



LASERs: Fundamentals and Applications

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Syllabus



- **Physics of Materials:** Crystal structure, crystal systems, bonding in solids, P.E curve and Properties of materials, miller indices, Brillouin zones, symmetry, Atomic Packing fraction, imperfections, energy bands in solids,, classification of solids, conductivity in metals and concepts of Fermi level, effective mass and holes, concept of phonons, electron distribution function, Fermi-Dirac distribution function, properties of bulk materials and nanomaterials. Carbon materials.
- **Laser and Fiber Optics:** Principles of lasers, Einstein Coefficients and their relations, Types of Lasers and their applications. Concept of optical fibers and types of optical fibers, modes of propagation, fiber optic communication, optical fiber sensors, connector and couplers.

LASER



Laser is one of the most recent treatment modalities available to physiotherapists.

Light Amplification by Stimulated Emission of Radiation

- A device produces a coherent beam of optical radiation by stimulating electronic, ionic, or molecular transitions to higher energy levels
- When they return to lower energy levels by stimulated emission, they emit energy.



History of LASER

- Invented in 1958 by Charles Townes (Nobel prize in Physics 1964) and Arthur Schawlow of Bell Laboratories



- Was based on Einstein's idea of the particle wave duality of light, more than 30 years earlier
- Originally called MASER



Year	Name	Development of Laser
1917	Einstein ²	On the Quantum Mechanics of Radiation
1954	Townes ³	Invention of MASER
1958	Schawlow and Townes ⁴	Invention of LASER
1960	Maiman ⁵	Built the first working laser
1963	Goldman ⁶	Introduced laser into medical field
1964	Goldman ⁷	Reported impact of laser beam to dental caries
1964	Bell Laboratories	Nd:YAG laser and CO ₂ laser were developed. Extended the application of laser into soft tissue
1980	Yamamoto and Sato ¹⁴	Nd:YAG laser was first reported to be used in dental caries prevention
1989	Myers and Myers ¹⁵	Development of a pulsed Nd:YAG laser, made application of laser in general dentistry possible
1990-	Ho:YAG, Er:YAG, Argon, Er:YSGG and other types of laser were invented. Laser has been widely applied in dentistry	

Laser: everywhere in your life



Laser printer



Laser pointer



Laser Barcode Scanner



Laser Cutting Machine



Laser Wound Healing



Laser Eye Surgery

Applications of Laser

Lasers have a wide range of applications across different fields, including industry, medicine, and telecommunications.



Industry

- **Manufacturing:** Cutting, welding, drilling, engraving, and marking materials like metal, glass, and quartz with high precision.
- **Electronics:** Trimming integrated circuit components and photolithography in semiconductor manufacturing.
- **Other:** Heat treatment, laser cleaning, and surface engineering.

Medicine

- **Surgery:** Performing precise surgeries, including bloodless operations and the removal of tumors.
- **Cosmetics:** Hair removal, tattoo removal, and treating skin conditions like acne and stretch marks.
- **Ophthalmology:** Correcting vision (e.g., LASIK {Laser-Assisted In Situ Keratomileusis}), treating cataracts, and repairing the retina.
- **Dentistry:** Removing tooth decay.
- **Other:** Breaking down kidney and gallstones (lithotripsy).

Applications of Laser



Telecommunications and electronics

- **Optical communication:** Transmitting high-speed data through fiber optic cables for the internet and phone networks.
- **Consumer electronics:** Used in barcode scanners, DVD players, and laser pointers.
- **Printers:** Key component in laser printers and for creating high-resolution printing plates.

Research and science

- **Measurement:** Used in surveying and for creating precise 3D models with LIDAR (Light Detection and Ranging uses remote sensing to develop models of objects)
- **Physics and chemistry:** Studying the structure of microorganisms and cells, producing chemical reactions, and in applications like optical trapping.
- **Astronomy:** Used for long-distance communication with satellites and for certain experiments.

Entertainment

- **Light shows:** Creating special effects and light displays at concerts and events.
- **Special effects:** Used in movies and shows to create visual effects.

Properties of Laser

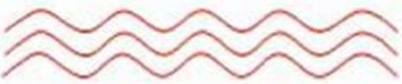
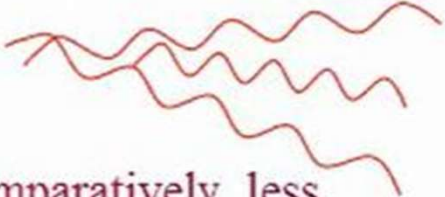


- The light emitted from a laser is **monochromatic**, that is, it is of one color/wavelength. In contrast, ordinary white light is a combination of many colors (or wavelengths) of light.
- Lasers emit light that is highly **directional**, that is, laser light is emitted as a relatively narrow beam in a specific direction. Ordinary light, such as from a light bulb, is emitted in many directions away from the source.
- The light from a laser is said to be **coherent**, which means that the wavelengths of the laser light are in phase in space and time. Ordinary light can be a mixture of many wavelengths.
- **Tunability**, **Collimated** and **High power** are other properties

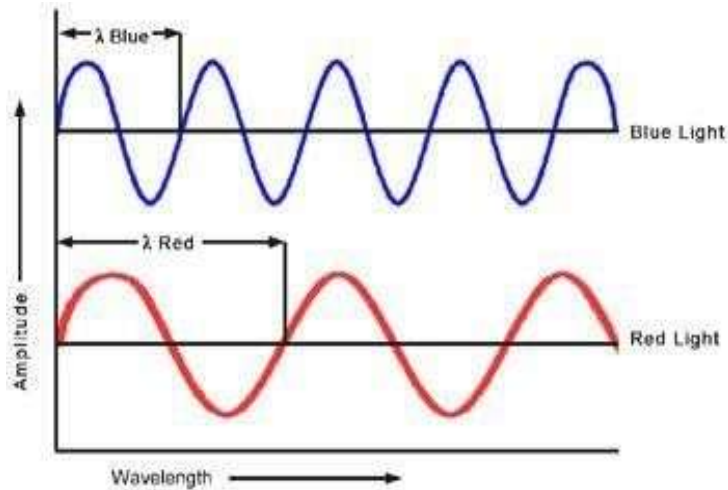
These properties of laser light are what can make it more hazardous than ordinary light. Laser light can deposit a lot of energy within a small area.



LASER is **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation.

<u>Laser as a light source</u>	<u>Non-laser light source</u>
1) Result of <u>stimulated emission</u> .	1) Result of <u>spontaneous emission</u>
2) Unidirectional, Angular spread is very small 	2) Diverges 
3) Coherent. 	3) Not coherent. 
4) Highly intense.	4) Intensity is comparatively less.
5) Monochromatic 	5) May not be monochromatic. 

Monochromaticity



Comparison of the wavelengths of red and blue light

Nearly monochromatic light

Example:

He-Ne Laser

$\lambda_0 = 632.5 \text{ nm}$

$\Delta\lambda = 0.2 \text{ nm}$

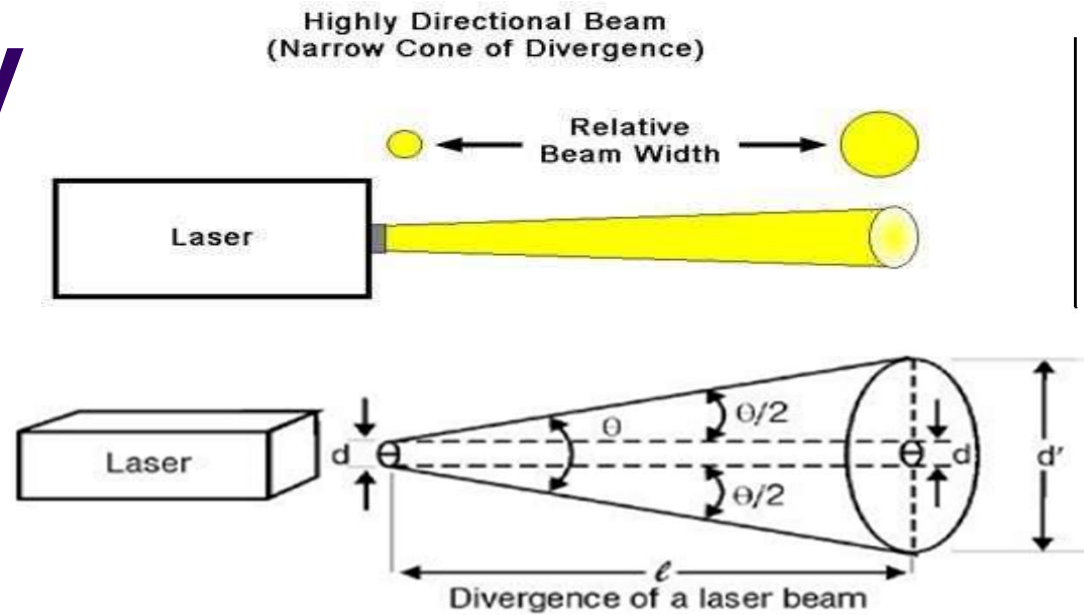
Diode Laser

$\lambda_0 = 900 \text{ nm}$

$\Delta\lambda = 10 \text{ nm}$

- Ordinary light consists of many wave lengths
- Laser light consists of only one wave length
- It means that each type of laser essentially produces only a single wavelength of light with a single color.
- Laser effect is a wavelength specific.

Directionality



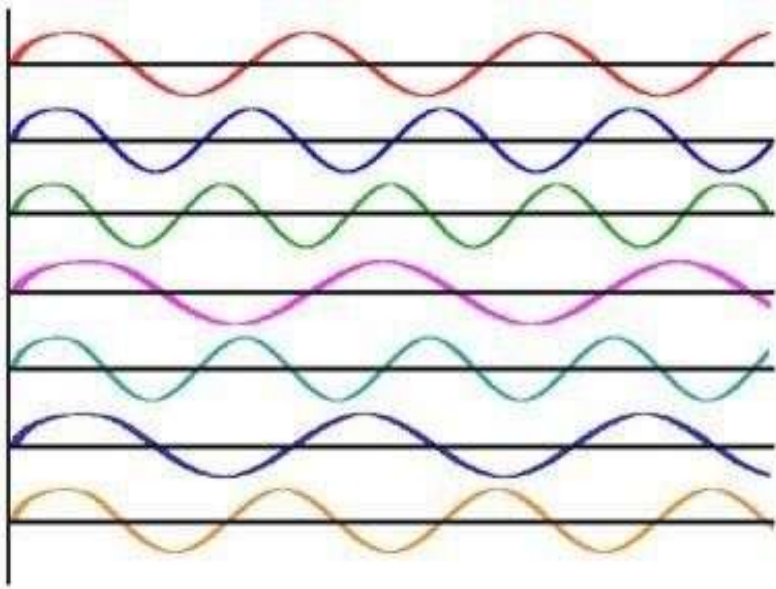
The diffraction-limited angle (θ)

Even after perfect collimation with a lens, the beam will diverge due to diffraction. This is an unavoidable effect of the light passing through a finite aperture, such as the lens itself. For a circular aperture, the diffraction-limited divergence angle is approximated by the Rayleigh criterion: [🔗](#)

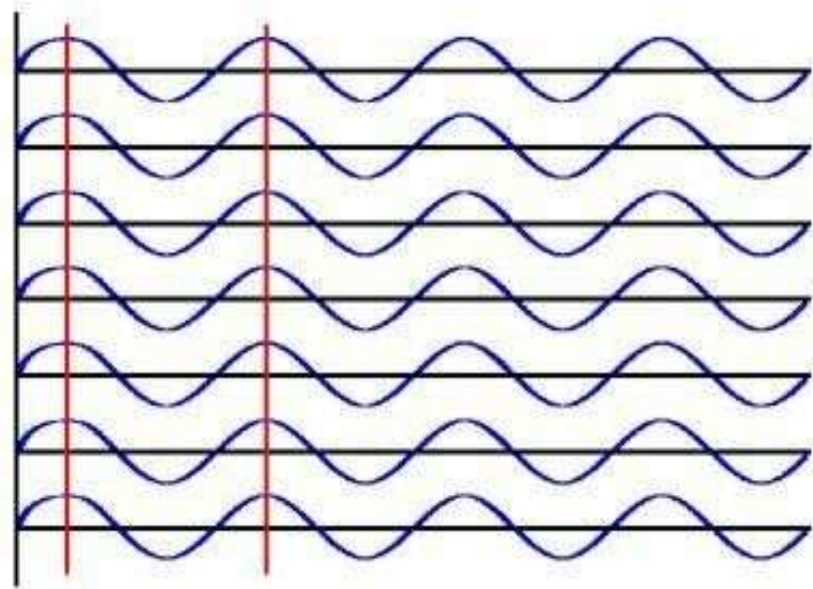
$$\theta \approx \frac{1.22\lambda}{D}$$

- θ is the half-angle of the divergence.
- λ is the wavelength of the light.
- D is the diameter of the aperture (the lens or reflector). [🔗](#)

Coherence



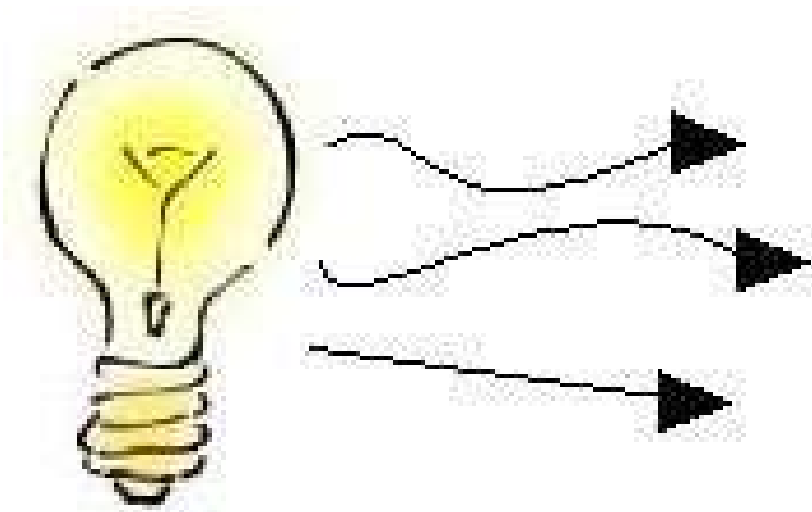
Incoherent light waves



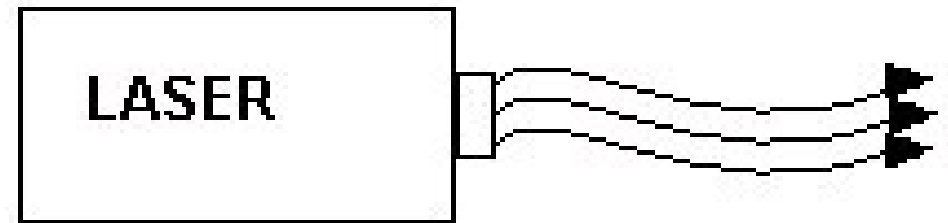
Coherent light waves

- Laser light comprises the identical wave length and forms that cause it to be greatly amplified.
- Laser radiation are coherent both temporal and spatial.
- Temporal coherence means that the peaks and troughs of the electric and magnetic fields all occur at the same time.
- Spatial coherence means they are all traveling in the same direction.

