LASER: CHARACTERISTICS

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Reference Books:

- **Modern Physics**
  Arthur Beiser

- **Understanding Lasers**
  Jeff Hecht

- **Lasers fundamentals and applications**
  K. Thyagarajan, A. Ghatak

What is LASER?

Light Amplification by Stimulated Emission of Radiation

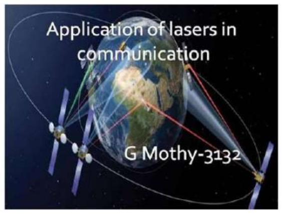
- Radiation: means electromagnetic radiation.
- Stimulated Emission: the way lasers produce light.
- Amplification: increase the amount of light emitted.
- Light: type of electromagnetic radiation produced.

Applications of LASER

Surveying

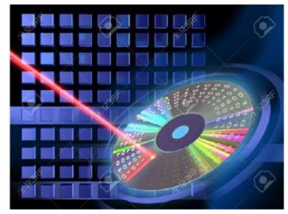
Laser Eye surgery

Welding and Cutting



Laser Communication

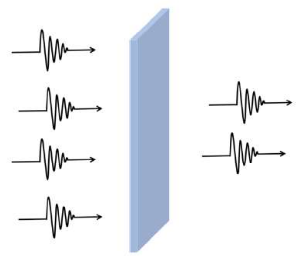
Barcode scanners



CD Read/Write

What happens when light interact with matter:

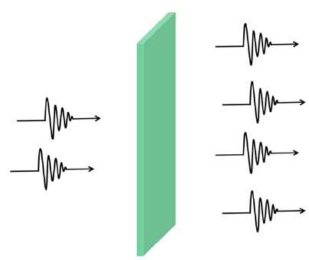
When light passes through materials it is usually absorbed.



In certain circumstances light may be amplified.

This was called "negative absorption".

It is the basis of laser action.

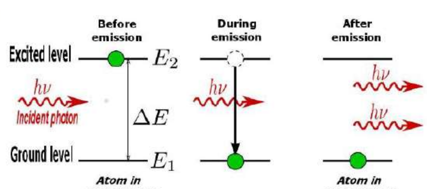


Radiation and its interaction with matter

When radiation interacts with matter the following processes may occur:

- Stimulated Absorption
- Spontaneous Emission
- Stimulated Emission

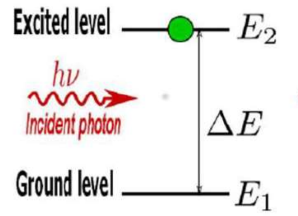
- let us consider two energy levels E1 and E2 some atom or molecule of a given material.
- The lowest energy level E1 is called the ground state and the higher energy levels are excited states. Here E1 < E2.
- The two levels in this discussion could be any two out of the infinite set of levels possessed by the atom.



$$E_2 - E_1 = \Delta E = h\nu$$

Stimulated Absorption

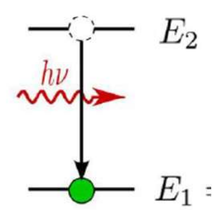
- Let us now assume that the atom is initially lying in ground state E1.
- The atom will remain in this level unless some external stimulus is applied to it.
- Let us assume, that an electromagnetic radiation of frequency ν is incident on the material.
- If the energy difference *E*2 -*E*1 is equal to the incident photon energy hν, then the atom to undergo transition from lower energy level to the excited state.
- This is the *stimulated absorption* process.



$$E_2 - E_1 = \Delta E = h\nu$$

Spontaneous Emission

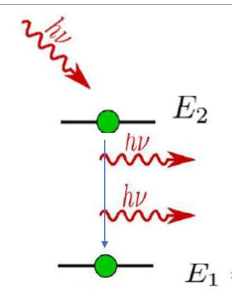
- Let us now assume that the atom is initially in level 2. Since *E*2 > *E*1, the atom will tend to decay to level 1.
- During this transition the atom must release the corresponding energy difference, *E*2-*E*1.
- Often this energy is released as electromagnetic radiation and this process is called *Spontaneous Emission*.
- Spontaneous emission is therefore characterized by the emission of a photon of energy *hν=E*2-*E*1.



$$E_2 - E_1 = \Delta E = h\nu$$

Stimulated Emission

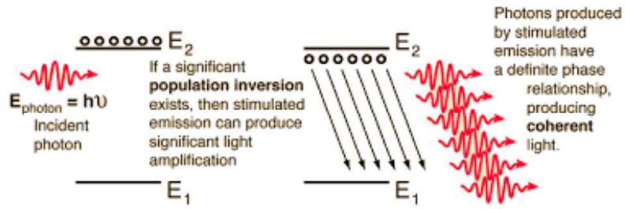
- Let us assume that the atom is found initially in level 2.
- If electromagnetic wave of frequency ν is incident on the material.
- The e.m wave has the same frequency as the atomic frequency, there is a finite probability that this wave will force the atom to undergo the transition from level 2 to level 1.
- In this case the energy difference *E*2 -*E*1 is delivered in the form of an e.m. wave + incident radiation.
- This phenomenon where radiation is emitted upon stimulation of an excited atom to transit from Level 2 to level one by the emission of two photons is called *Stimulated emission*.

