Engineering Physics

(PHY1701)

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Contents

- Laser Characteristics,
- Spatial and Temporal Coherence,
- Einstein Coefficient & its significance,
- Population inversion,
- Two, three & four level systems,
- Pumping schemes,
- Threshold gain coefficient,
- Components of laser,
- Nd-YAG, He-Ne, CO2 and their engineering applications

❖ William Silfvast, Laser Fundamentals, 2008, Cambridge University Press.

Introduction

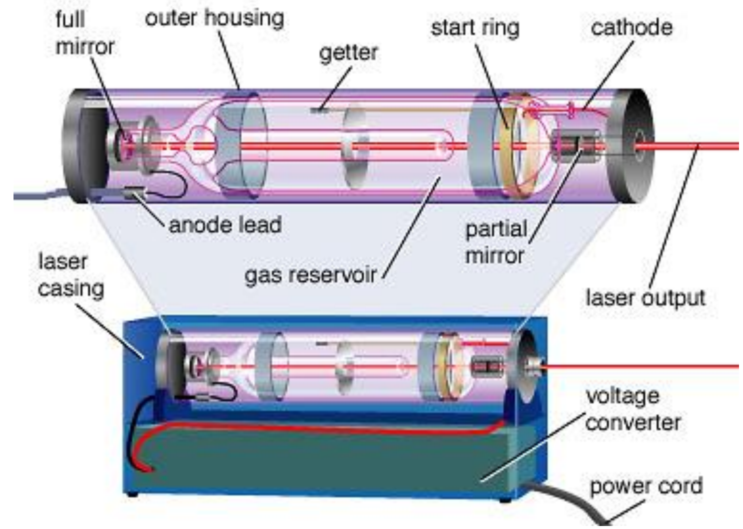
History of the LASER:

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


- It was based on Einstein's idea of the "particle wave duality" of light, more than 30 years earlier.
- Originally called MASER (m = "microwave")

What is Laser?

LASER: 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.
- A laser is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation.

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.
- These three 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.

Characteristics of Laser

Monochromatic:

It means that it consist of one color or wavelength.

- **Divergence and directionality:**

it means that the beam is well collimated and travels long distance with very little spread.

- **Coherence:**

it means that all the individual waves of light are moving precisely together through time and space.

- **Brightness:**

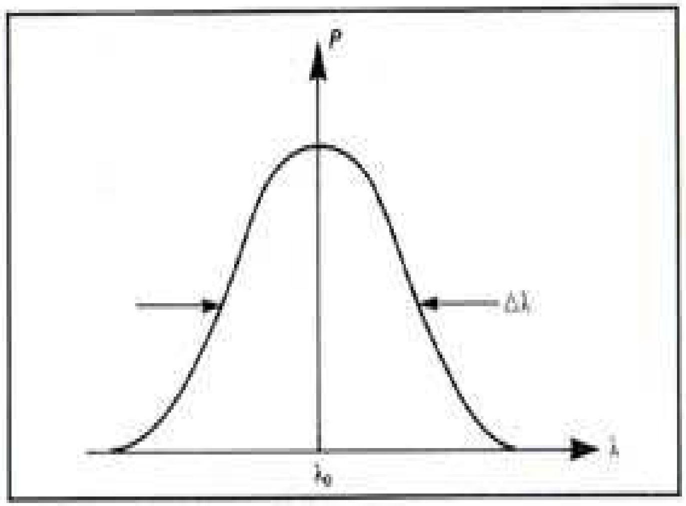
The radiance of laser is an important factor. It is defined as the power emitted per unit surface area per unit solid angle.

Characteristics of Laser

- **Monochromatic** (emit only **one wave length**)
- **Coherent** (all in **same phase**-improve focusing)
- **Polarized** (in **one plane**-easy to pass through media)
- **High Directionality** (in **one direction** & non spreading,angular speed= 1mm /meter)
- **High Intensity** (can focus over small area of 10^(-6))

Monochromatic nature

It means that it consist of one color or wavelength.



