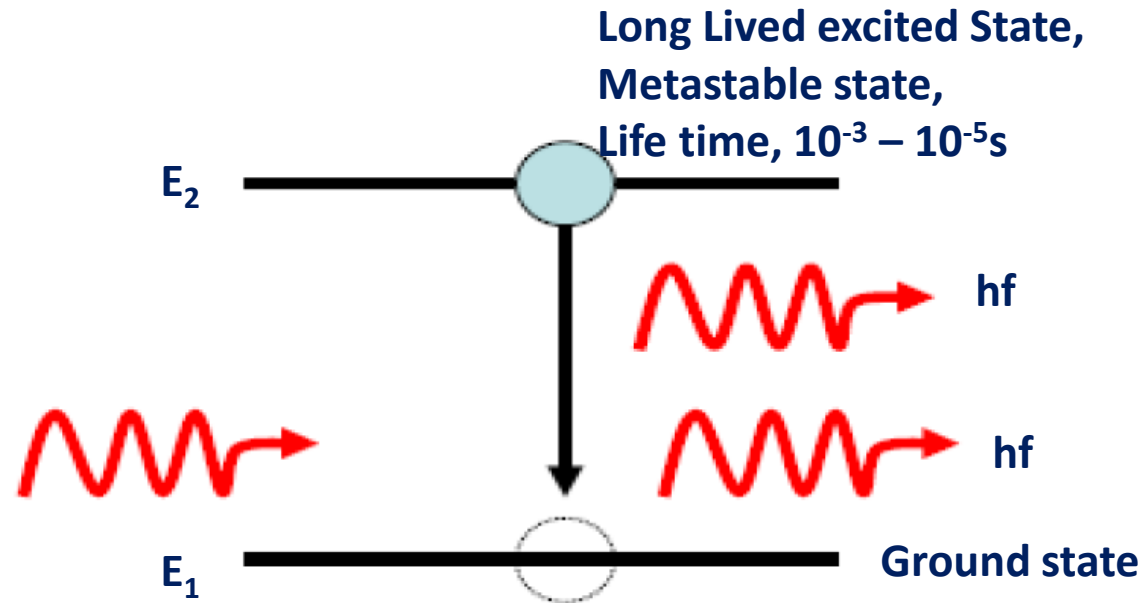
- System having atoms in excited state.
- Goes to downward transition with emitting photons, $h\nu = E_1 - E_2$.
- Emission is random, so if not in same phase becomes incoherent.
- The transition depends on atoms in excited state N_2 .

$$P_{21(\text{spont})} \propto N_2 = A_{21} N_2$$

- Where, A_{21} = Einstein coefficient for spontaneous Emission. we get Incoherent radiation due to spontaneous emission.

□ Stimulated Emission

Stimulated emission



E_1 = Ground State

E_2 = Excited State

$$E = E_2 - E_1$$

$$= \Delta E$$

$$= hf$$

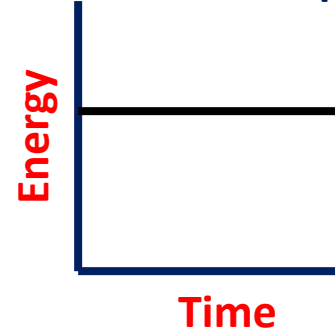
- System having atoms in excited state.
- Downward transition of atoms with emission of photons.
- $2h\nu = E_1 - E_2$. After applying photon energy $h\nu$.
- Emission depends on energy density $u(\nu)$ & No. of atoms in excited state N_2
- $P_{21(\text{stimul})} \propto u(\nu) N_2 = B_{21} N_2 u(\nu)$
- Where, B_{21} = Einstein coefficient for Stimulated Emission.
- Thus one photon of energy $h\nu$ produces two photons of energy $h\nu$ in same phase & direction. So, we get coherent light amplification of radiation by stimulated emission.

Types of Lasers

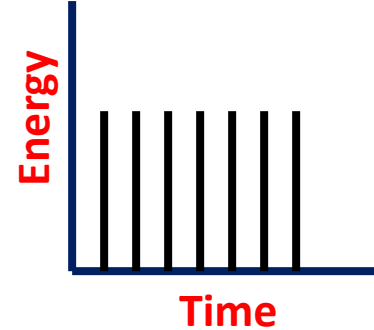
Basis of the operation mode

- Continuous wave Lasers(CW)
- Pulsed Lasers(P)

Continuous output



Pulsed output



According to their wavelength

- Visible Region, Infrared Region, Ultraviolet Region, Microwave Region.

According to the Lasing/Active medium/source

- Dye Lasers, Gas Lasers, Chemical Lasers, Metal vapor Lasers, Solid state Lasers, Semi conductor Lasers

Essential components of a laser:

1. Active medium or Gain medium : It is the medium in which population inversion and hence stimulated emission (laser action) is established. It can be a gas, a solid or a liquid.



2. Pumping mechanism : Mechanism of exciting atoms from the lower energy state to a higher energy state by supplying energy from an external source.

Different Pumping Mechanisms:

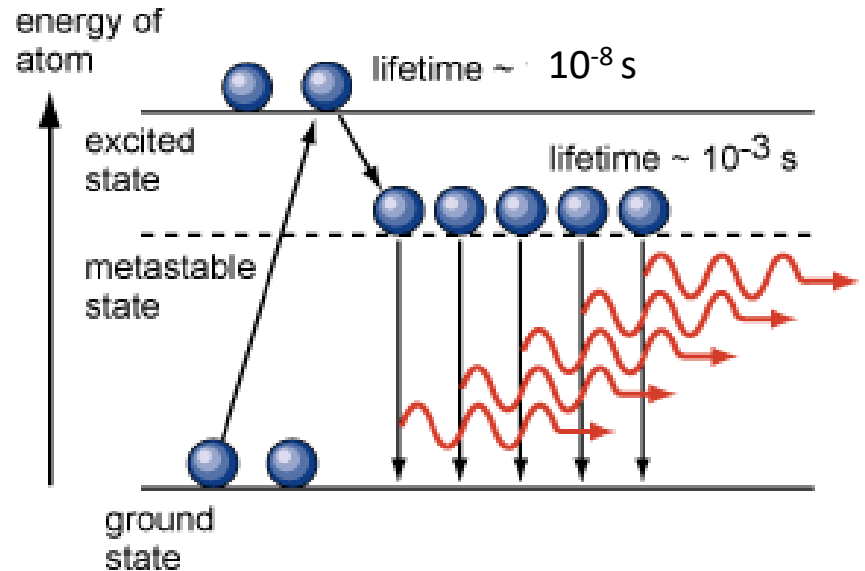
- i. Optical pumping:* Atoms are excited by means of an external optical source. This is adopted in solid state lasers such as ruby laser and Nd:YAG laser.
- ii. Electrical discharge:* *The electrons are accelerated to a high velocity by a strong electric field.* By inelastic atom-electron/atom-atom collisions, population inversion is established. Suitable for Gas lasers.
- iii. Chemical pumping:* By suitable chemical reaction in the active medium, population of excited state is made higher compared to that of ground state. Suitable for liquid lasers.
- iv. Direct Conversion:* In this type pumping, a direct conversion of electric energy into light takes place. This technique of pumping is adopted in semiconductor laser.