Incandescent vs. Laser Light



1. Many wavelengths
2. Multidirectional
3. Incoherent



1. Monochromatic
2. Directional
3. Coherent

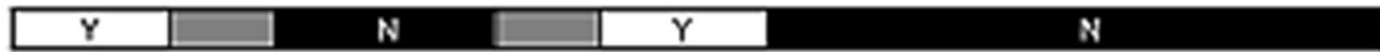


How LASERs are different compared to X-rays?

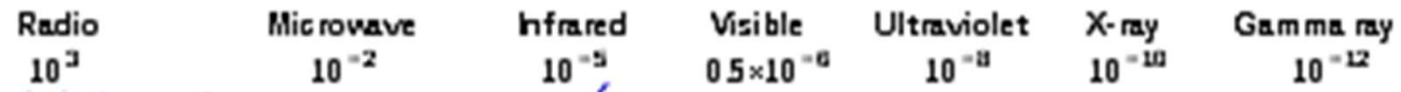
LASERs	X-rays
1) Wavelength of few thousand angstroms .	1) Wavelength of few angstroms .
2) LASERs are highly coherent .	2) X-rays are not highly coherent.
3) LASERs are obtained due to phenomenon called stimulated emission of radiation .	3) X-rays are given out when high speed electrons strike the target of high atomic number and melting point.



Penetrates Earth's Atmosphere?



Radiation Type
Wavelength (m)

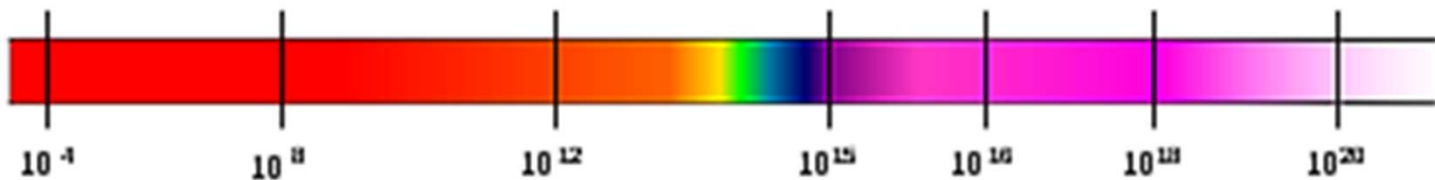


Approximate Scale
of Wavelength

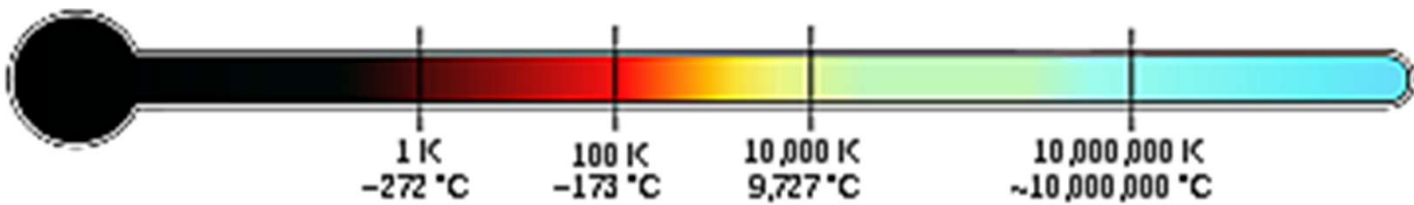


Buildings Humans Butterflies Needle Point Protozoans Molecules Atoms Atomic Nuclei

Frequency (Hz)



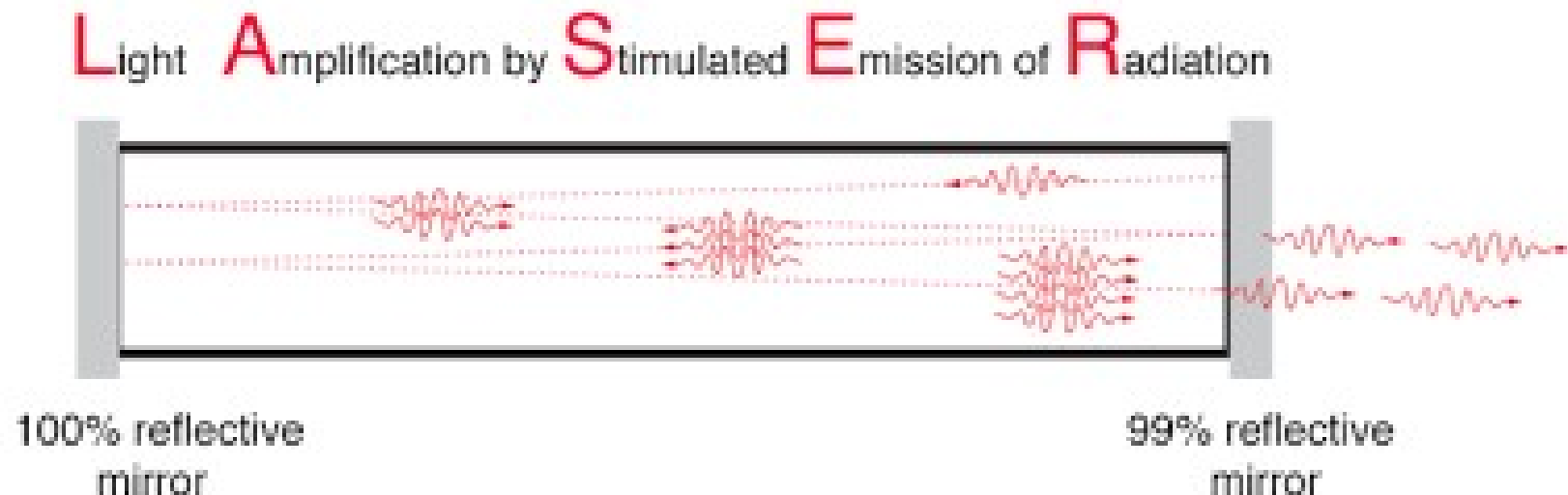
Temperature of
objects at which
this radiation is the
most intense
wavelength emitted



Basic concepts for a laser



- Absorption
- Spontaneous Emission
- Stimulated Emission
- Population inversion





Ground State of an atom :

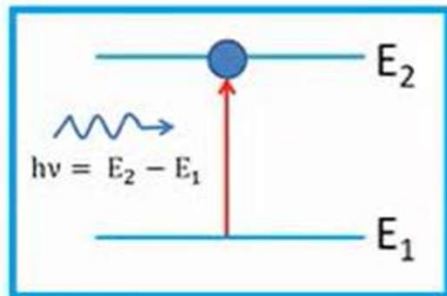
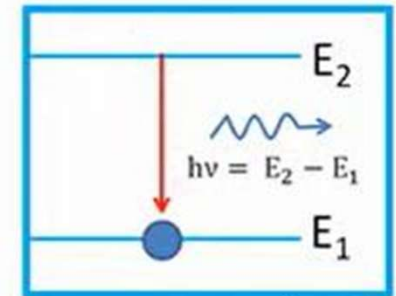
- The lowest stable state of the atom.
- Electrons move in their respective orbits without emitting energy.

Excited State of an atom :

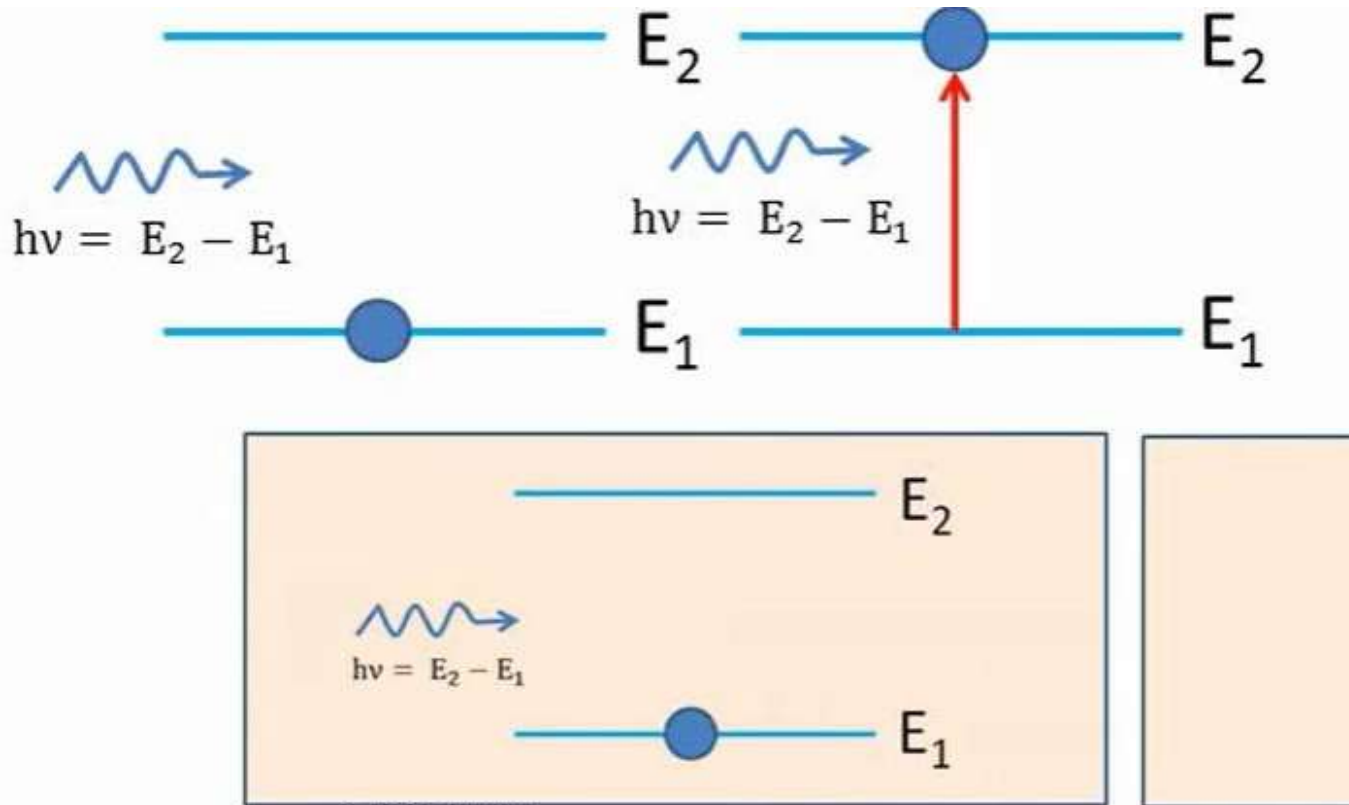
- If electrons get sufficient energy, they jump to the higher energy level and the atom is said to be excited state.

Quantum Transition :

- Passing of an atom from one energy state to the other state.
- Whenever quantum transition occurs between energy states E_1 and E_2 , energy $E_2 - E_1 = h\nu$ is absorbed or released as a radiation.

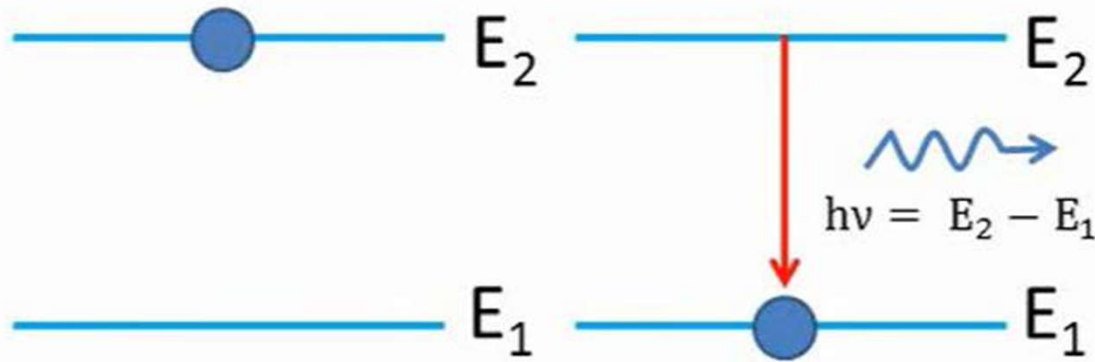
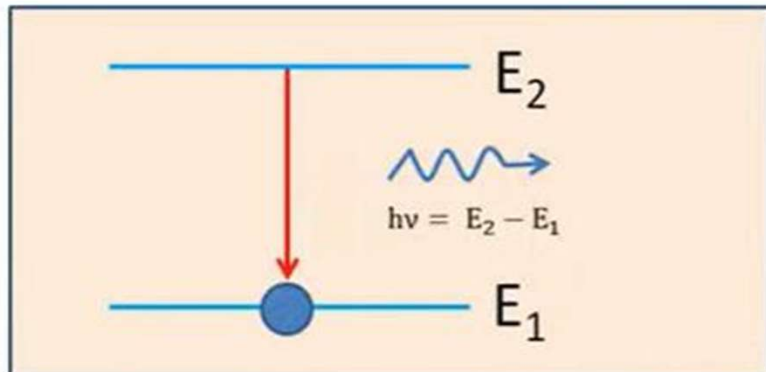


Absorption



- Energy is absorbed by an atom, the electrons are **excited** into vacant energy shells.