Nearly monochromatic light

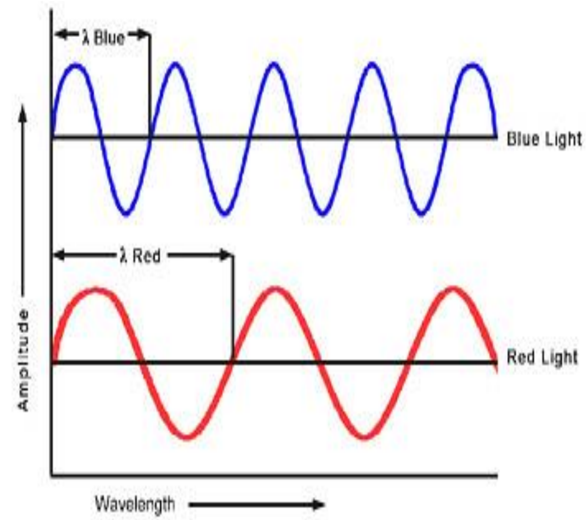
Example:

He-Ne Laser

λ_0 = 632.5 nm, $\Delta\lambda$ = 0.2 nm

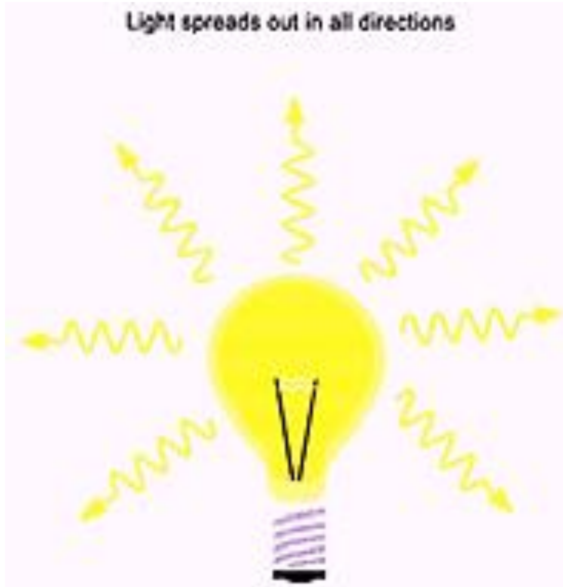
Diode Laser

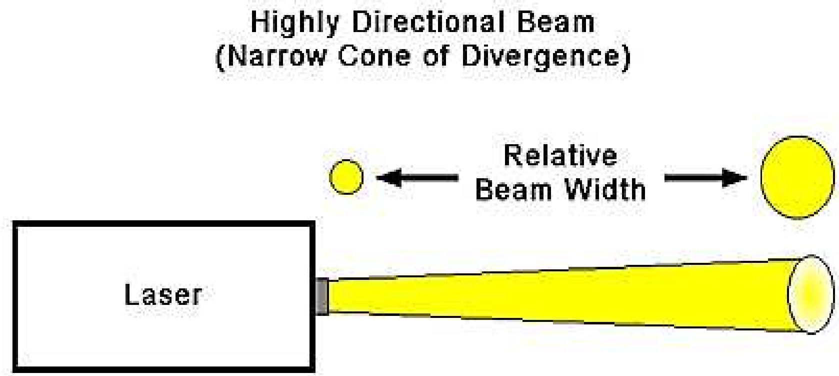
λ_0 = 900 nm, $\Delta\lambda$ = 10 nm



Comparison of the wavelengths of red and blue light

Directionality





Conventional light source

Divergence angle (θ_d)

Beam divergence: $\theta_d = \beta\, \lambda / D$

$\beta \sim 1$ = f(type of light amplitude distribution, definition of beam diameter)