3. Optical resonator :

- **A pair of mirrors placed on either side of the active medium is known as optical resonator.**
- **One mirror is completely silvered and the other is partially silvered.**
- **The laser beam comes out through the partially silvered mirror.**

Population Inversion

- Population inversion is the state of achieving more number of atoms in the excited state compared to the ground state
- Population inversion can be achieved by a process called pumping



- The electrons remain only for 10^{-8} sec in the excited state, so most of them jump back to the ground state by emitting photons. But some of them jump to the metastable state which is intermediate to excited and ground states.
- They (electron) can stay in metastable state for more than 10^{-3} sec. So number of electrons increases in metastable state. **This we call population inversion**
- Population inversion can be achieved between metastable state and ground state only

□ Relation between Einstein's 'A' and 'B' coefficients

- In 1917, Einstein obtained a mathematical expression for the existence of two different kinds of processes,
(1) Spontaneous emission
(2) Stimulated emission
- Consider all atoms are in thermal equilibrium at T.
- Radiation of frequency ν & energy density $u(\nu)$.
- N_1 & N_2 are atoms in E_1 & E_2 respectively.
- In equilibrium, absorption rates & emission rates must be same.
- i.e. $B_{12} N_1 u(\nu) = A_{21} N_2 + B_{21} N_2 u(\nu)$
 $A_{21} N_2 = u(\nu) [B_{12} N_1 - B_{21} N_2]$
So, $u(\nu) = [A_{21} N_2 / (B_{12} N_1 - B_{21} N_2)]$ -----(1)

$$u(\nu) = \frac{\frac{A_{21}}{B_{21}}}{\left[\frac{B_{12}N_1}{B_{21}N_2} - 1\right]} \text{-----}(2)$$

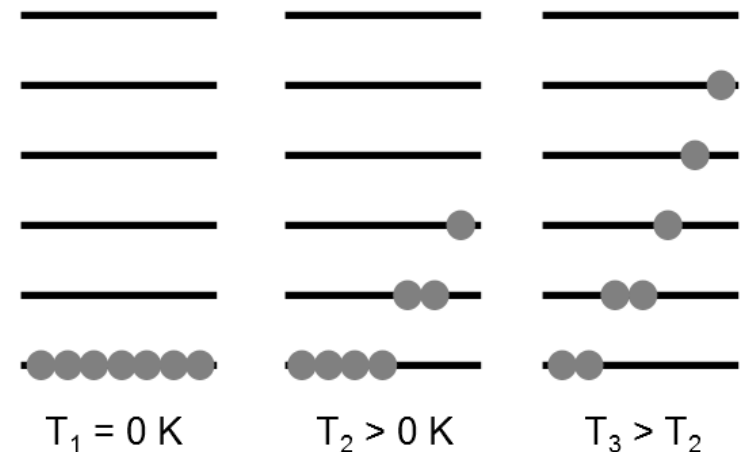
- Boltzmann distribution**

- $N_1 = N_0 e^{-E_1/kT} \text{-----}(3)$

$$N_2 = N_0 e^{-E_2/kT}$$

- So,**

$$\frac{N_1}{N_2} = e^{(E_2 - E_1)/kT} \text{-----}(4)$$



- But,** $E_2 - E_1 = h\nu \text{-----}(5)$

- So,** $\frac{N_1}{N_2} = e^{h\nu/kT} \text{-----}(6)$

$$u(\nu) = \frac{\frac{A_{21}}{B_{21}}}{\left[\frac{B_{12}}{B_{21}}e^{h\nu/kT}-1\right]} \text{----- (7)}$$

- According to Planck's radiation formula,

$$u(\nu) = \frac{8\pi h\nu^3}{c^3} \frac{1}{[e^{h\nu/kT}-1]} \text{----- (8)}$$

If the equations 7 and 8 to be identical, we must have,

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

&
$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3} \text{----- (9)}$$

- So, Ratio of spontaneous to stimulated emission:

$$R = \frac{N_2 A_{21}}{N_2 B_{21} u(\nu)} = \frac{A_{21}}{B_{21} u(\nu)} = \frac{8\pi h\nu^3}{c^3 u(\nu)} \text{----- (10)}$$

- So, $u(\nu) = \frac{8\pi h\nu^3}{c^3 R}$ $u(\nu) = \frac{8\pi h\nu^3}{c^3} \frac{1}{[e^{h\nu/kT} - 1]}$

$$\Rightarrow R = [e^{h\nu/kT} - 1]$$

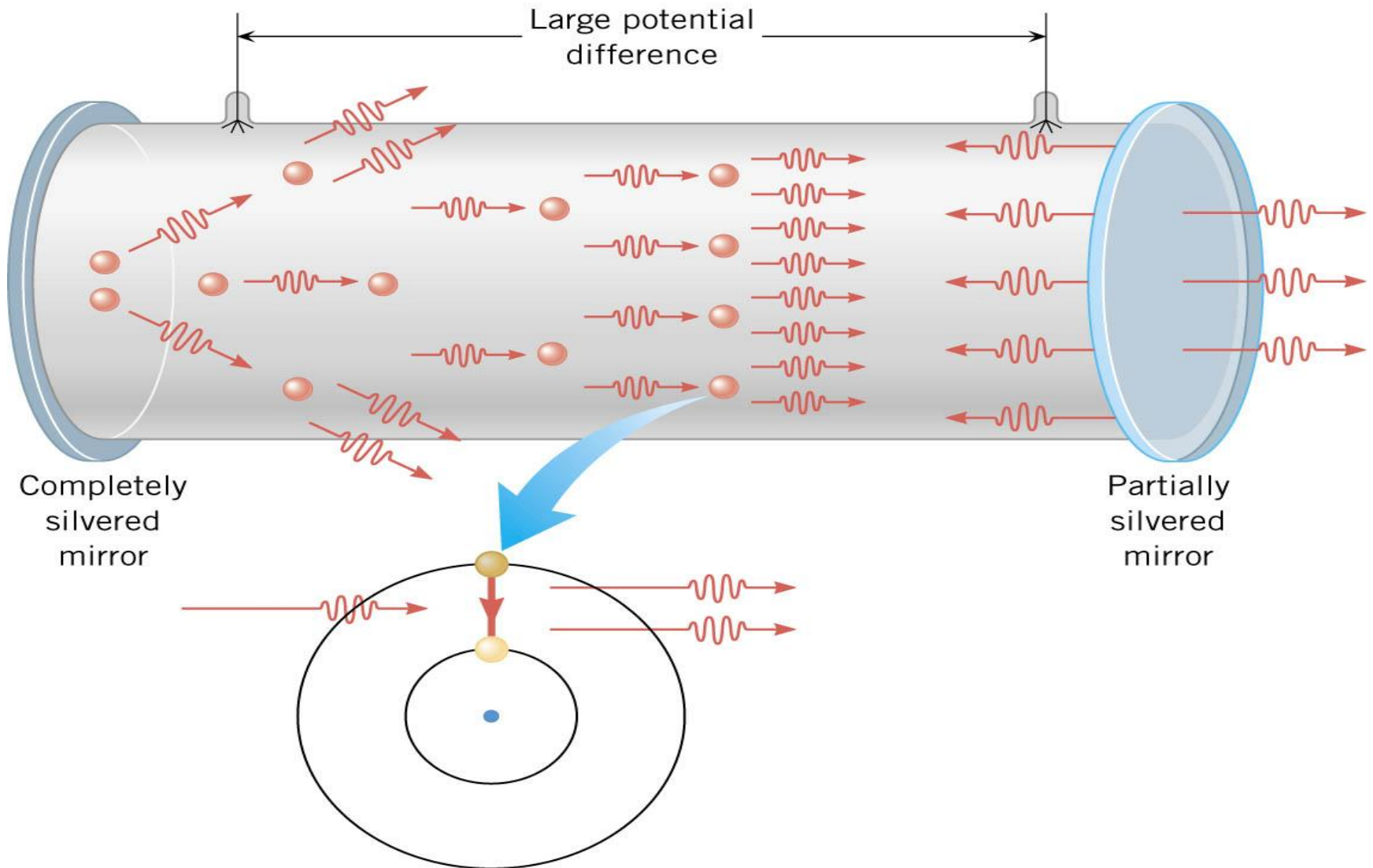
So, $R = \frac{A_{21}}{B_{21}u(\nu)} = [e^{h\nu/kT} - 1]$