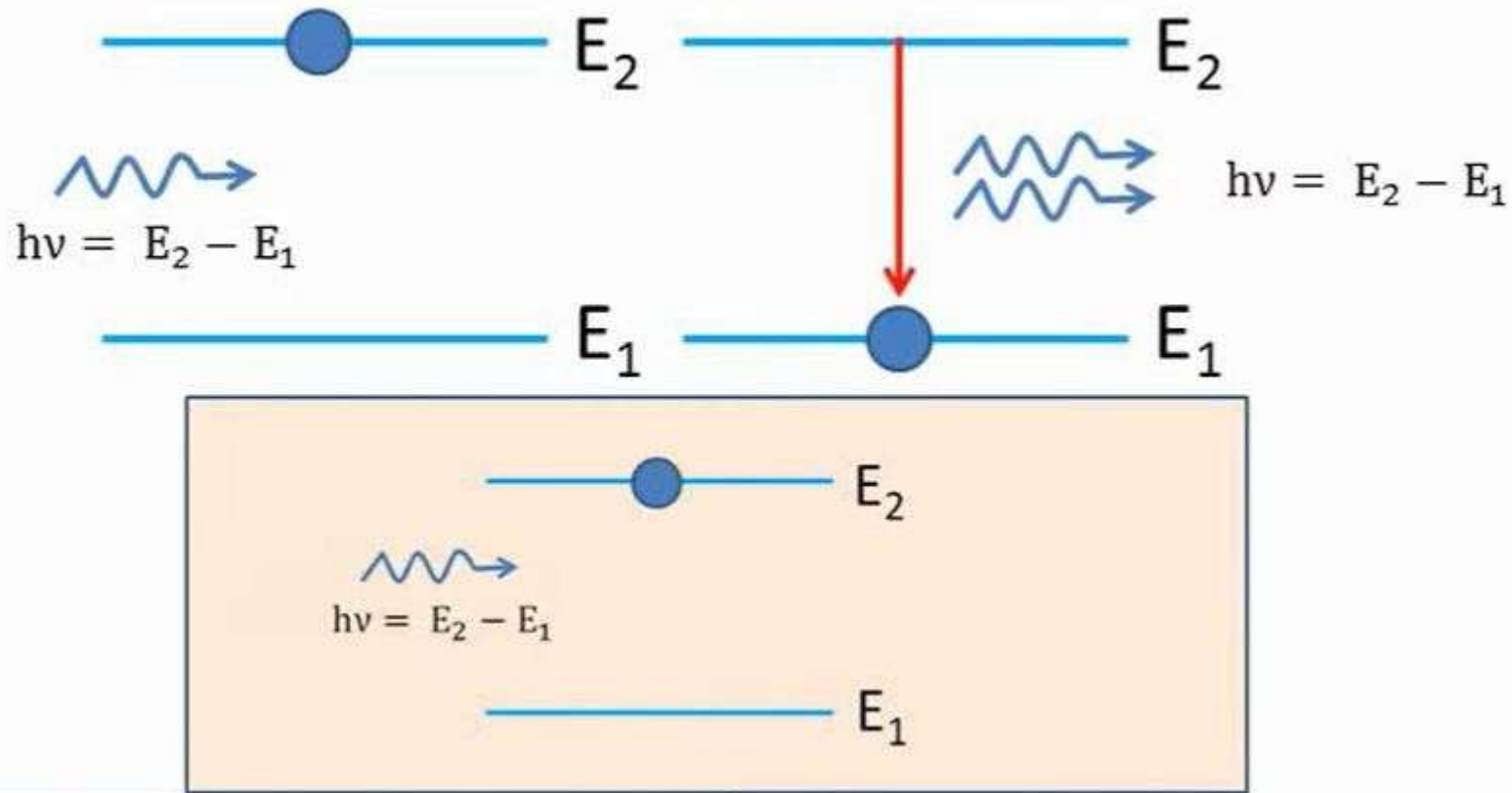
Spontaneous Emission



- Excited atom can stay at the excited level for a limited time known as life-time of that state.
- Life time is normally 10^{-8} second

- The atom decays from level 2 to level 1 through the emission of a photon with the energy $h\nu$. It is a completely **random** process.

Stimulated Emission



atoms in an upper energy level can be triggered or stimulated in phase by an **incoming photon** of a **specific energy**.



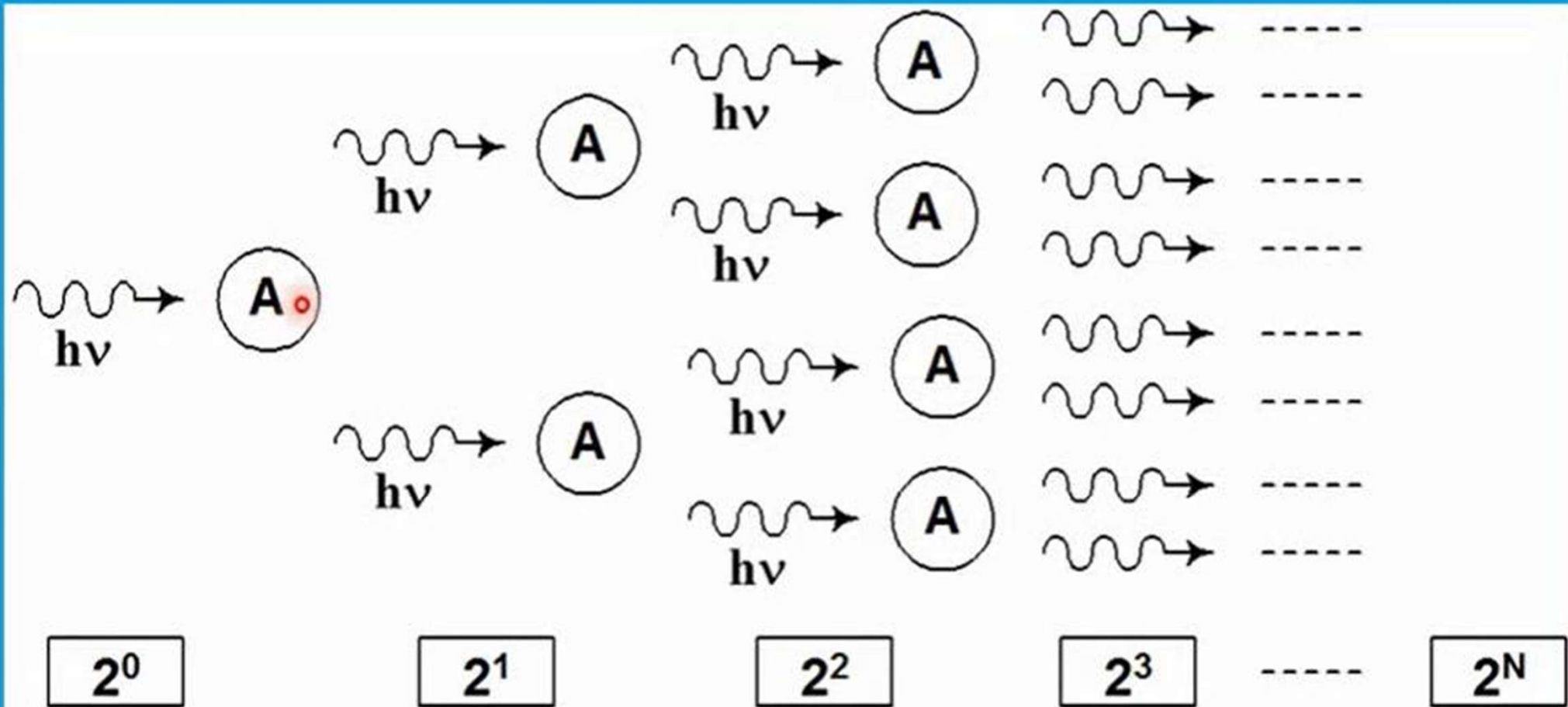
Stimulated Emission

The **stimulated photons** have unique properties:

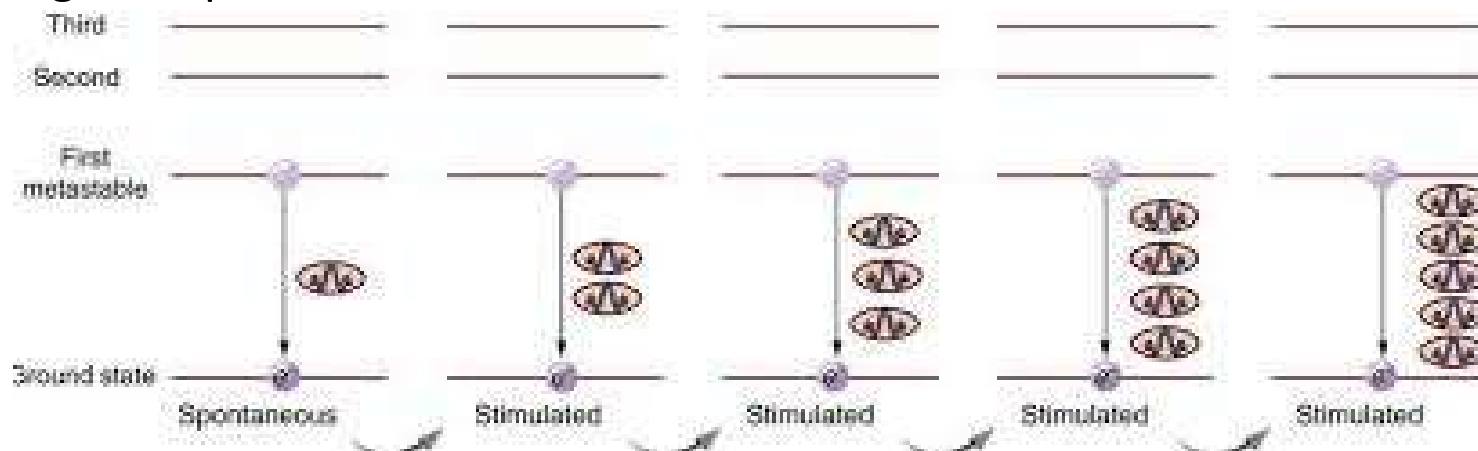
- **In phase** with the incident photon
- **Same wavelength** as the incident photon
- Travel in **same direction** as incident photon



Spontaneous Emission	Stimulated Emission
<p>1) Spontaneous emission is a result of the transition of an atom from the excited state to the lower energy state which happens due natural tendency of the atom to attain minimum energy.</p> <p>2) No external agent is involved.</p> <p>3) Results in ordinary light.</p> <p>4) Light obtained is not coherent.</p>	<p>1) Stimulated emission of radiation is the process in which photons are used to stimulate atom in excited state to fall down to lower energy state.</p> <p>2) Photons need to be incident as stimuli.</p> <p>3) Can be utilized to get Laser beam.</p> <p>4) Coherent light can be obtained.</p>



Light Amplification continues till the atoms available in excited state

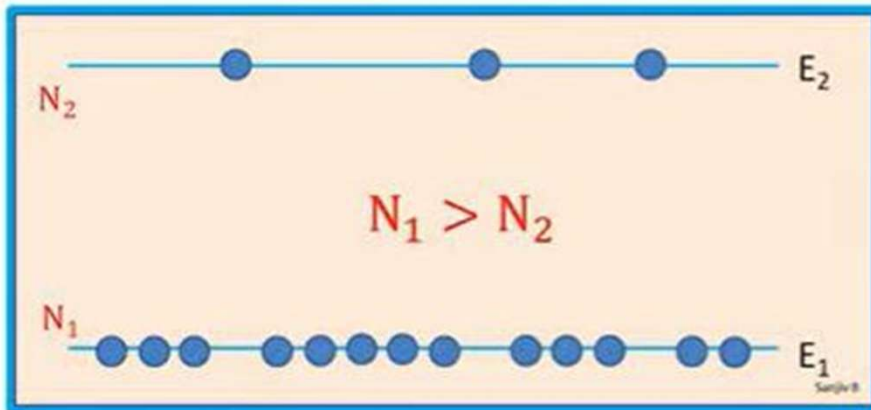


Population Inversion

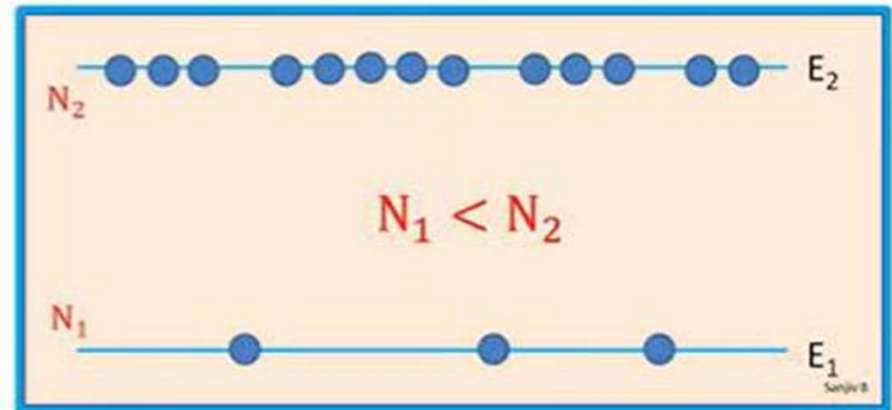


- A state in which a substance has been energized, or excited to specific energy levels.
- More atoms or molecules are in a higher excited state.
- The process of producing a population inversion is called **pumping**.
- Examples:
 - by lamps of appropriate intensity
 - by electrical discharge

Population Inversion



N_1 = Number of atoms in the lower energy level.
 N_2 = Number of atoms in the higher energy level.

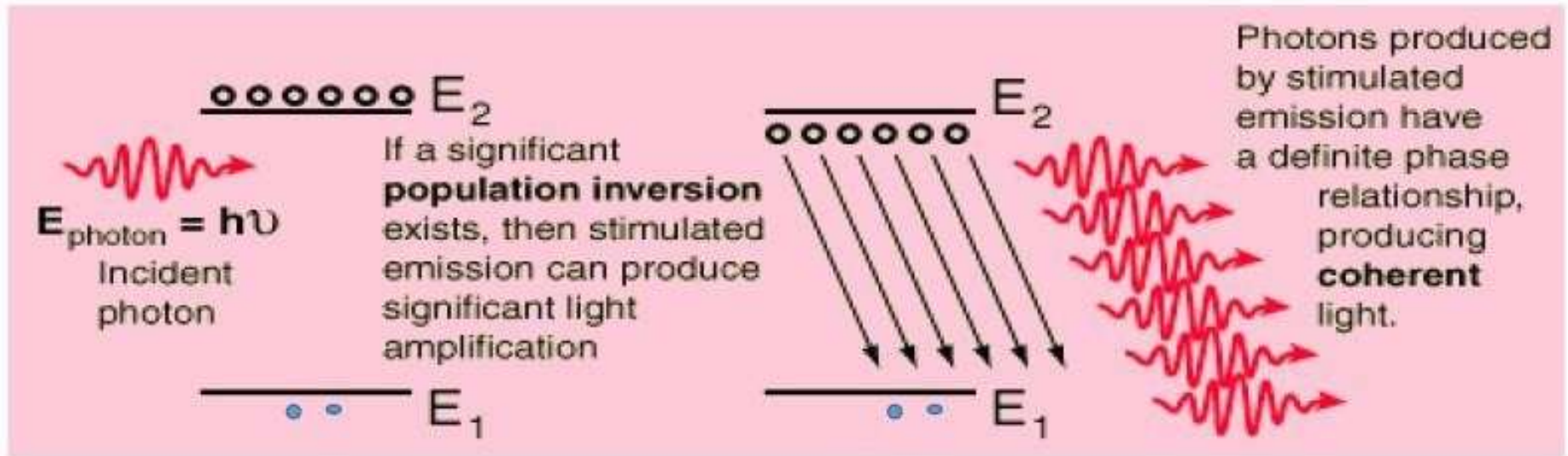


In Normal equilibrium, $N_1 > N_2$

Stimulated emission to be effective for light amplification, it should occur at large scale. This is achieved by adjusting $N_2 > N_1$

Getting more number of atoms in higher energy level than the lower energy level ($N_2 > N_1$) is called **Population Inversion**.