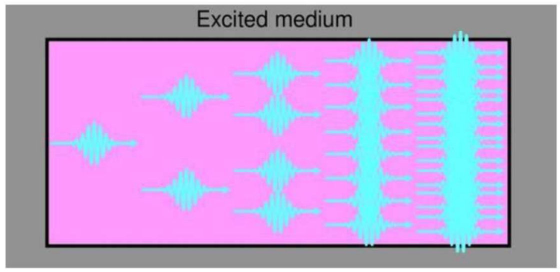


$$E_2 - E_1 = \Delta E = h\nu$$

Spontaneous Emission	Stimulated Emission
Radiative decay process from level 2 to level 1 - occurs on its own after lifetime.	Occurs due to external stimulus –radiation of energy ΔE=E2-E1=hν
Phases of emitted photons is different for different atoms	Incident e.m. wave and the emitted wave of any atom are in phase and along the same direction
Incoherent and broad bandwidth of emitted light	Coherent and narrow bandwidth of emitted light

Stimulated Emission leads to a chain reaction and laser emission



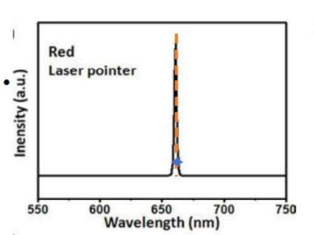


Properties of laser beam

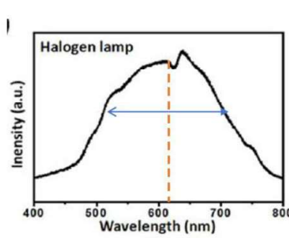
1. Monochromaticity
2. Coherence
3. Directionality
4. Intensity and Brightness

Monochromaticity:

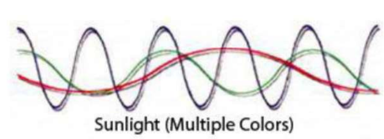
- Light from a conventional broadband source consists of a range of frequencies/wavelength. This range of frequencies is called bandwidth.
- Laser light has narrow bandwidth. Thus, resembling a single frequency source called Monochromatic source.
- Monochromaticity in lasers may arise due to two reasons:
  - Only the e.m. waves of a given frequency are amplified
  - The two mirror arrangement in the resonant cavity. Oscillations can occur only at the resonant frequencies of the cavity

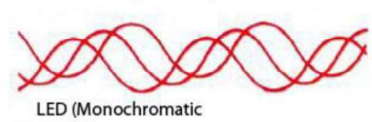


Narrow bandwidth Laser source



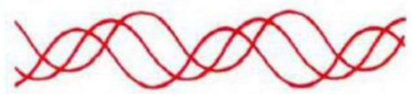
Broad Bandwidth conventional light source



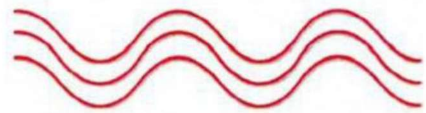


Coherence:

- Coherence is a measure of the correlation between the phases measured at different (temporal and spatial) points on a wave.
- When two waves are in Phase with each other, they are said to be coherent.
- Ordinary light source is incoherent and the wave front differs at every point.
- Laser light is generated as a long continuous wave train as compared to conventional light source. Due to High coherence it results in extremely high power.



LED (Monochromatic and Non-coherent)

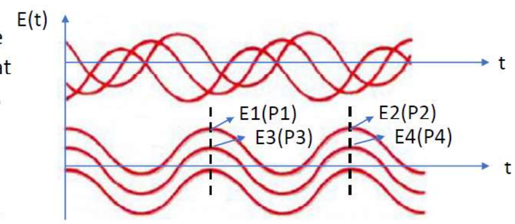


Laser (Monochromatic and Coherent)

- There are two types of Coherence:
  1. Spatial Coherence
  2. Temporal Coherence

Spatial Coherence:

- When two identical light waves separated by a distance are travelling in the same direction and have constant phases at different times, then they are said to be Spatially coherent.
- Spatial coherence is inversely proportional to the divergence or directionality of laser beam.
- Spatial coherence in lasers allows them to be focused to a tight spot and also allows a laser beam to stay narrow over great distances



Variation of Electric field with time

- To define spatial coherence, let us consider two points *P*1 and *P*2 that, at time *t* =0, lie on the same wave-front of some given e.m. wave.
- *Let E*1 (t) and E2 (t) be the electric fields at P1 and P1 at time t=0.
- By definition, the difference between the phases of the two field at time *t* =0 is zero. Now, if this difference remains zero at any time *t* > 0, we will say that there is *perfect spatial coherence.*