- If $h\nu \ll kT$, at a given temperature, then by expanding the exponential term as $(1 + h\nu/kT)$, we get

$$\frac{A_{21}}{B_{21}u(\nu)} = \frac{h\nu}{kT} \quad \text{then } R \ll 1$$

- This shows that no. of stimulated emissions far exceeds that of spontaneous emission
 - Valid in microwave region (MASER)
- If $h\nu \gg kT$ – Spontaneous emission dominates over stimulated emissions
 - Valid in visible region, incoherent

Light Amplification



Light Amplification

- ❖ With active medium in the inverted state, a photon of appropriate energy can stimulate the emission of a cascade of photons

⇒ Amplification

- Initial photon may be looked upon as the input signal
 - Active medium as the quantum optical amplifier and
 - Emerging light as the amplified output
- Degree of amplification is measured as Gain ⇒ *the increase in intensity when a light beam passes through an active medium*
 - Gain is the amount of stimulated emission which a photon can generate as it travels in given distance

$$G = \frac{1}{I_0} \frac{dI}{dx}$$

Where G is gain in intensity per unit length of the active medium and I_0 is the initial intensity of light beam

- If $G=4$ per cm, it means that one photon produces Four photons per each centimeter it travels in the medium.

Threshold Condition for Lasing

- Light bouncing back and forth in the optical resonator
- Undergoes **amplification** as well as suffers **various losses**

Losses occur mainly due to:

(i) **Transmission at the output mirror**

(ii) **Scattering & Diffraction of light within the active medium**

▪ **For the proper build up of oscillations:**

- **Essential is that the amplification between two consecutive reflections of light from rear end mirrors should balance losses**

Determination of threshold gain by considering the change in intensity of a beam of light undergoing a round trip within the resonator

➤ Consider the laser medium fills the space between the mirrors M_1 & M_2 , of reflectivity R_1 & R_2 respectively

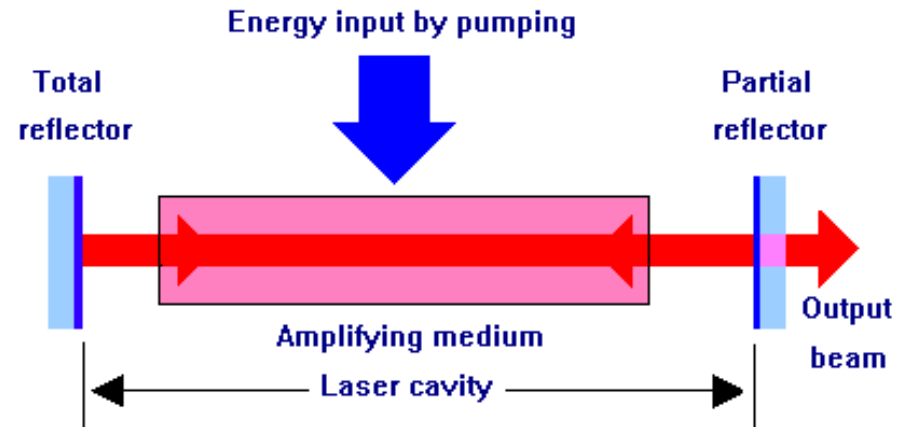
➤ Mirrors are separated by a distance L , Therefore the cavity length = L

➤ Let I_0 - the intensity of the light beam at M_1

➤ Traveling from mirror M_1 to mirror $M_2 \Rightarrow$ beam intensity increases from I_0 to $I(L)$, which is given by; $I(L) = I_0 e^{(\gamma - \alpha)L}$

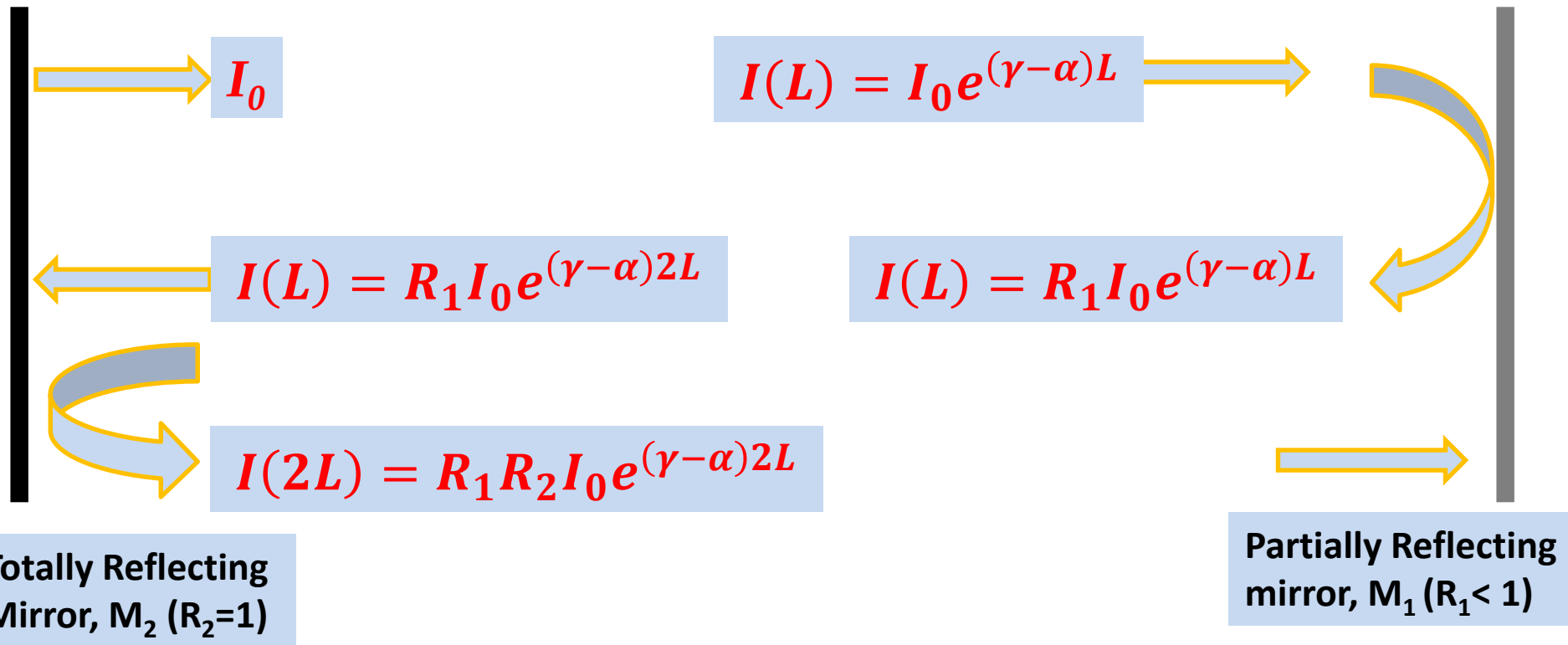
➤ After reflection at M_2 , the beam Intensity will be; $I(L) = R_2 I_0 e^{(\gamma - \alpha)L}$