Condition for Lasing



Population Inversion

When no. of atoms per unit volume in higher energy state becomes greater than that of no. of atoms per unit volume in lower energy state, this condition is called "Population inversion". This sets stimulated emission and emits identical photons as of incident photon.

"Threshold Condition For Lasing"

Pumping



Pumping is the process of supplying energy to a laser's gain medium to excite its atoms into higher energy states, a necessary step for achieving **population inversion** and enabling laser action

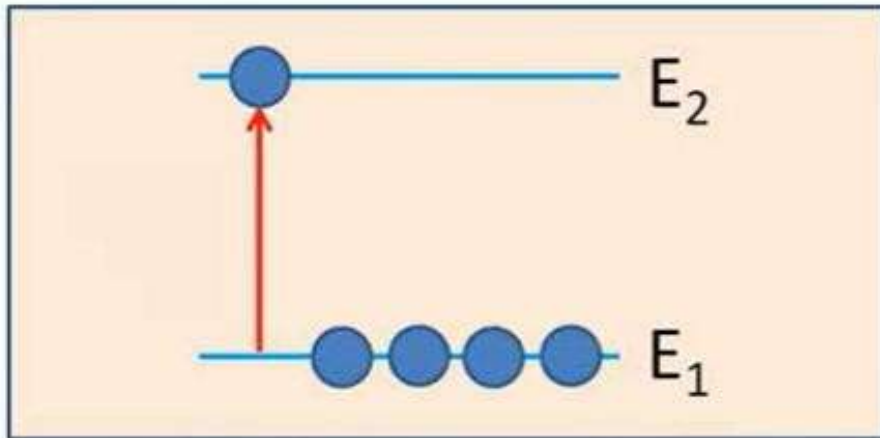
The main types of pumping in a laser are **optical, electrical, chemical, and gas dynamic**, which provide energy to create a population inversion in the laser medium.

- Optical pumping uses light,
- electrical pumping uses an electric current or discharge,
- chemical pumping uses a chemical reaction, and
- gas dynamic pumping uses compressed gas

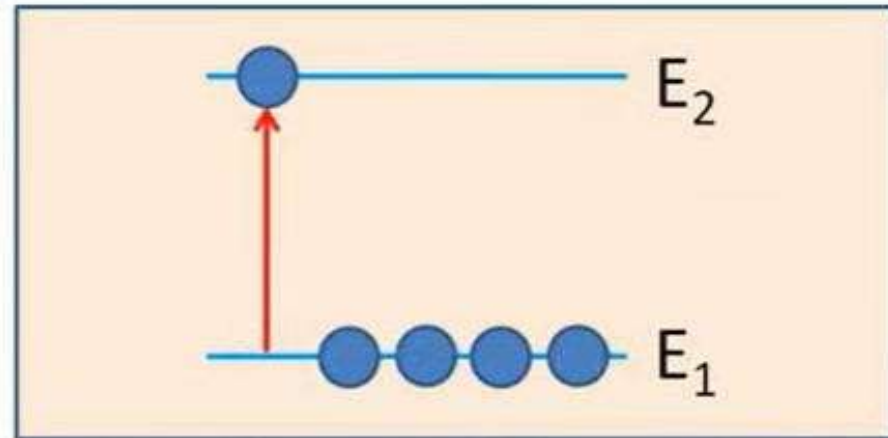
Other methods:

- **Direct Conversion:** Converts energy directly into laser output, often used in semiconductor lasers.
- **Inelastic Atom-Atom Collisions:** Energy is transferred between colliding atoms to excite them.
- **Thermal Pumping:** Heat is used to raise the temperature of the laser medium, which can achieve population inversion in some cases.

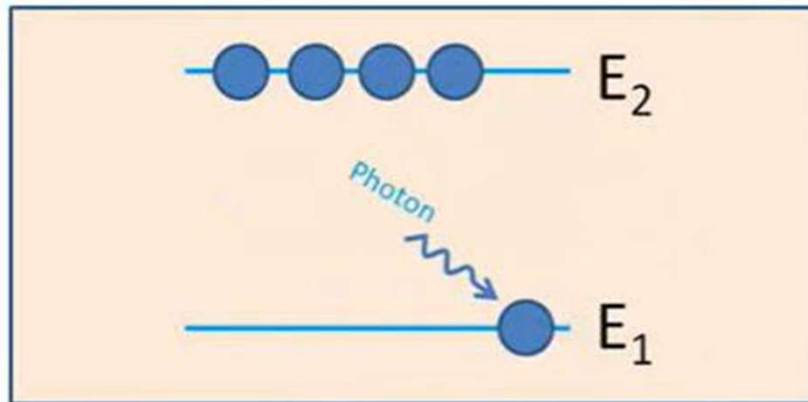
- To achieve population inversion, atoms must be continuously promoted from lower energy level to the higher energy level.
- The process by which atoms are raised from the lower energy level to the higher energy level is called Pumping.



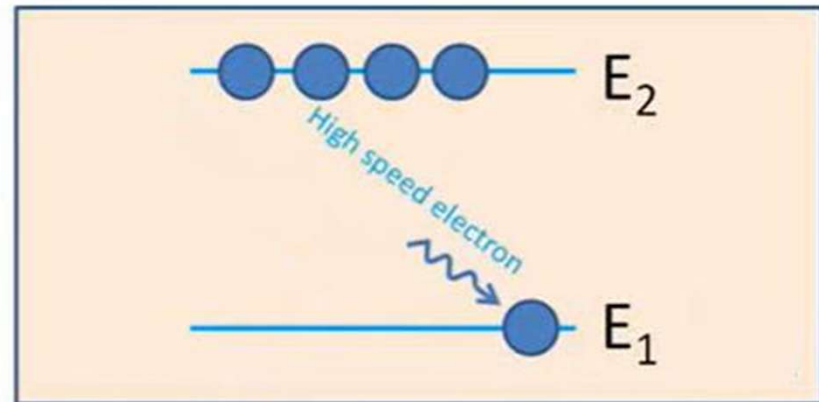
Optical Pumping



Electrical Pumping



Optical Pumping



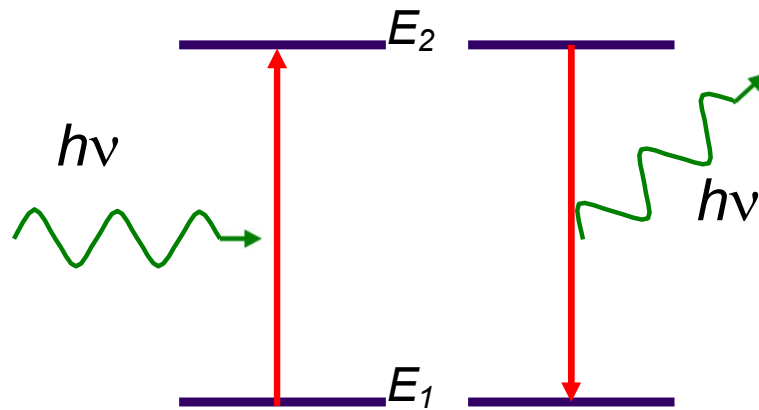
Electrical Pumping



Two level system

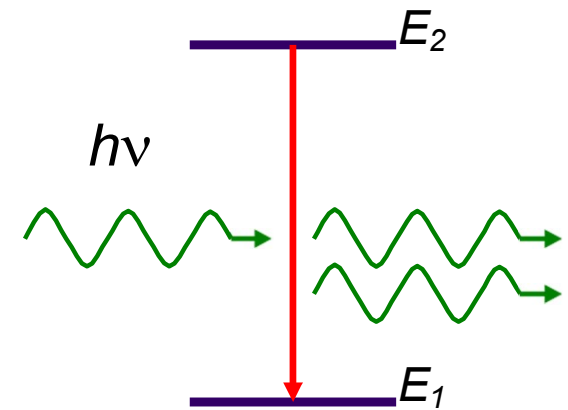


$$h\nu = E_2 - E_1$$

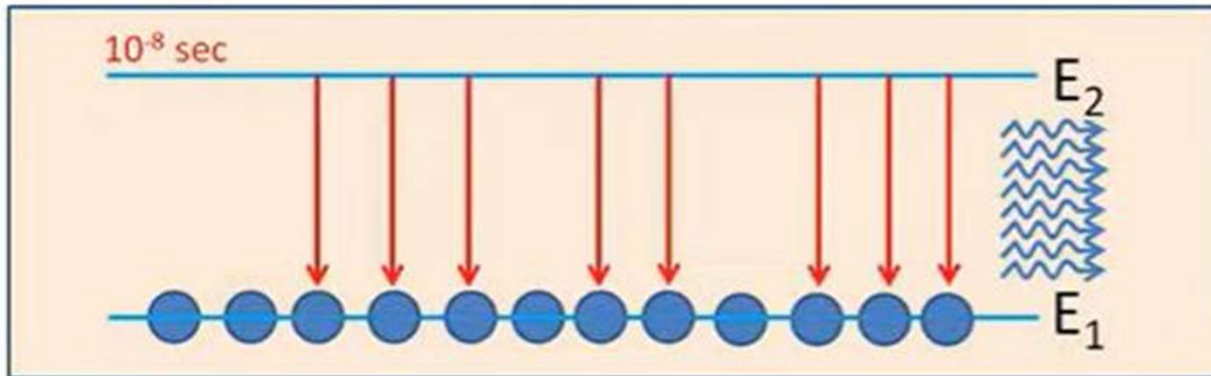


absorption

Spontaneous
emission

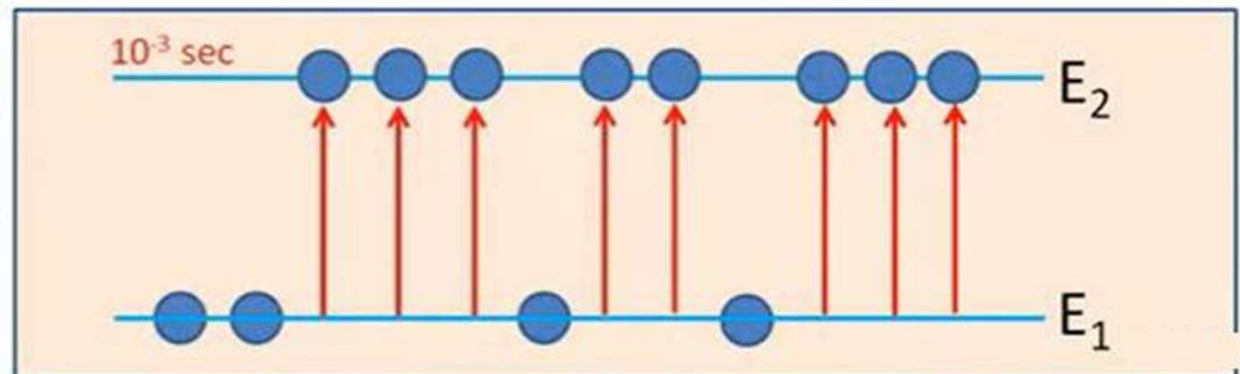


Stimulated
emission



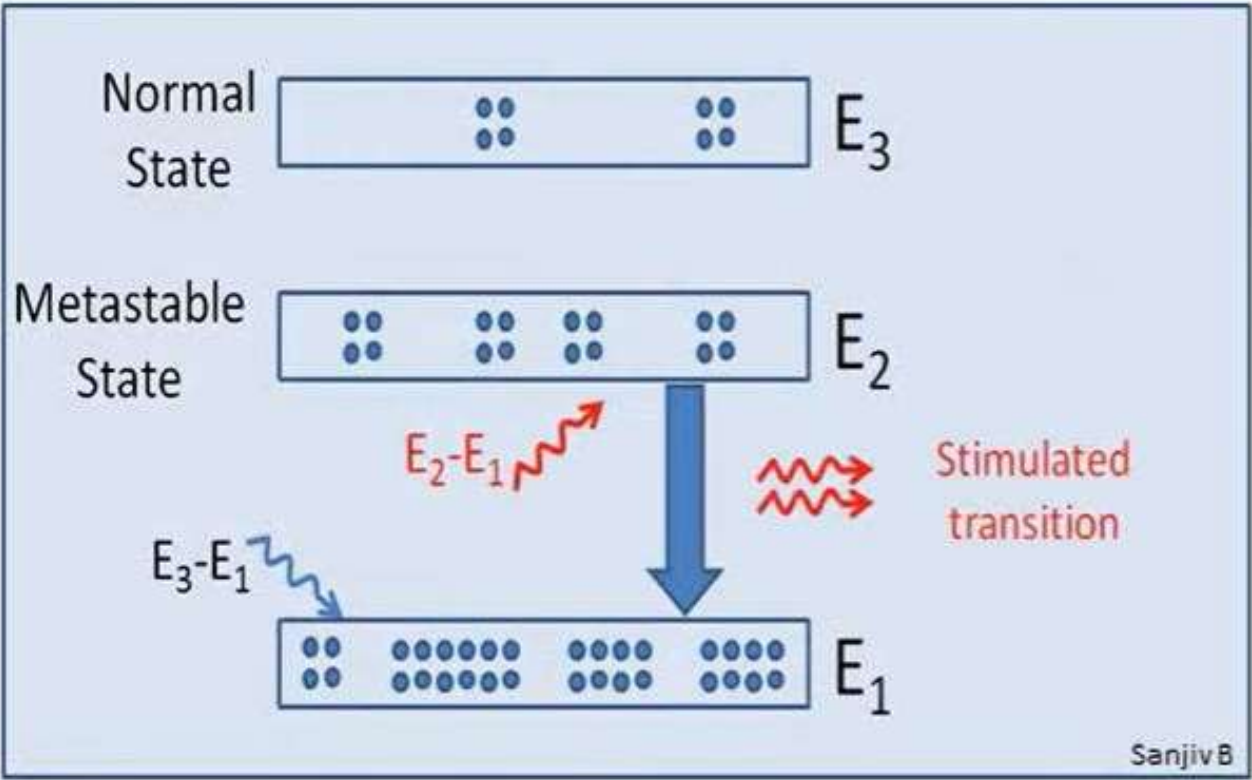
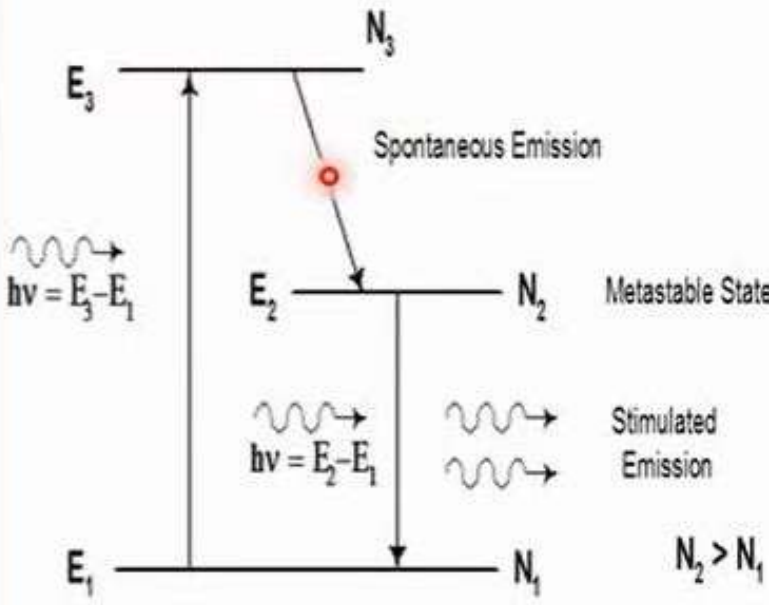
Non Metastable State