λ = wavelength, *D = beam diameter*

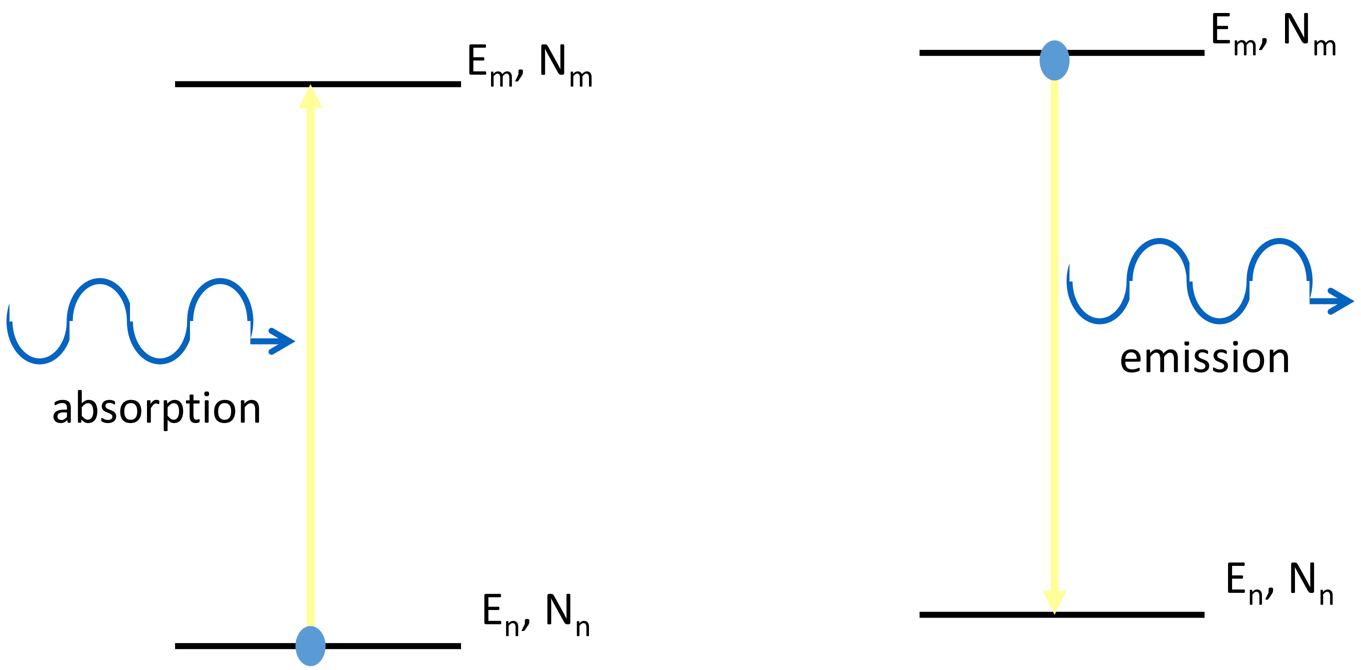
Basic concepts for a laser

- **Absorption**

- **Spontaneous Emission**

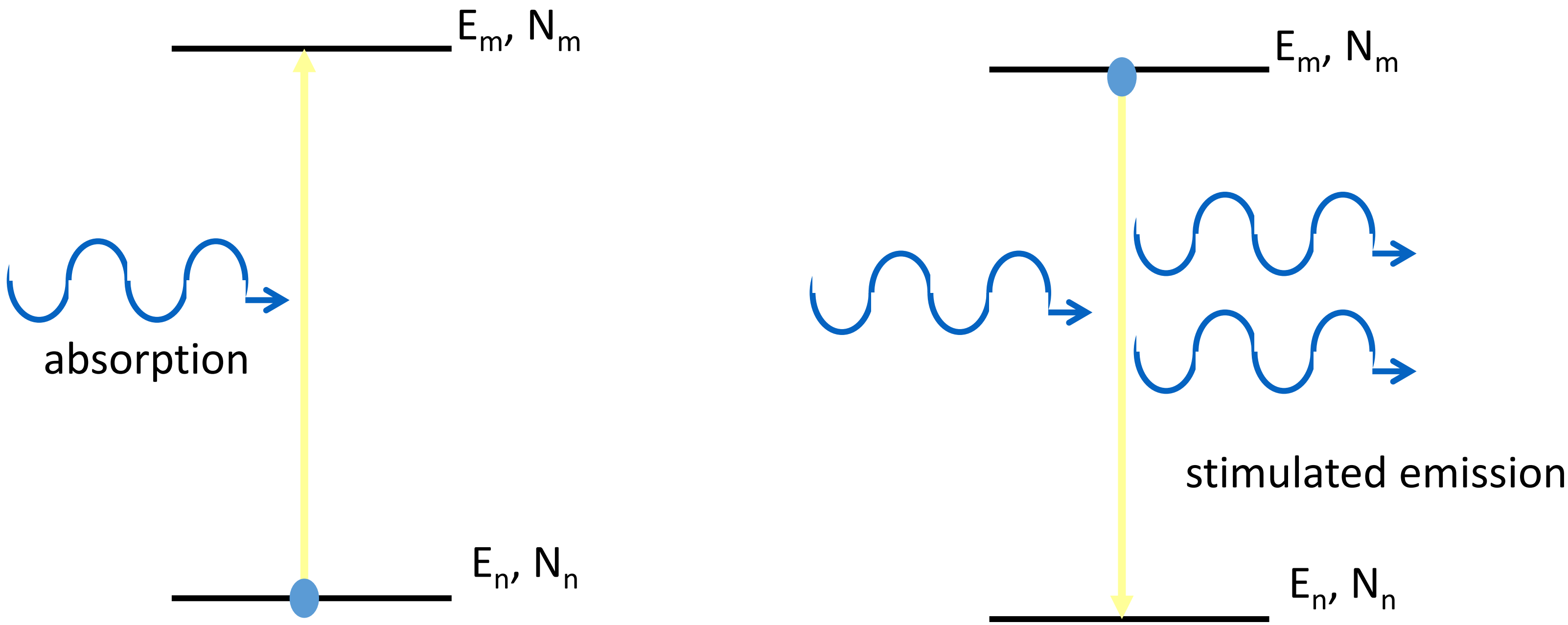
- **Stimulated Emission**

Absorption and Spontaneous Emission



- ✓ **Light from bulbs are due to spontaneous emission**

Absorption and Stimulated Emission