➤ After a complete round trip (Reflection from M_1), the final Intensity will be; $I(2L) = R_1 R_2 I_0 e^{(\gamma - \alpha)2L}$



Schematic of Amplification of Light Beam Through Cavity

Length of Active Medium, l = Cavity Length, L



Gain in a **round trip** can be calculated as,

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

- Product $R_1 R_2$ represents the losses at the mirrors
- whereas ' α ' includes all the distributed losses such as, **scattering**, **diffraction** and **absorption** occurring in the medium, and called attenuation coefficient
- ' γ ' is called Gain Coefficient

- Losses are balanced by gain, when $G \geq 1$ or $I(2L) \geq I_0$. It leads to the condition that,

$$R_1 R_2 e^{(\gamma - \alpha)2L} \geq 1 \quad \text{or} \quad e^{(\gamma - \alpha)2L} \geq \frac{1}{R_1 R_2}$$

Taking logarithm on both sides, we get

$$(\gamma - \alpha)2L \geq -\ln R_1 R_2$$

$$(\gamma - \alpha) \geq -\frac{1}{2L} \ln R_1 R_2$$

$$\therefore \gamma \geq \alpha - \frac{1}{2L} \ln R_1 R_2$$

$$\therefore \gamma \geq \alpha + \frac{1}{2L} \frac{1}{\ln R_1 R_2}$$

Condition for lasing!!!

- Shows that the initial gain must exceed the sum of losses in the cavity
- The condition is used to determine the threshold value of pumping energy necessary for lasing action
- ❖ ‘ γ ’ Amplification of the laser, dependent on how hard the laser medium is pumped
- ❖ As the pump power is slowly increased, a value of ‘ γ_{th} ’ called **threshold value** will be reached and the laser starts oscillating

Threshold value of gain coefficient ‘ γ_{th} ’ of is given by

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

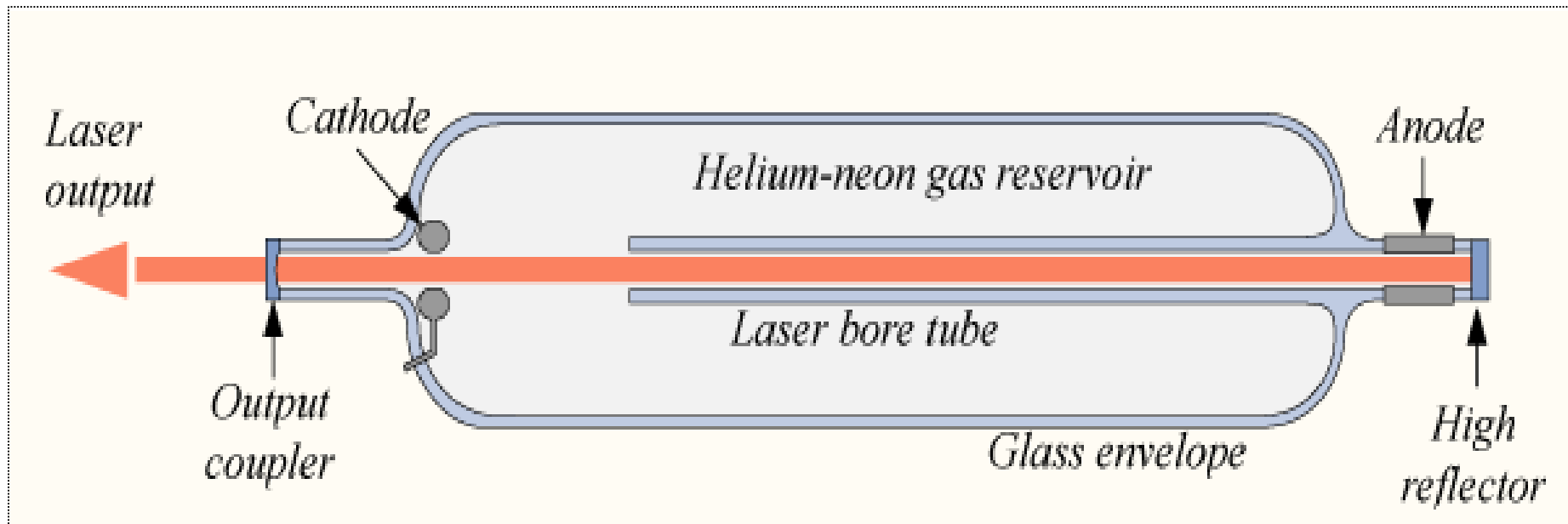
For the laser to oscillate, $\gamma > \gamma_{th} \Rightarrow$ Threshold condition for lasing

- ❖ This states the criterion when the net gain would be able to counteract the effect of losses in the cavity

❑ Gaseous Laser (He – Ne Laser)

- A helium - neon laser, usually called a He-Ne laser, is a type of small gas laser. He-Ne lasers have many industrial and scientific uses, and are often used in laboratory demonstrations of optics.
- He-Ne laser is an atomic laser which employs a four-level pumping scheme.
- The active medium is a mixture of 10 parts of helium to 1 part of neon.
- Neon atoms are centers and have energy levels suitable for laser transitions while helium atoms help efficient excitation of neon atoms.

- The most common wavelength is 6328 Å. These lasers produced powers in the range 0.5 to 50 mW in the red portion of the visible spectrum.
- They have long operating life of the order of 50,000 hrs.



❑ Construction...