Metastable State

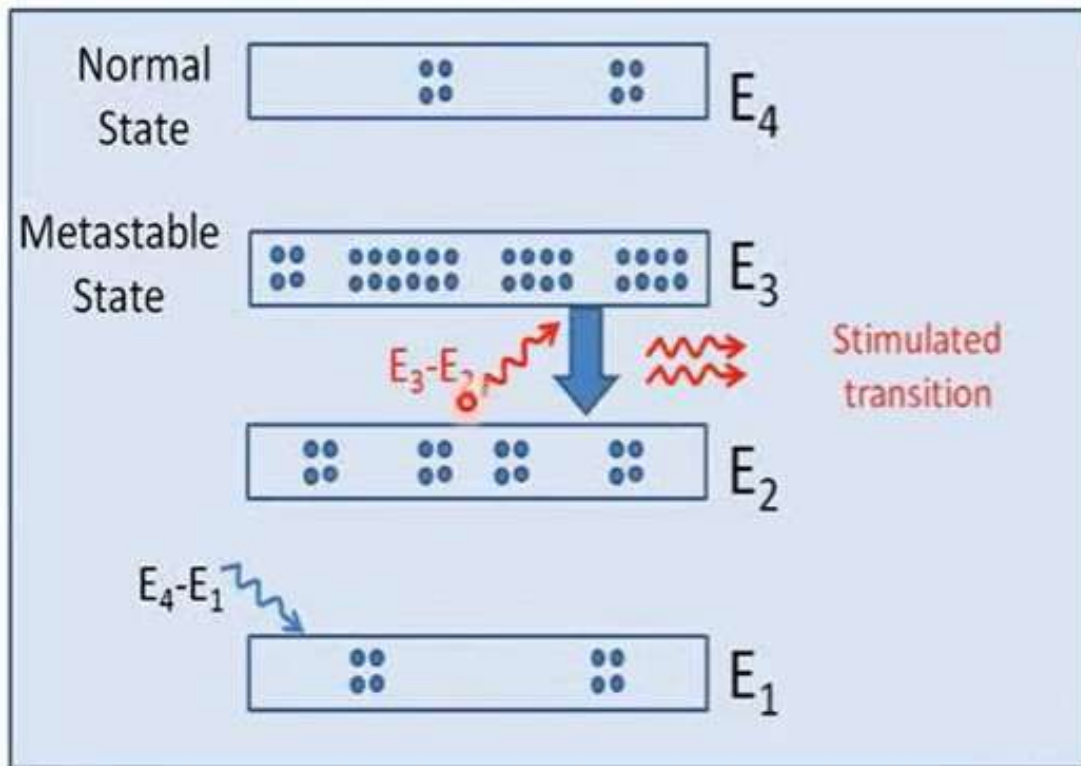
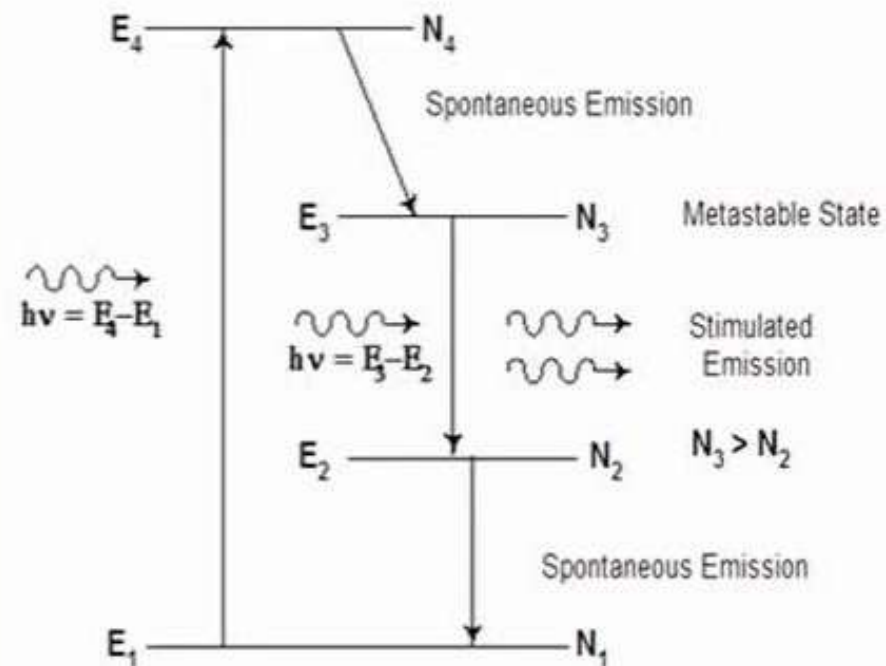


If the metastable state does not exist, there could be no population inversion and hence, no stimulated emission and hence no laser operation.

Three level system

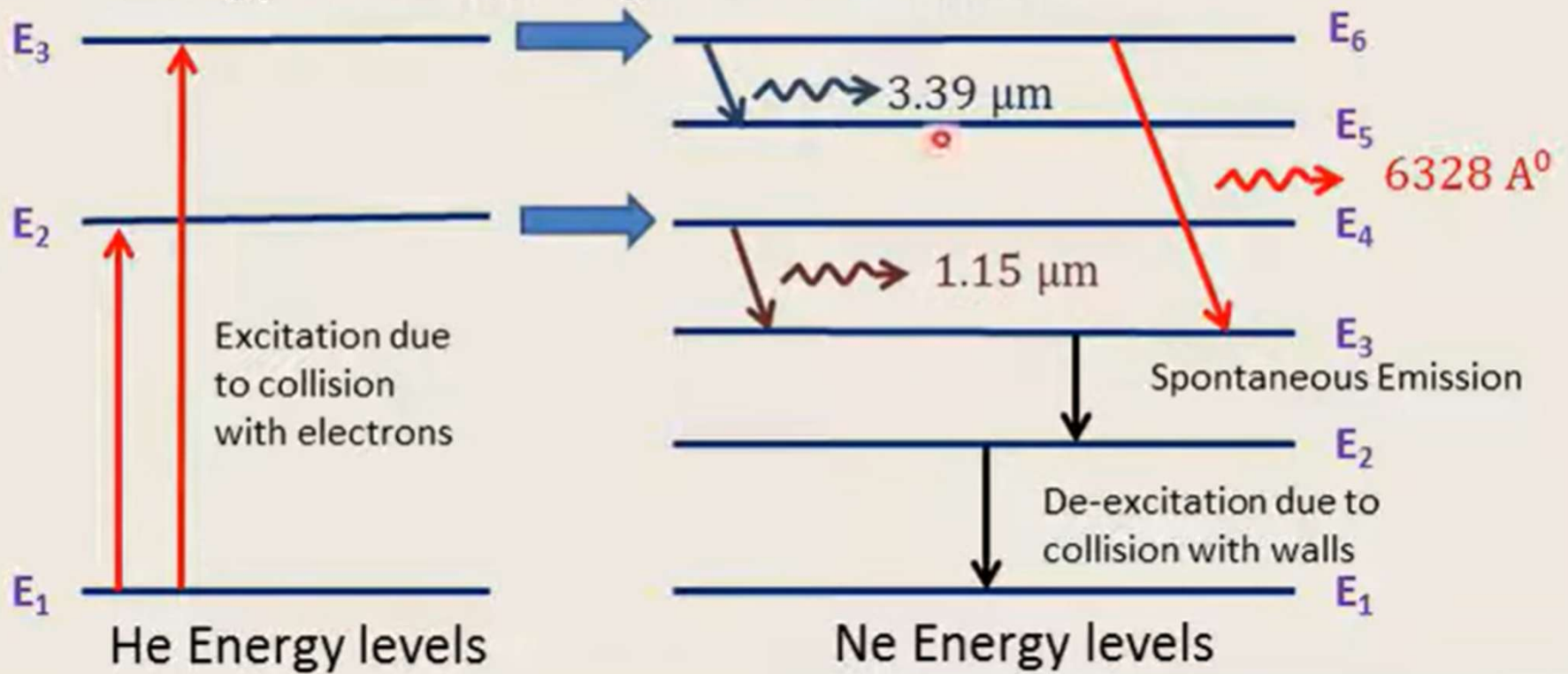


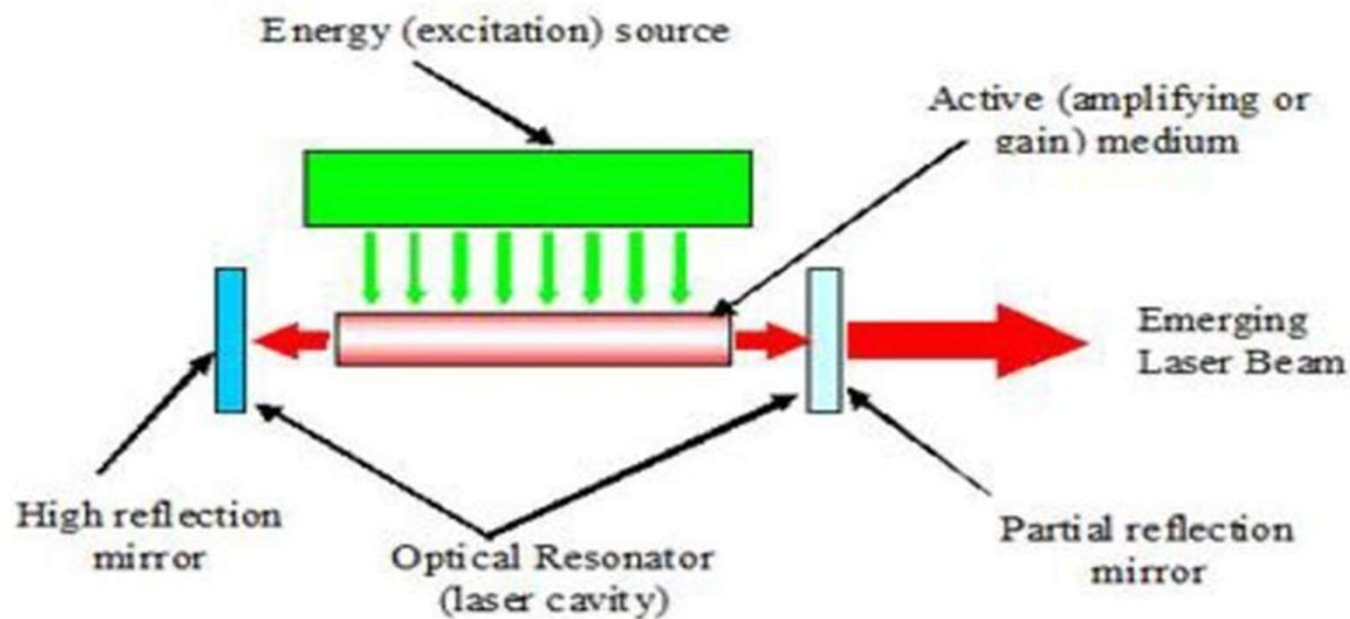
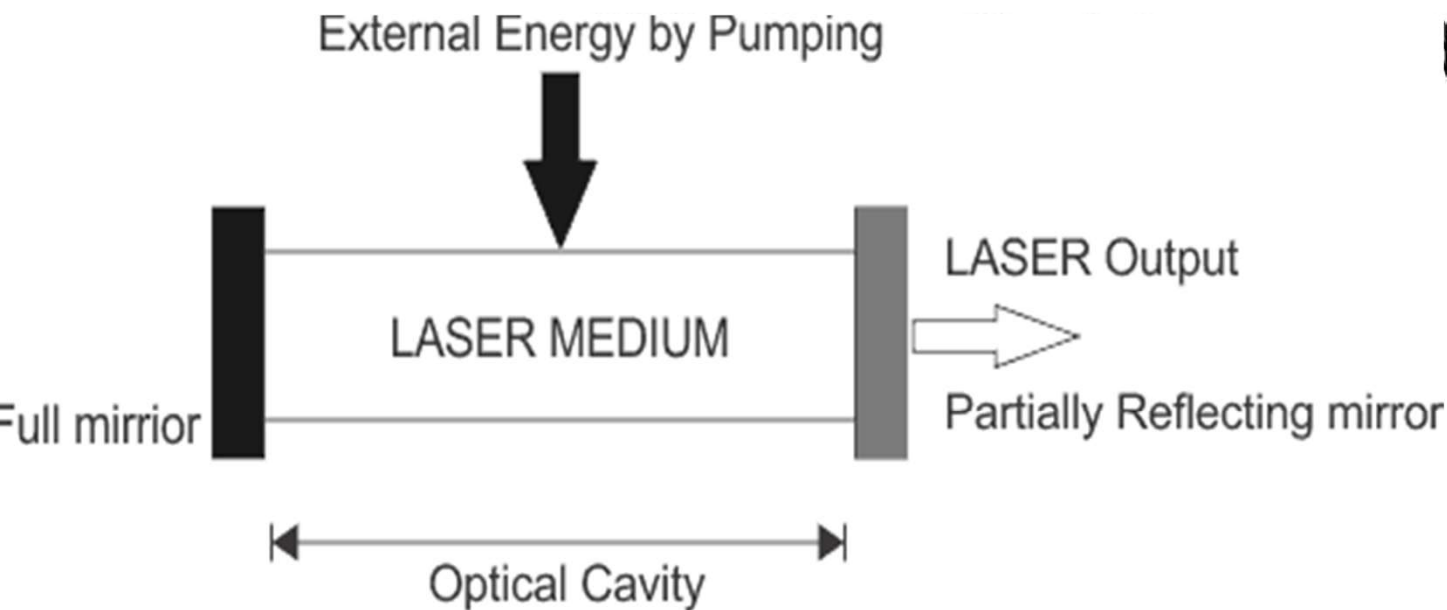
Four level system