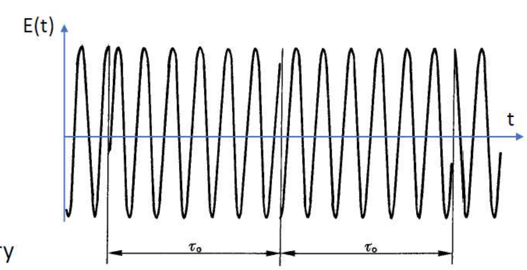
$\Delta p' = (p_1 - p_2)$ is same as

$\Delta p'' = (p_3 - p_4)$

At t=0 and t>0

Temporal Coherence:

- When a light wave travelling in a direction has constant phase at different time periods then it is said to have temporal coherence.
- Temporal coherence is directly proportional to the Monochromaticity of laser beam.
- Temporal coherence allows them to emit light with a very narrow spectrum



Let us consider the electric field of the e.m. wave at a given point P, at times t and t $+\tau_0$.
If, for a given time delay τ_0, the phase difference between the two field (E1(t) and E2(t)) remains the same for any time t, we will say that there is a temporal coherence over a time τ_0.

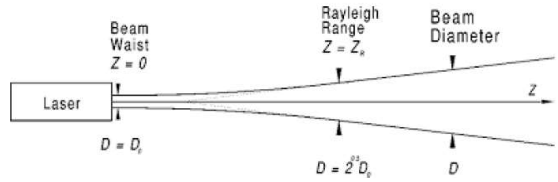
Note: The two concepts of temporal and spatial coherence are indeed independent of each other. In fact, examples can be given of a wave having perfect spatial coherence but only limited temporal coherence (or vice versa).

Directionality:

Laser light can be focused to small dimensions making it highly directional.
Directionality is measured in terms of beam divergence.
Laser beam has less divergence or spreading and remains as parallel set of rays to a certain range called Rayleigh range.

Rayleigh criterion $\theta = \dfrac{1.22\lambda}{D}$

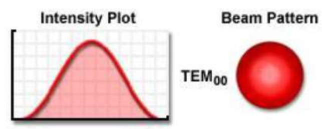
Beam divergence measured form Rayleigh criterion.
Θ-angle of divergence
λ-wavelength of laser light
D- diameter of laser's aperture.



Intensity:

Power per unit area is the measure of Intensity.
High intensity due to directionality.

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

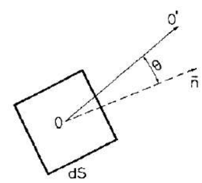


Brightness:

Brightness of a given source of light is defined as the power emitted per unit surface area per unit solid angle.

Consider dS-Elemental surface at point O, dP-power emitted by the elemental surface dS into a solid angle dΩ.

$$dP = B \cos\theta \, dS \, d\Omega$$



$\vec{n} = normal\ vector\ to\ dS$
Θ=angle between OO' and $\vec{n}$
cos Θ=projection of OO' on $\vec{n}$

Laser beam of Power P, with a circular cross-section of aperture diameter D and divergence $\theta = \frac{\beta\lambda}{D}$ β-Numerical Co-efficient=1.22

Since θ is small, cos θ=1

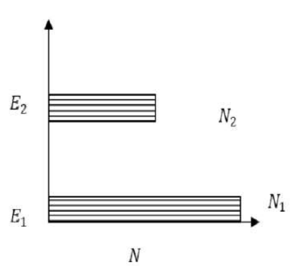
Area of circular laser beam spot $= \dfrac{\pi D^2}{4}$

Emission solid Angle, $d\Omega = \pi\theta^2$

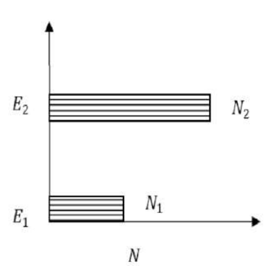
$\therefore B = \left(\dfrac{2}{\pi\beta\lambda}\right)^2 P$ → Brightness of the Laser Beam

Population inversion

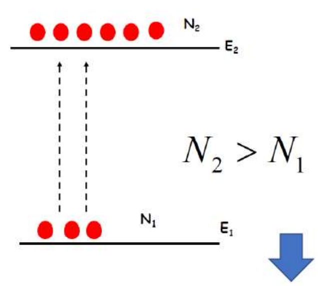
The number of atoms present in the excited (or higher) state is greater than the number of atoms present in the ground state (or lower) state is called population inversion.



At normal conditions $N_1 > N_2$



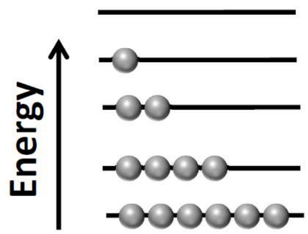
After population inversion is achieved $N_2 > N_1$



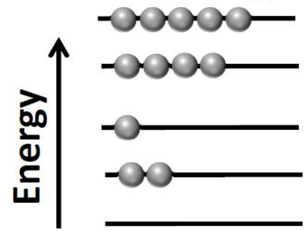
Necessary condition for laser action to take place

Population Inversion

In normal situation all things wants to be lowest energy state.



Normal Situation



Population Inversion

For stimulated emission to dominate, the majority of atoms must be in an excited state, so spontaneously emitted photons are more likely to stimulate emission than to be absorbed by atoms in the ground state. This is called a population inversion.