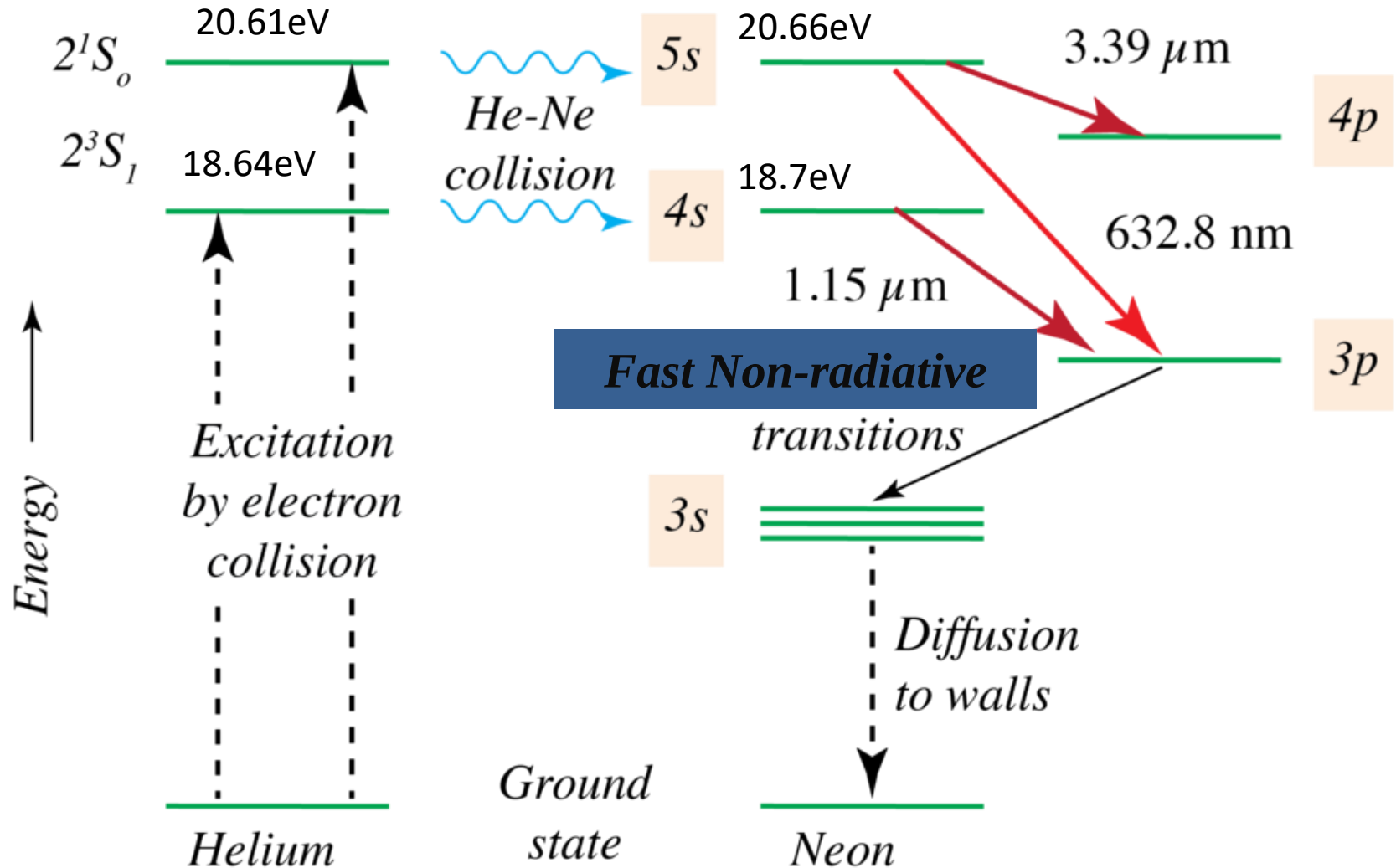
- It consists of a glass discharge tube of about typically 30 cm long and 1.5 cm diameter.
- The tube is filled with a mixture of helium and neon gases in the 10:1.
- Electrodes are provided in the tube to produce a discharge in the gas.
- They are connected to a high voltage power supply. The tube is hermetically sealed with glass windows oriented at Brewster angle to the tube. The cavity mirrors are arranged externally.

Working...

- When the power is switched on , a high voltage of about 10 kV is applied across the gas.
- It is sufficient to ionize the gas.
- The electrons and ions are produced in the process of discharge are accelerated toward the anode and cathode respectively.
- The electrons have smaller mass, they acquire higher velocity. They transfer their kinetic energy to helium atoms through inelastic collisions.
- The initial excitation affects only the helium atoms. They are in metastable state and cannot return in ground state by the spontaneous emission.

- The excited helium atoms can return to the ground state by transferring their energy to neon atoms through collision. This transfer of energy takes place when two colliding atoms have initial energy state same. It is called resonant transfer of energy.
- So, the pumping in He-Ne Laser occurs when the helium atom in the metastable state collides with neon atom in the ground state the neon atom is excited and the helium atom drops back to the ground state.
- The role of helium atom is thus to excite neon atom and cause, population inversion. The probability of energy transfer from helium atoms to neon atoms is more as there are 10 atoms of helium per 1 neon atom in gas mixture.
- Without the Brewster windows, the light output is unpolarized, because of Brewster windows laser output is linearly polarized.

Energy Level Diagram



- When the excited Ne atom passes from metastable states (5s) to lower level (3p), it emits photon of wavelength 632 nm.
- This photon travels through the gas mixture parallel to the axis of tube, it is reflected back and forth by the mirror ends until it stimulates an excited Ne atom and causes it to emit a photon of 632nm with the stimulating photon.
- The stimulated transition from (5s) level to (3p) level is laser transition.

- Although 6328 Å is standard wavelength of He-Ne Laser, other visible wavelengths 5430 Å (Green) 5940 Å (yellow-orange), 6120 Å (red-orange) can also produced.
- Overall gain is very low and is typically about 0.010 % to 0.1 %.
- The laser is simple practical and less expensive.
- The Laser beam is highly collimated, coherent and monochromatic.

❑ Applications of He-Ne Laser...

- The Narrow red beam of He-Ne laser is used in supermarkets to read bar codes.
- The He-Ne Laser is used in Holography in producing the 3D images of objects.
- He-Ne lasers have many industrial and scientific uses, and are often used in laboratory demonstrations of optics.

CO₂ LASER

Introduction :

- CO₂ lasers belong to the class of **molecular gas lasers**.
- Like in the case of atoms, electrons in molecules can also be excited to higher energy levels, and the distribution of electrons in the levels define the electronic state of the molecule.
- Besides, these electronic levels, the molecules have other energy levels.
- C.K.N. Patel designed CO₂ laser in the year 1964.

Active medium :

It consists of a mixture of CO_2 , N_2 and helium or water vapor. The active centers are CO_2 molecules lasing on the transition between the rotational levels of vibrational bands of the electronic ground states..

Optical resonators :

A pair of concave mirrors placed on either side of the discharge tube, one completely polished and the other partially polished.

Pumping :

- Population inversion is created by electric discharge of the mixture.
- When a discharge is passed in a tube containing CO_2 , electron impacts excite the molecules to higher electronic and vibrational-rotational levels.
- This level is also populated by radiation-less transition from upper excited levels.
- The resonant transfer of energy from other molecules, such as, N_2 , added to the gas, increases the pumping efficiency.

Cont'd.....