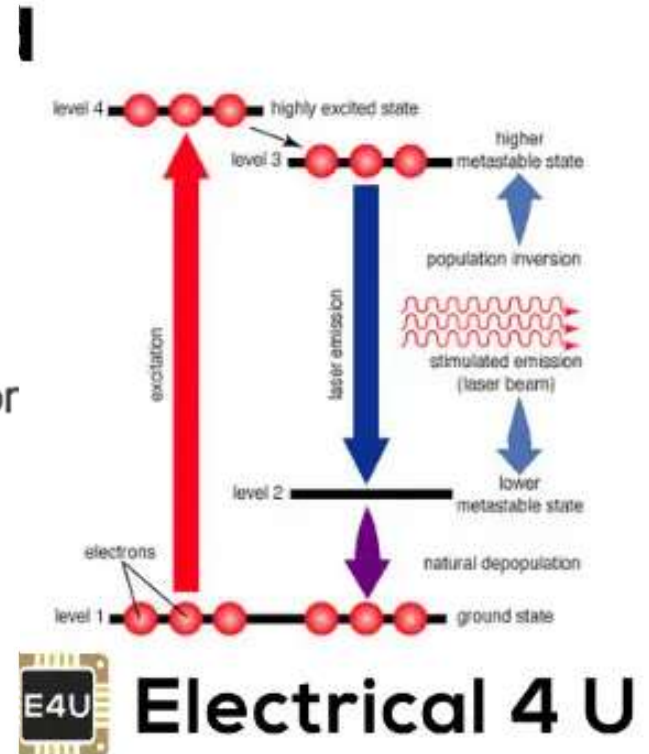


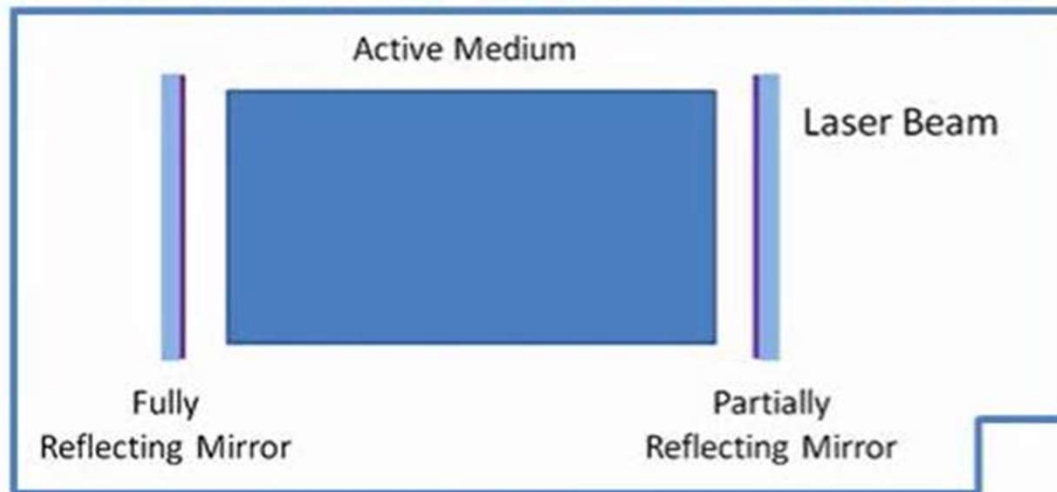
Energy Transfer through inelastic collision





Components of LASER

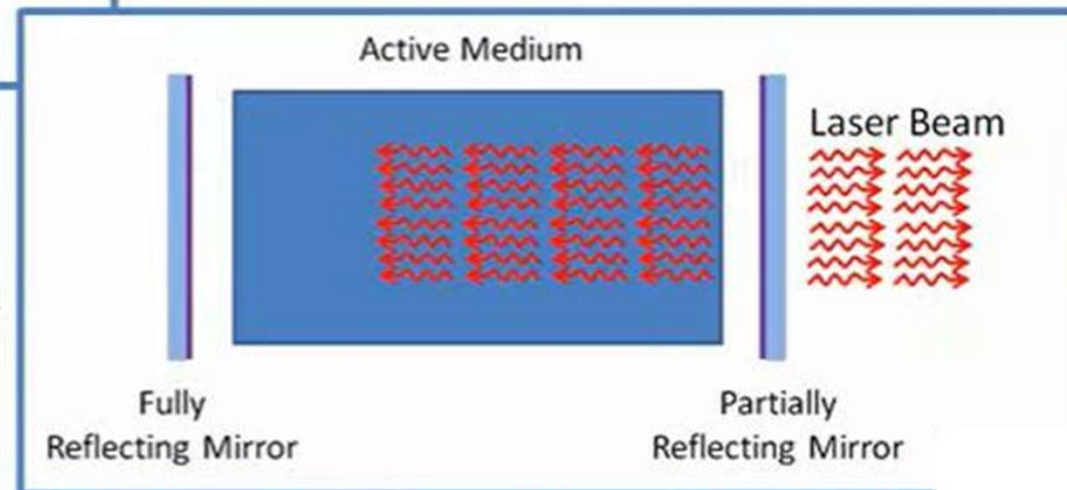




Resonant Cavity

Role of Resonant Cavity

1. Resonant cavity is useful for enhancing the light amplification.
2. Resonant cavity is used to get a laser beam in one direction.





Max Planck (German Physicist) introduced his groundbreaking theory of energy quanta in **1900**, which includes the relation $E=h\nu$. His work laid the theoretical foundation for lasers, though the first functional laser was not created until 1960.

Max Planck proposes that energy is emitted and absorbed in discrete packets, or quanta, to solve the problem of black-body radiation. He establishes the equation $E=h\nu$, where E is energy, h is Planck's constant, and ν is the frequency of the radiation.

Black body radiation: An idealized object that absorbs all incident radiation and emits radiation based solely on its temperature. Planck's law provides the formula for the spectral radiance of this emission across all wavelengths.

In Planck's radiation law, the spectral energy density is given by:

$$\rho_\nu(\nu, T) = \frac{8\pi h}{c^3} \frac{\nu^3}{\exp(h\nu/k_B T) - 1}$$

But Planck's derivation of the above formula used a mixed bag of contradictory assumptions, some of which were later found to be inconsistent with experimental fact.

Einstein Analysis to Planck's work



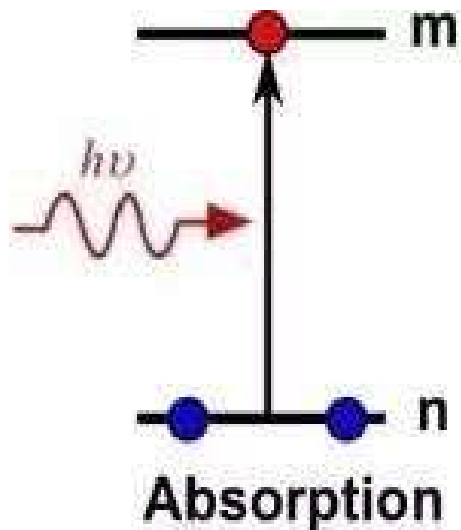
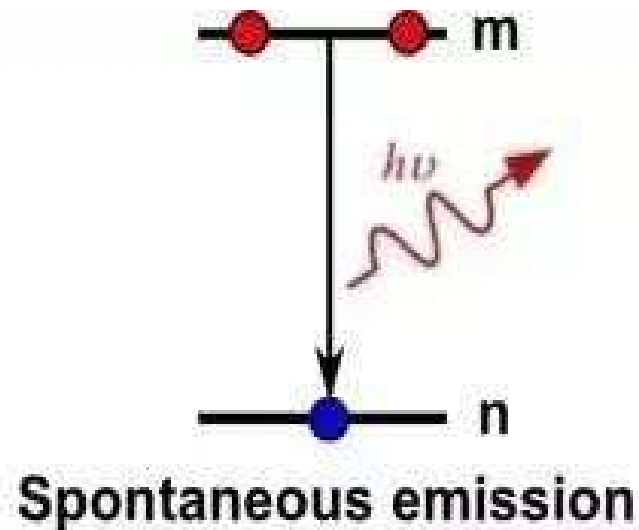
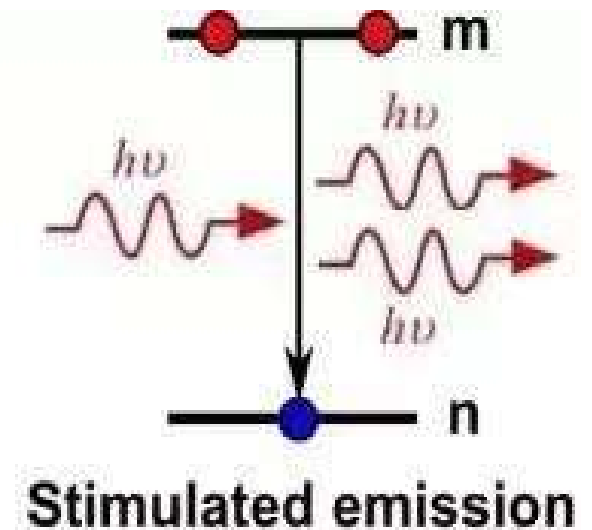
- His derivation used classical electrodynamics to relate the energy of an oscillator to the energy density of the radiation field
- Planck then turned around and assumed that this classical oscillator was split into equally spaced energy levels.
- Planck considered that the oscillators were quantized but not the light. But Einstein had demonstrated in 1905 that light itself displayed quantum behavior.
- Bohr had demonstrated that all systems of atoms had energy levels, but the energy levels were in general **not** equally spaced.

Therefore, although Einstein praised Planck's courage in making the quantum leap – **his derivation was of unparalleled boldness** – he noted that Planck's analysis – remains unsatisfactory that the electromagnetic-mechanical analysis [that Planck used] is incompatible with quantum theory

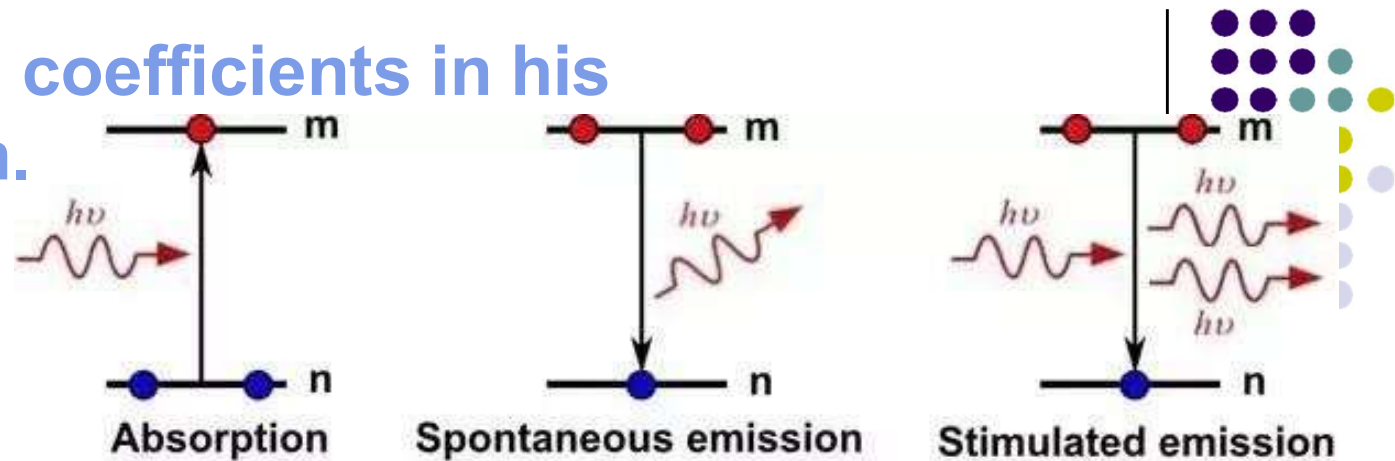
Einstein Analysis to Planck's work



Going further, Einstein stated that the classical elements in Planck's derivation must be replaced by quantum-theoretical contemplations on the interaction between matter and radiation.



Einstein's A and B coefficients in his theory of radiation.



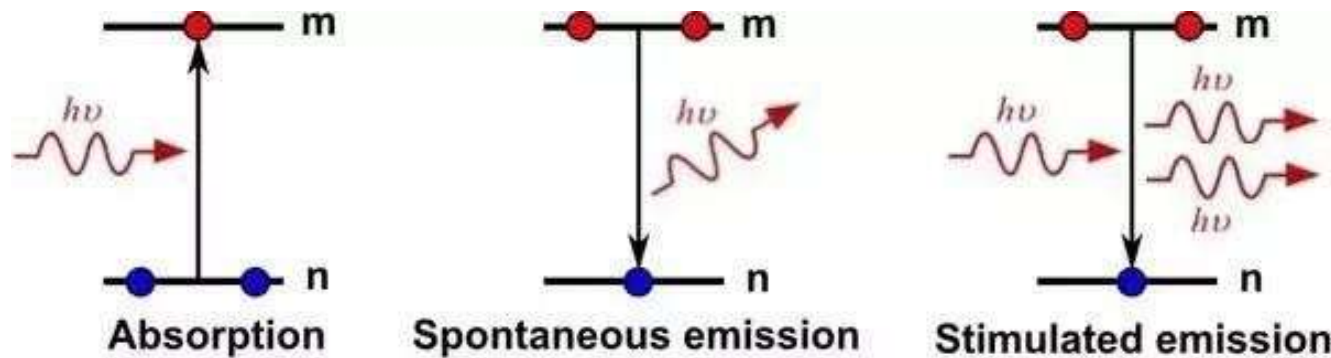
Consider a pair of energy levels of an atom (or molecule), m and n .

When light of the right frequency shines on the atom, it can absorb a photon and make a transition from state n to state m with a probability that is proportional to the intensity of the light.

Einstein designated the proportionality constant for this transition B_{nm} .

According to Einstein, a finite probability exists for an excited atom to undergo *spontaneous emission* of a photon.

He designated this probability A_{mn} , a number which is independent of whether light is shining on the atom or not.



Besides spontaneous emission, Einstein also considered *stimulated emission* events.

The probability of stimulated emission was proportional to the intensity of the incoming radiation with a proportionality constant of B_{mn} .

Einstein was able to demonstrate that $B_{nm} = B_{mn}$.

In other words, the induced emission probability and the absorption probability must be equal.