- Nitrogen here plays the role that He plays in He-Ne laser.
- A carbon dioxide (CO_2) laser can produce a continuous laser beam with a power output of several kW while, at the same time, can maintain high degree of spectral purity and spatial coherence.
- In comparison with atoms and ions, the energy level structure of molecules is more complicated and originates from three sources: electronic motions, vibrational motions and rotational motions.

Fundamental Modes of vibration of CO₂:

Three fundamental modes of vibration for CO₂

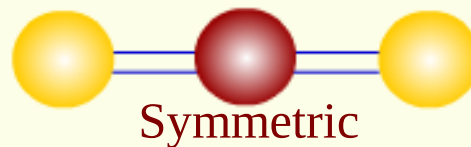
- Symmetric stretching mode (frequency ν_1),
 - Bending mode (ν_2) and
 - Asymmetric stretching mode (ν_3).
- In the symmetric stretching mode, the oxygen atoms oscillate along the axis of the molecule simultaneously departing or approaching the carbon atom, which is stationary.

Cont'd...

- In the 'bending mode', the molecule ceases to be exactly linear as the atoms move perpendicular to the molecular axis.
- In 'asymmetric stretching', all the three atoms oscillate: but while both oxygen atoms move in one direction, carbon atoms move in the opposite direction.
- The 'internal vibrations' of carbon dioxide molecule can be represented approximately by linear combination of these three normal modes.

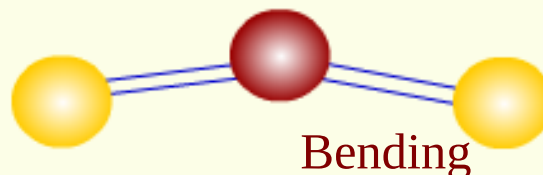
VIBRATION OF CO₂ MOLECULE

(1) Symmetric stretching mode



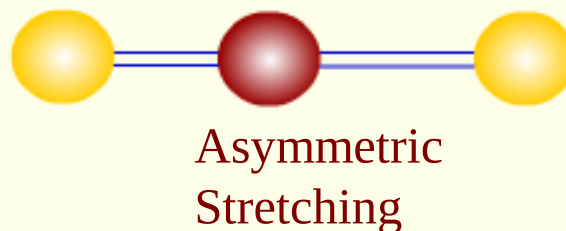
C - stationary
O - vibrates
simultaneously along
molecular axis

(2) Bending mode

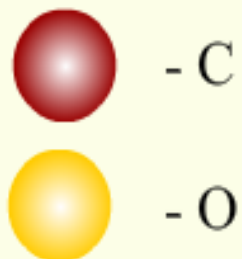


C & O vibrate
perpendicular to
molecular axis

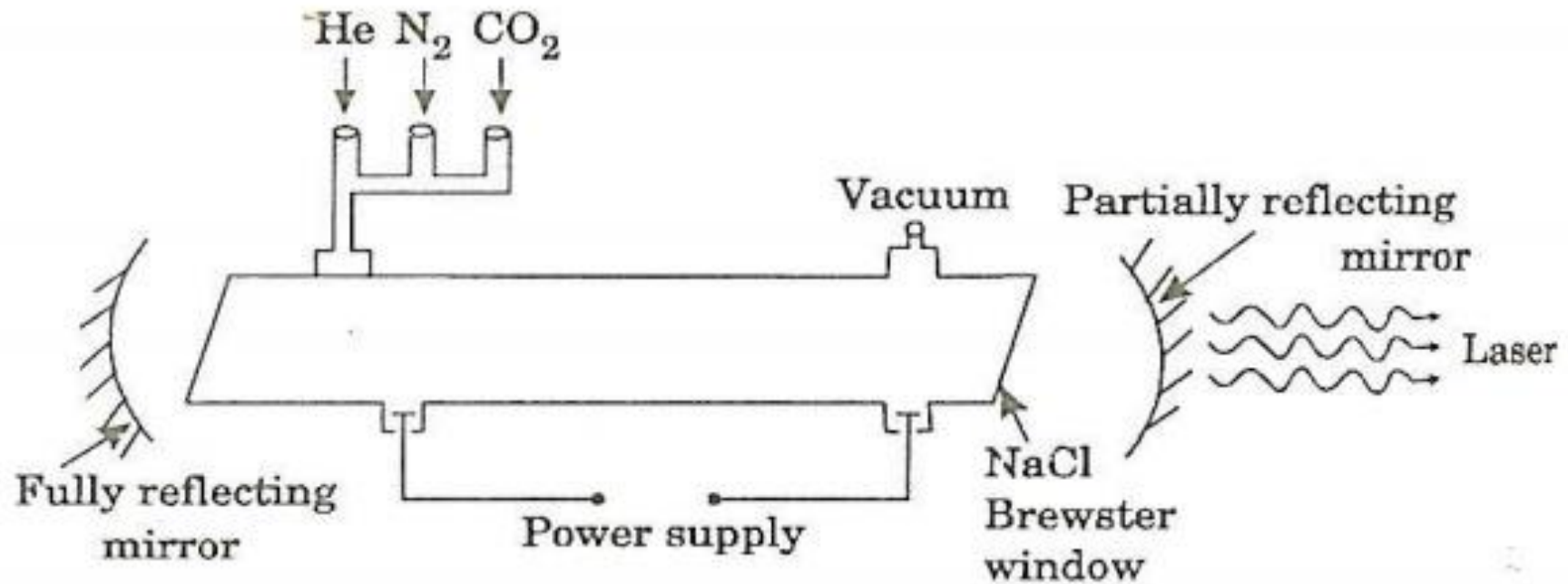
(3) Asymmetric stretching mode



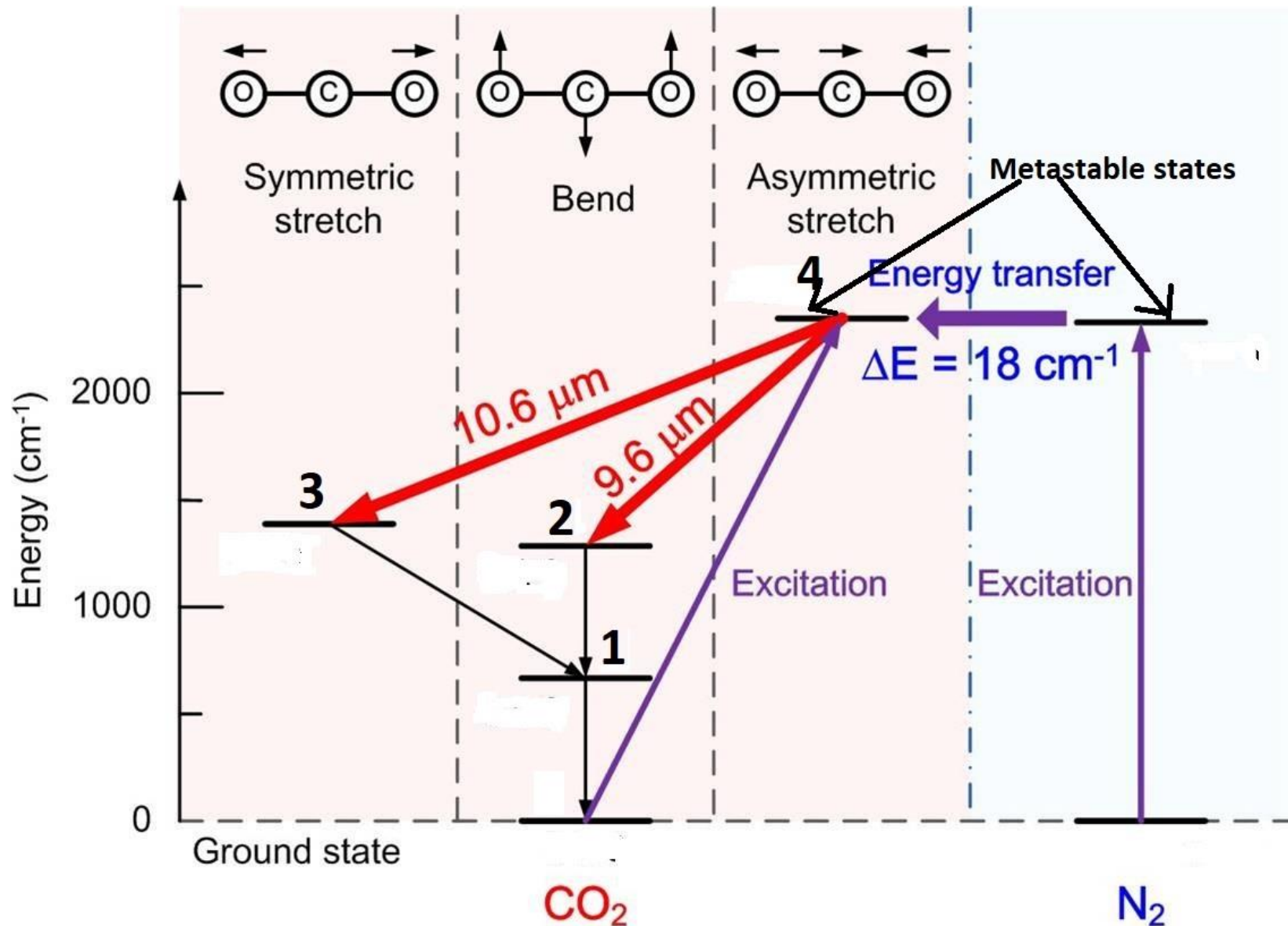
C & O atoms vibrate in
opposite directions
along molecular axis



CO₂ LASER Schematic



ENERGY LEVEL DIAGRAM



Working:

- As the electric discharge is passed through the tube, which contains a mixture of carbon dioxide, nitrogen and helium gases, the electrons striking nitrogen molecules impart sufficient energy to raise them to their first excited vibrational-rotational energy level.
- This energy level corresponds to one of the vibrational - rotational level of CO_2 molecules, designated as level 4.
- Collision with N_2 molecules, the CO_2 molecules are raised to level 4.
- The lifetime of CO_2 molecules in level 4 is quite significant to serve practically as a metastable state.
- Hence, population inversion of CO_2 molecules is established between levels 4 and 3, and between levels 4 and 2.
- The transition of CO_2 molecules between levels 4 and 3 produce lasers of wavelength 10.6 microns and that between levels 4 and 2 produce lasers of wavelength 9.6 microns.

- The He molecules increase the population of level 4, and also help in emptying the lower laser levels.
- The molecules that arrive at the levels 3 and 2 decay to the ground state through non-radiative and collision induced transitions to the lower level 1, which in turn decays to the ground state.
- The power output of a CO₂ laser increases linearly with length. Low power (upto 50W) continuous wave CO₂ lasers are available in sealed tube configurations.

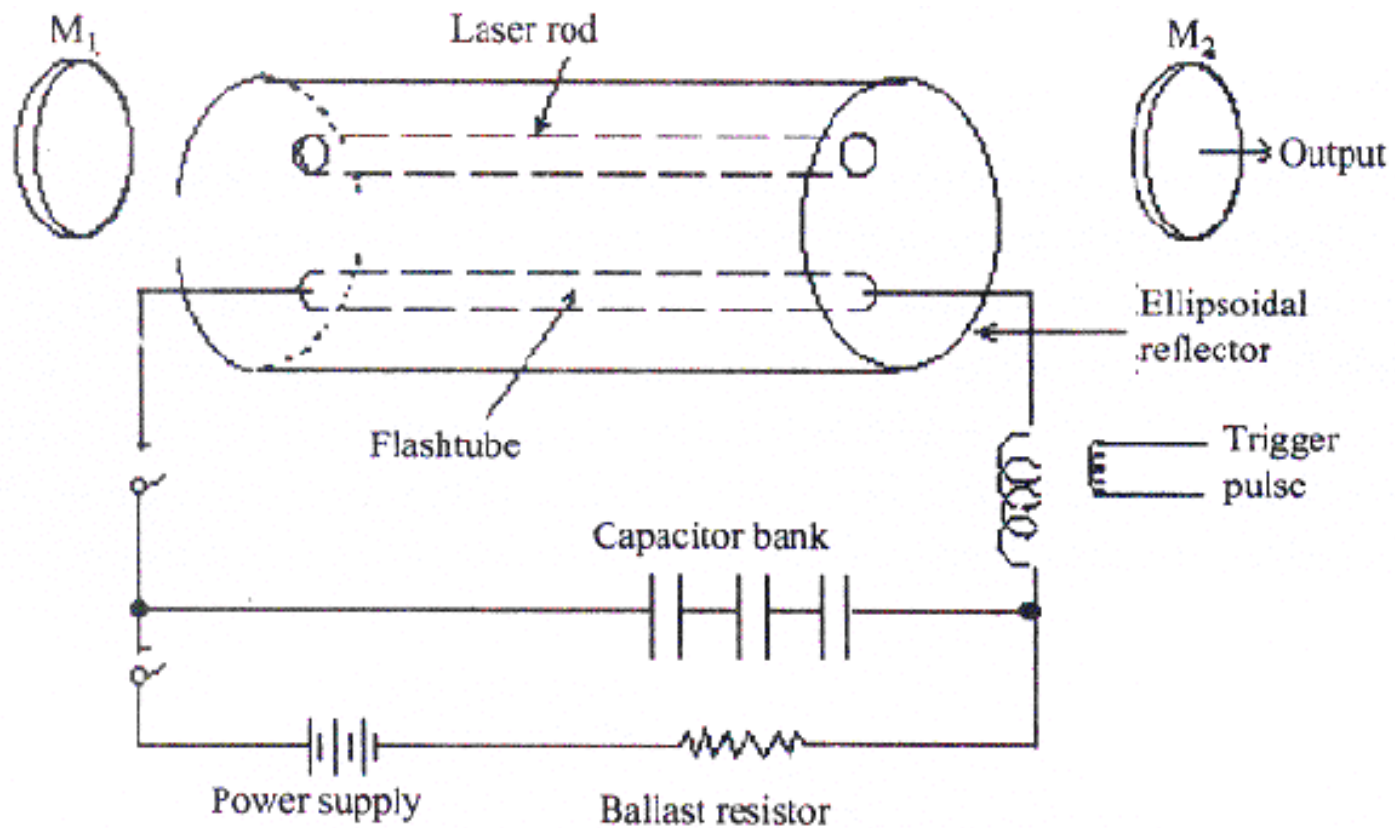
Contd.