Let N_n be the number of atoms in state n and N_m be the number of atoms in state m . Then the rate at which atoms go from state n to state m is given by

$$R_{n \rightarrow m} = N_n B_{nm} I(\omega)$$

while the rate at which atoms go from state m to state n is given by

$$R_{m \rightarrow n} = N_m [A_{mn} + B_{mn} I(\omega)].$$

At equilibrium, $R_{n \rightarrow m} = R_{m \rightarrow n}$

Einstein pointed out that this equilibrium condition must hold between any pair of states, as well as balancing out overall. Unlike Planck's derivation, where it was necessary for the energy levels to be equally spaced before a sum could be taken of the contributions of an infinite series of harmonic oscillators, **Einstein's energy levels had no restrictions on their spacing.**

From the Boltzmann distribution [↗](#), we know the ratio of N_m to N_n at equilibrium:

$$N_m = N_n e^{-(E_m - E_n)/kT}$$

Einstein assumed that only light with a frequency corresponding to the energy difference would be effective in driving the transition from n to m , so that

$$E_m - E_n = \hbar\omega. \text{ Hence,}$$

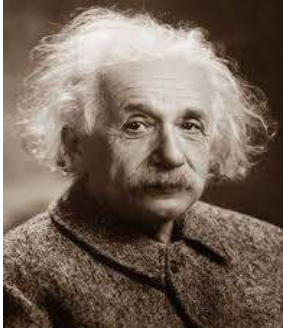
$$N_m = N_n e^{-\hbar\omega/kT}$$

We can thus write

- $N_n B_{nm} I(\omega) = N_m [A_{mn} + B_{mn} I(\omega)]$
- $B_{nm} I(\omega) e^{\hbar\omega/kT} = A_{mn} + B_{mn} I(\omega)$
- $I(\omega) = \frac{A_{mn}}{B_{nm} e^{\hbar\omega/kT} - B_{mn}}$
- Since $I(\omega)$ goes to infinity as temperature goes to infinity, $B_{nm} = B_{mn}$. In other words, the induced emission probability and the absorption probability must be equal.
- $I(\omega) = \frac{A_{mn}/B_{mn}}{e^{\hbar\omega/kT} - 1}$
- Einstein argued that he could use [Wien's distribution law](#) (also called [Wien's radiation law](#)) in the numerator to deduce $A_{mn}/B_{mn} = \hbar\omega^3 / \pi^2 c^2$



Einstein's Relation



Einstein laid the theoretical foundation for lasers in **1917** with his paper on the quantum theory of radiation, which introduced the concept of stimulated emission and the related Einstein coefficients. Foundation of Charles H. Townes's maser (microwave laser) in 1953 and Theodore H. Maiman's first working laser in 1960.



Under thermal equilibrium, the mean population N_1 and N_2 in the lower energy level (E_1) and upper energy level (E_2) respectively must remain constant

**Number of atoms absorbing photons
per second per unit volume**

$$\left. \begin{array}{l} \text{Number of atoms absorbing} \\ \text{photons per second per unit} \\ \text{volume} \end{array} \right\} = B_{12} \rho(\nu) N_1$$

1

$$\left. \begin{array}{l} \text{Number of atoms emitting} \\ \text{photons per second per unit} \\ \text{volume} \end{array} \right\} = A_{21} N_2 + B_{21} \rho(\nu) N_2$$

2

**Number of atoms emitting photons
per second per unit volume**

In Equilibrium,

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

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

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

Dividing numerator and denominator by $B_{12} N_2$,

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

3

$\rho(\nu)$ is the energy density of incident light

B_{12} , A_{21} and B_{21} are Einstein coefficients of absorption, spontaneous emission and stimulated emission respectively



$$\rho(v) = \frac{\frac{A_{21}}{B_{12}}}{\frac{N_1}{N_2} - \frac{B_{21}}{B_{12}}} \quad (3)$$

From Boltzmann equation, population N of energy level E at temperature T is given by -

$$N = e^{\frac{-E}{kT}}$$

$$\text{Therefore, } N_1 = e^{\frac{-E_1}{kT}} \quad (4)$$

$$N_2 = e^{\frac{-E_2}{kT}} \quad (5)$$

Divide (4) by (5)

$$\therefore \frac{N_1}{N_2} = e^{-(E_1-E_2)/kT} = e^{(E_2-E_1)/kT} = e^{h\nu/kT} \quad (6)$$

Substituting in (3)

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



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

This radiation must be identical to the radiation formula given by Planck which gives density of photons as -

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

Comparing (7) and (8)

$$\therefore B_{21} = B_{12} \quad (9)$$

$$\text{and} \quad \frac{A_{21}}{B_{12}} = \frac{8 \pi h \nu^3}{c^3}$$

$$\text{i.e.} \quad A_{21} = \frac{8 \pi h \nu^3}{c^3} B_{12} \quad (10)$$



Einstein Relation

$$\therefore B_{21} = B_{12}$$

9

Thus probability of upward transition is equal to probability of downward transition.

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

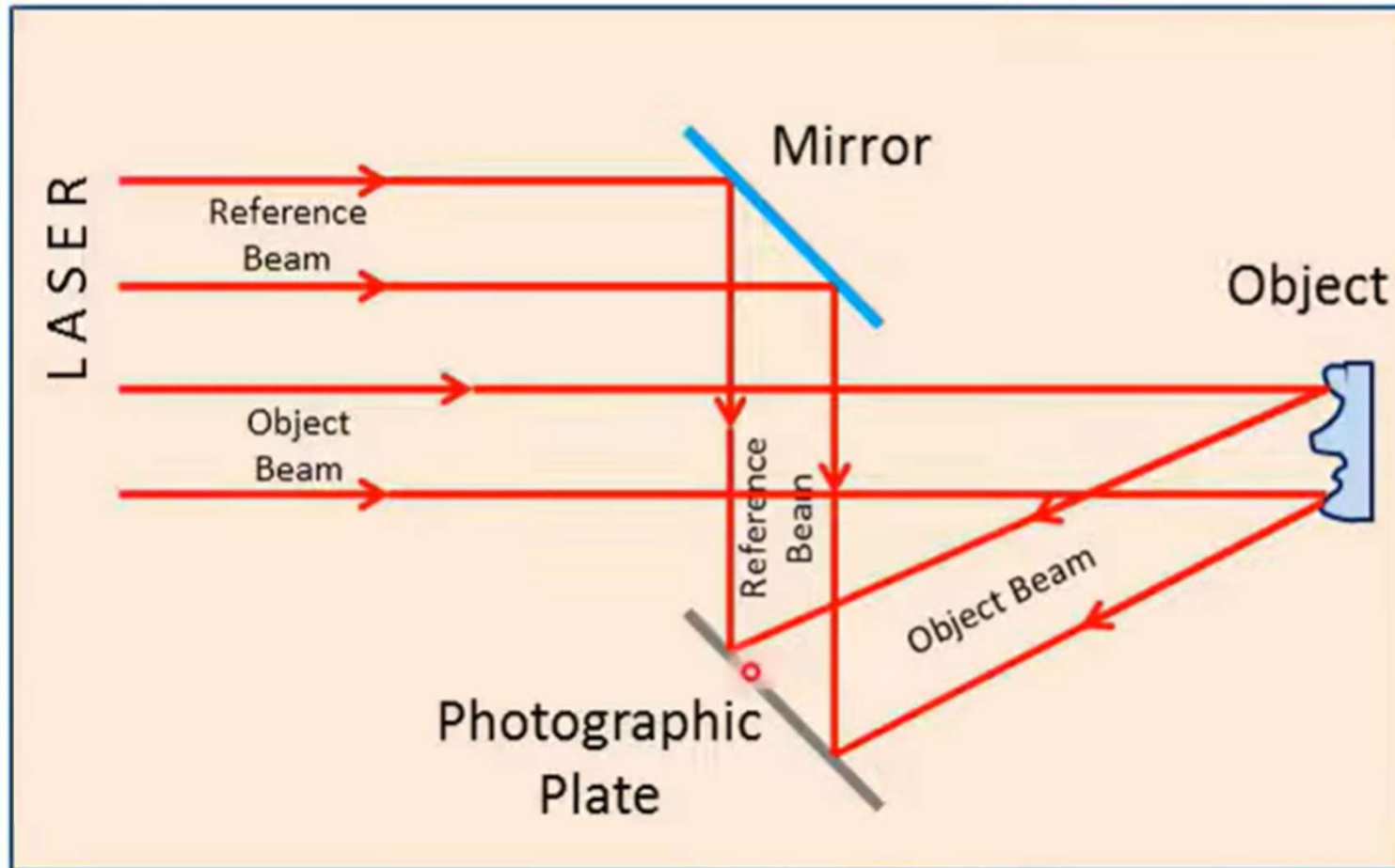
10

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

Spontaneous emission dominates over the stimulated emission if the energy difference ($E_2 - E_1 = h\nu$) between the two levels is high.

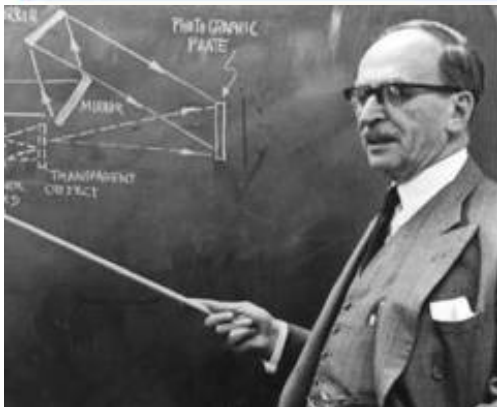
So it is difficult to achieve lasing action in higher frequency ranges and low wavelengths.

Lasers – Holography

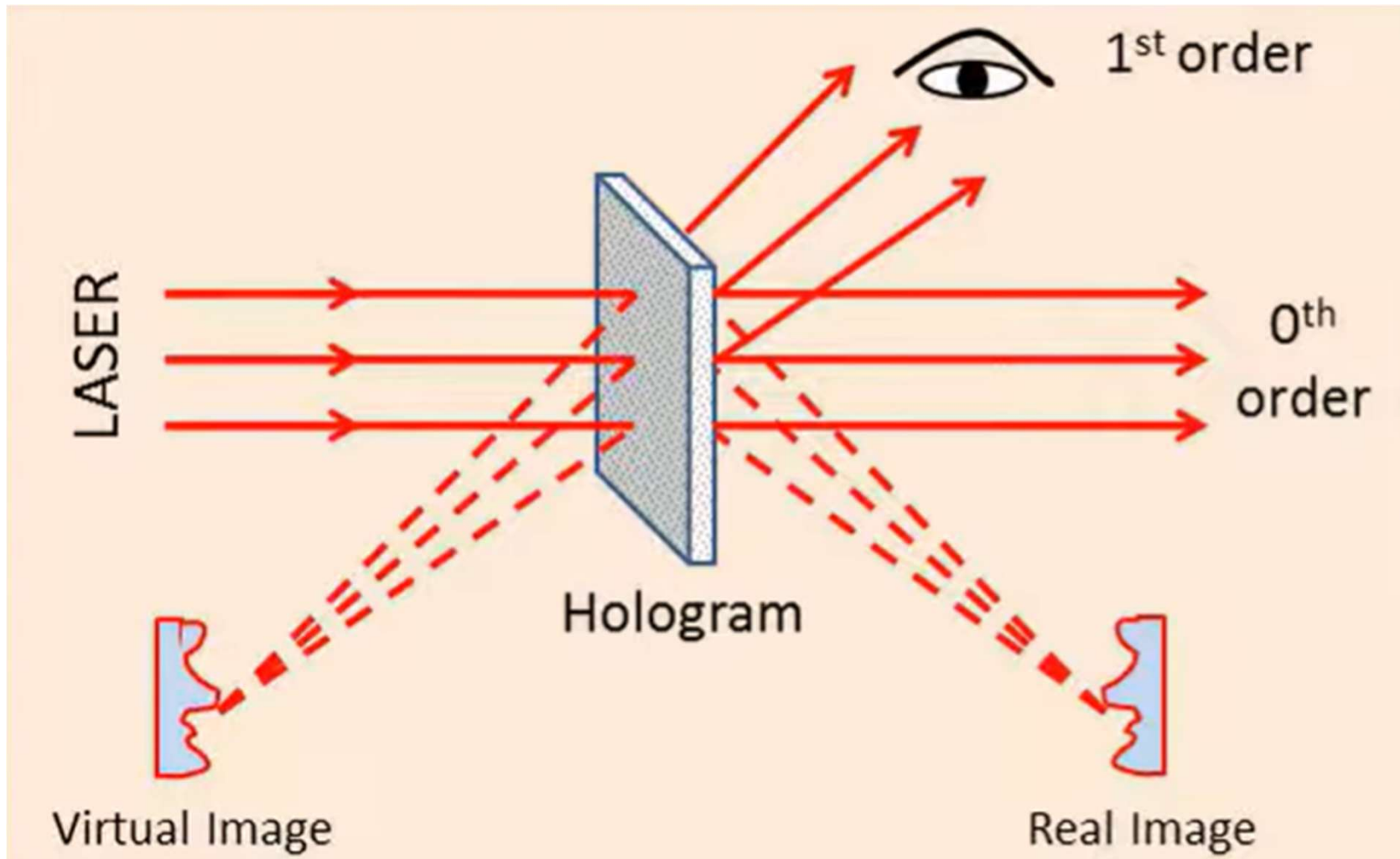


3D imaging

Intensity and phase both are recorded



Dennis Gabor, a Hungarian-British physicist, invented the hologram in **1948**. He was awarded the Nobel Prize in Physics in 1971 for his work in developing the holographic method





Lasers – Applications



Industry



Manufacturing





The ground state and excited state of the laser is separated by 1.8 eV. Calculate the ratio of number of atoms in the excited state to the ground state and wavelength of radiation emitted at 27°C.

$$\text{Given : } E_2 - E_1 = 1.8 \text{ eV} = 1.8 \times 1.6 \times 10^{-19} = 2.88 \times 10^{-19} \text{ J} \\ T = 27^\circ\text{C} = 300^\circ\text{K}, \quad k = 1.38 \times 10^{-23} \text{ J/K}$$

We know, Number of atoms in energy level $E = N = e^{\frac{-E}{kT}}$

N_2 = number of atoms in excited state and N_1 = number of atoms in ground state

$$\frac{N_2}{N_1} = e^{\frac{-(E_2 - E_1)}{kT}} = e^{\frac{-(2.88 \times 10^{-19})}{1.38 \times 10^{-23} \times 300}} = 6.14 \times 10^{-31}$$

$$E_2 - E_1 = h\nu = \frac{hc}{\lambda}$$

$$\therefore \lambda = \frac{hc}{E_2 - E_1} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{2.88 \times 10^{-19}} = 6900 \text{ A}^\circ$$



Find the ratio of population of higher energy state to lower energy state when the optical pumping is used at 27°C and photons of wavelength $6982 \times 10^{-8}\text{m}$ are emitted.

$$\text{Given : } E_2 - E_1 = h\nu = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{6982 \times 10^{-8}} = 2.848 \times 10^{-21}\text{J}$$
$$T = 27^\circ\text{C} = 300^\circ\text{K}, \quad k = 1.38 \times 10^{-23}\text{J}/^\circ\text{K}$$

We know, population of energy level $E = N = e^{\frac{-E}{kT}}$
 N_2 = population of atoms in higher energy state and
 N_1 = population of atoms in lower energy state

$$\frac{N_2}{N_1} = e^{\frac{-(E_2 - E_1)}{kT}} = e^{\frac{-(2.848 \times 10^{-21})}{1.38 \times 10^{-23} \times 300}} = 0.503$$



If wavelength of the laser beam is $6550 \text{ \AA}$, calculate the energy and momentum of photon.

Given : $\lambda = 6550 \text{ \AA} = 6550 \times 10^{-10} \text{ m}$

$$E = h\nu = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{6550 \times 10^{-10}} = 3.0366 \times 10^{-19} \text{ J}$$

According to De Broglie hypothesis,

$$\lambda = \frac{h}{p}$$

$$\therefore p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{6550 \times 10^{-10}} = 1.012 \times 10^{-27} \text{ kg} \frac{\text{m}}{\text{s}}$$

Types of LASER



Lasers are classified into 6 types based on the types of medium used in them, and they are:

- Solid-state lasers (Ruby, Nd: YAG)
- Gas lasers (CO₂ and He-Ne, Ar-ion)
- Liquid lasers (Dyes: ethylene glycol, ethyl, or methyl, as the laser medium)
- Semiconductor lasers (GaAs based PN Junction Diode)
- Chemical lasers (HF and Deuterium Fluoride)
- Metal-vapour lasers (He-Cd and Cu Vapour)

Semiconductor and solid-state lasers are both lasers with a solid lasing medium, but they have several differences:

- Solid-state lasers are optically pumped, meaning they receive energy in the form of light. Semiconductor lasers are excited by an electric current passing through them.
- Solid-state lasers are typically made of an optically transparent crystal or glass doped with activated ions or other substances. Semiconductor lasers are made of materials like gallium arsenide (GaAs), cadmium sulfide (CdS), indium phosphide (InP), and zinc sulfide (ZnS).

Types of LASER

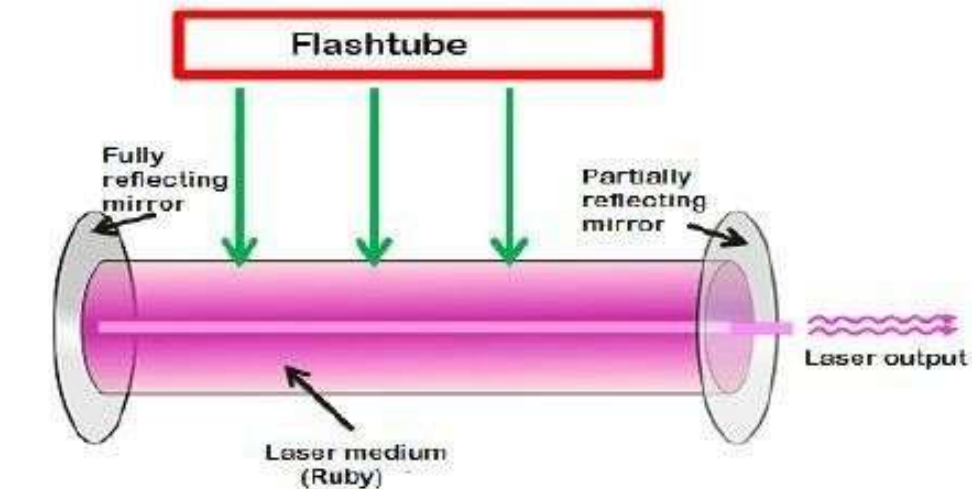
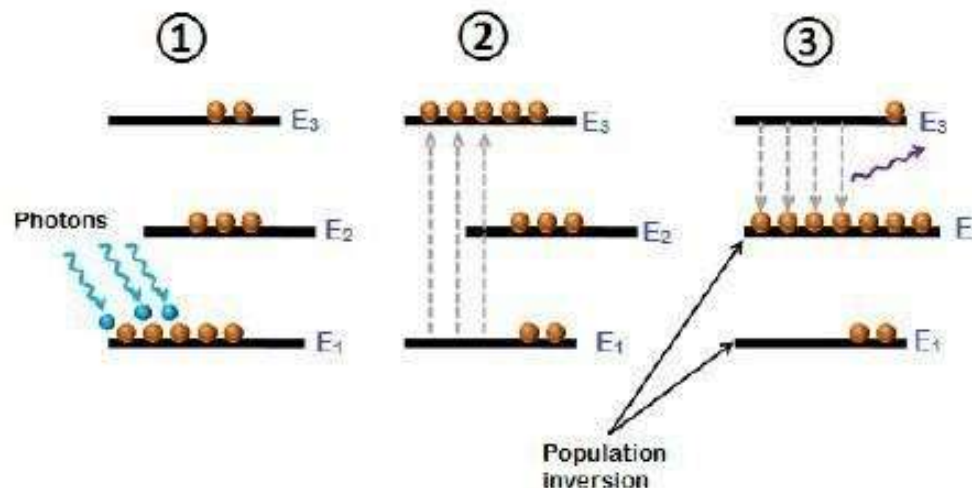


Types of Industrial Laser:

Depending on the followings:

1. The state of Lasing Material
(Solid **OR** Gas)
2. The range of the laser wavelength
(Short **OR** Large Wavelength)
3. The mode of operation
(CW-Laser **OR** PW-Laser)
4. The pumping method
(Optical Pumped **OR** Discharge Pumped)

Ruby Laser



$\text{Cr} - \text{AlO}_3$
Similar to Neodimium-YAG

Solid laser
pulsed

Pumping: Flashlamp

Excited atom: Cr^{3+}

Laser levels: Cr^{3+}

$P = 100 \text{ MW}$

$D = 0.5 \dots 5 \text{ mm}$

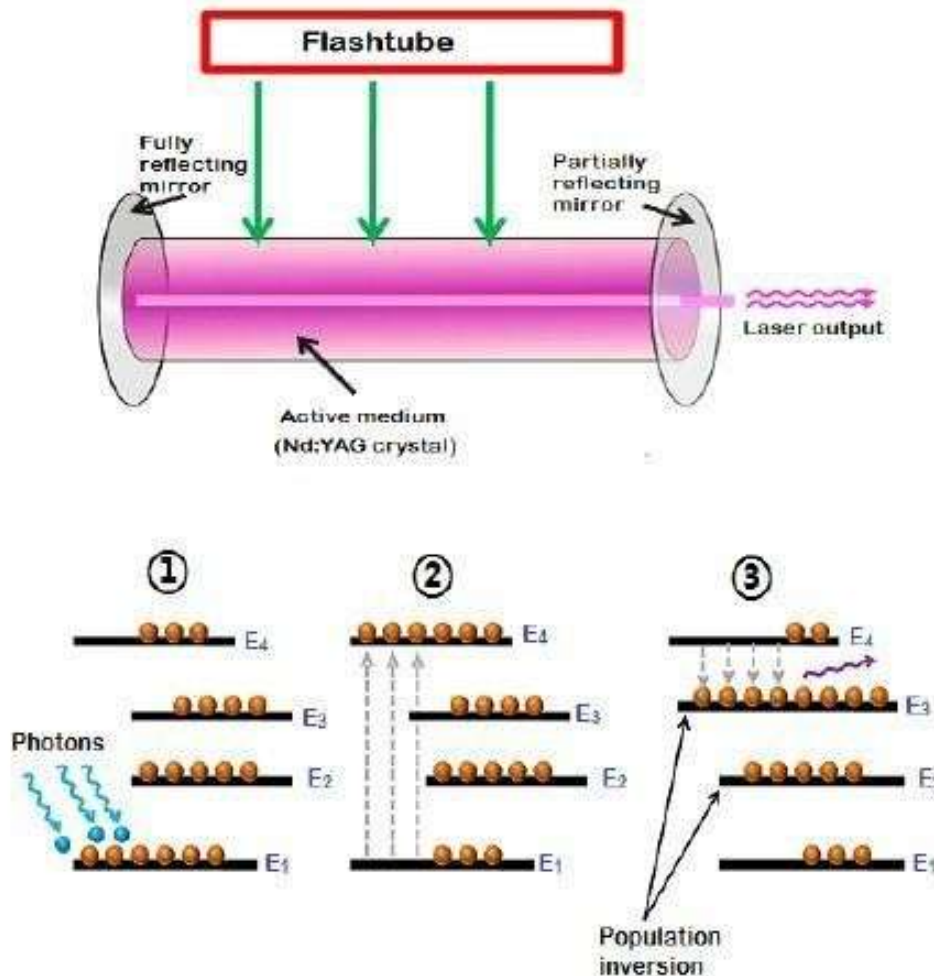
Divergence = $0.5 - 1 \text{ mrad}$

$\lambda = 694 \text{ nm}$

Cooling: water / air

Pulse width: 10 ns

Nd:YAG Laser



Physics and Radio-Electronics

Neodimium - $\text{Y}_3\text{Al}_5\text{O}_{12}$ granite

Solid laser

Pulsed or C.W.

Pumping: flashlamp

Excited atom: Nd^{3+}

Laser levels: Nd^{3+}

$P = 60 \text{ W (c.w.)} \dots 1 \text{ MW}$

$D = 0.5 \dots 5 \text{ mm}$

Divergence = $0.5 - 1 \text{ mrad}$

$\lambda = 1065 \text{ nm}$

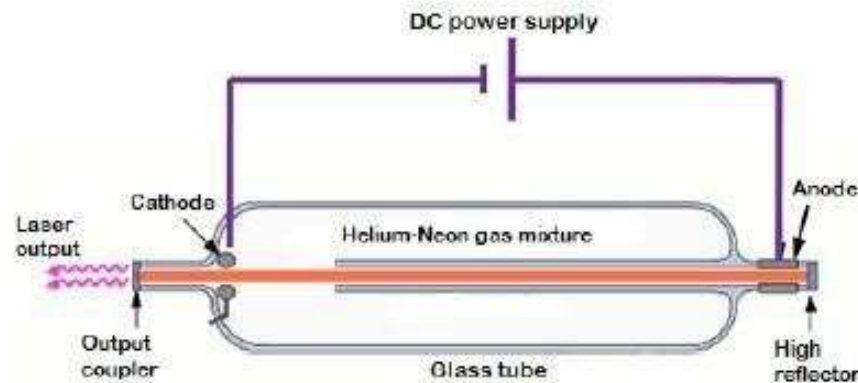
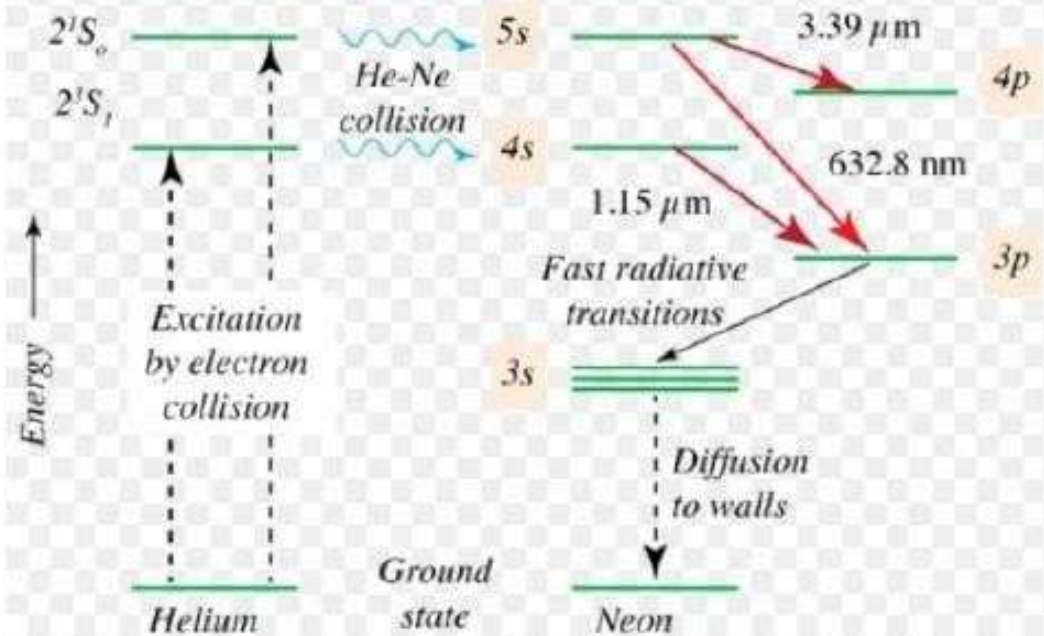
Cooling: water

Pulse width: 10 ns (Q-switched)

Similar: ruby, Er-YAG, Tm-YAG

Non-linear optics: $532, 355, 266 \text{ nm}$

He-Ne Laser



Gas (atomic) laser
 continuous wave (c.w.)
 Pumping: electric pulse
 Excited atom: He
 Laser levels: Ne
 He:Ne = 10:1
 p = 1 torr
 Exit mirror: T = 2 %
 P = 1 ... 100 mW
 D = 1 mm
 Divergence = 1 mrad
 $\lambda = 632.8 \text{ nm}$
 $\lambda = 543 \text{ nm}$

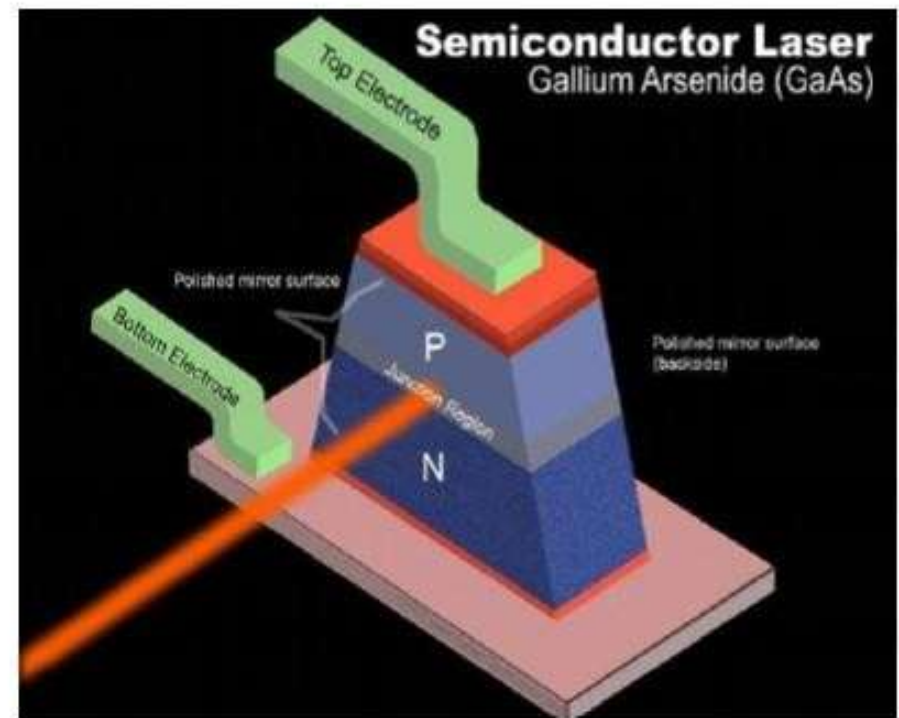


Semiconductor laser-Construction

Active Medium: Heavily doped Semiconductor material such as GaAs, InP, etc.

Optical Resonator:

- By cleaving two ends (110) optical resonator is obtained
- Due to refractive indices difference between material and air ideally $R=33\%$.
- It is increased by coating both end with suitable materials such as Al_2O_3 , TiO_2 etc.



Excitation Source : Current is pumping source.