- Some are available in sizes like torches for medical use, with 10-30 W power.
- Typical power per unit length is 200-600 W/m.
- Some of these lasers are large room sized metal working lasers with output power 10-20 kW.
- Recently CO₂ lasers with continuous wave power output exceeding 100 kW have been made.
- The wavelength of radiation from these lasers is 10.6μm.

Nd: YAG Laser (Doped insulator laser) :

Lasing medium :

- The host medium for this laser is Yttrium Aluminum Garnet (YAG = $\text{Y}_3\text{Al}_5\text{O}_{12}$) with 1.5% trivalent neodymium ions (Nd^{3+}) present as impurities.
- The (Nd^{3+}) ions occupy the lattice sites of yttrium ions as substitutional impurities and provide the energy levels for both pumping and lasing transitions.
- When an (Nd^{3+}) ion is placed in a host crystal lattice it is subjected to the electrostatic field of the surrounding ions, the so called crystal field.
- The crystal field modifies the transition probabilities between the various energy levels of the Nd^{3+} ion so that some transitions, which are forbidden in the free ion, become allowed.

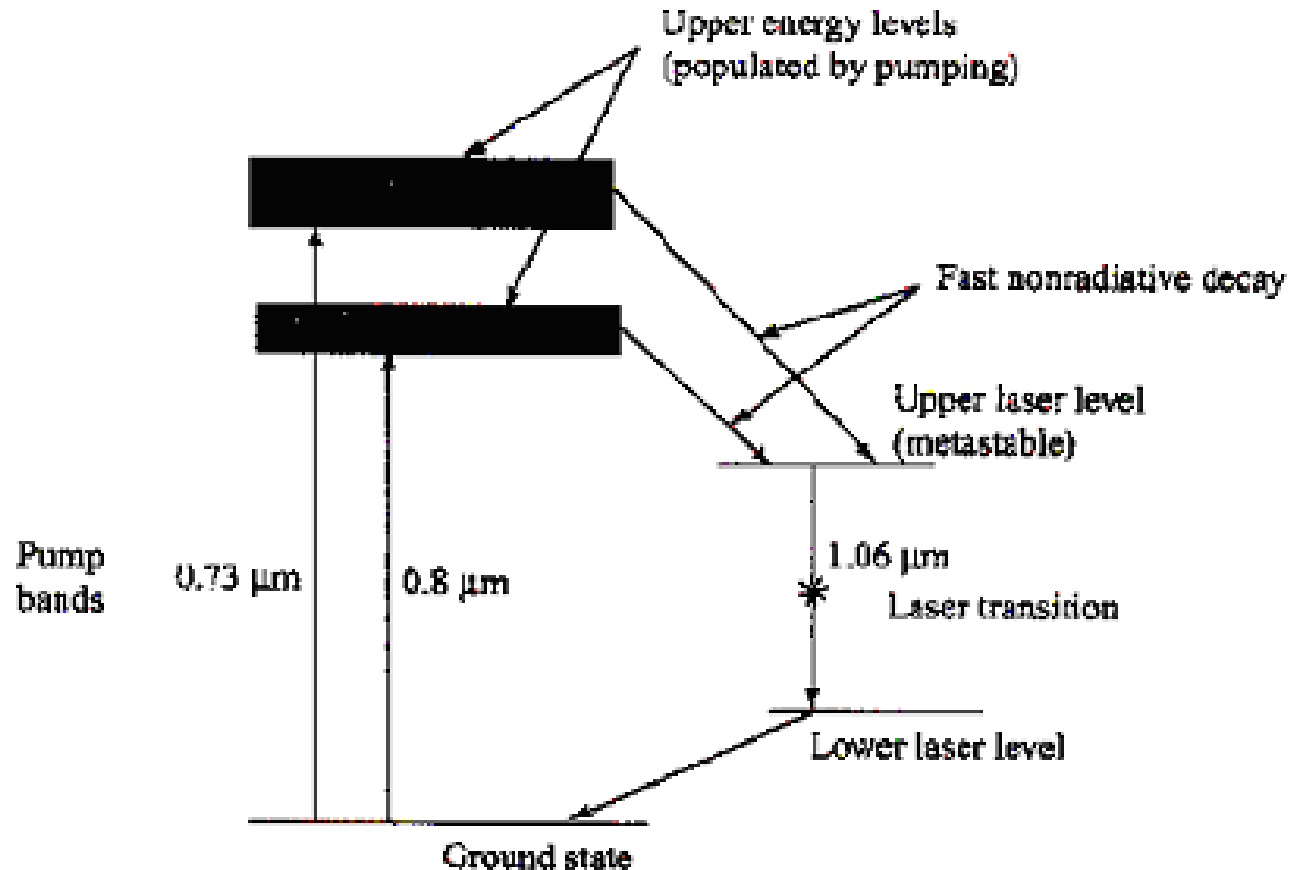


Schematic of Nd: YAG laser

Construction

- The length of the Nd: YAG laser rod varies from 5cm to 10cm depending on the power of the laser and its diameter is generally 6 to 9 mm.
- Optical pumping mechanism is employed.
- The laser rod and a linear flash lamp are housed in a elliptical reflector cavity
- Since the rod and the lamp are located at the foci of the ellipse, the light emitted by the lamp is effectively coupled to the rod.
- The ends of the rod are polished and made optically flat and parallel.

ENERGY LEVEL DIAGRAM



Simplified energy level diagram for the Nd-ion in YAG showing the principal laser transitions

- **This laser system has two absorption bands (0.73 μm and 0.8 μm)**
- **Laser transition takes place between two laser levels at 1.06 mm.**

Output Characteristics :

- The laser output is in the form of pulses with higher repetition rate
- Xenon flash lamps are used for pulsed output.
- Nd: YAG laser can be operated in CW mode also using tungsten-halide incandescent lamp for optical pumping.
- Continuous output powers of over 1 kW are obtained.

Nd:YAG laser applications :

- These lasers are used in many scientific applications which involve generation of other wavelengths of light.
- The important industrial uses of YAG and glass lasers have been in materials processing such as welding, cutting, drilling.
- Since $1.06\text{ }\mu\text{m}$ wavelength radiation passes through optical fibre without absorption, fibre optic endoscopes with YAG lasers are used to treat gastrointestinal bleeding.

Application of Lasers...

- Laser beam is used to measure distances of sun, moon, stars and satellites very accurately.
- Can be used for measuring velocity of light, to study spectrum of matters, to study Raman effect.
- Can be used for increasing speed and efficiency of computer.
- Used for welding.
- Used in 3D photography called holography.

❑ **Application of Lasers...**

- **Used for communication, T. V. transmission, to search the objects under sea.**
- **Used to predict earthquake.**
- **Laser tools are used in surgery.**
- **Used for detection and treatment of cancer.**
- **Used to straight line alignment for construction of dam, tunnels etc.**
- **Used in fiber optic communication.**
- **Used in military, like LIDAR.**
- **Used to accelerate some chemical reactions.**