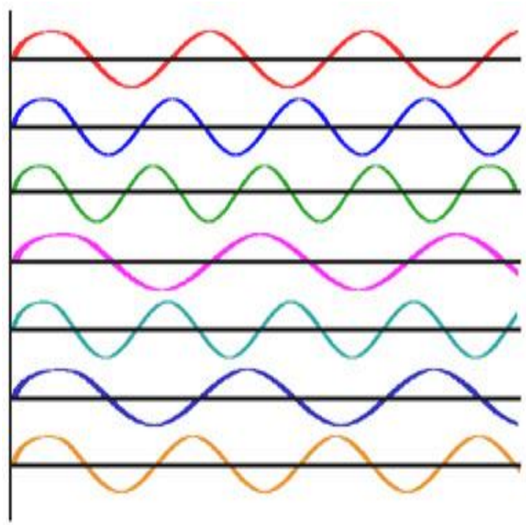
- ✓ **Laser light results from stimulated emission**

Stimulated vs Spontaneous Emission

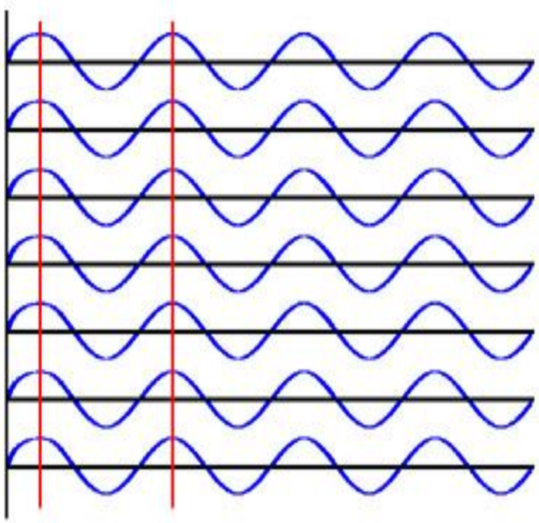
- Stimulated emission requires the presence of a photon.
- An “incoming” photon stimulates a molecule in an excited state to decay to the ground state by emitting a photon.
- The stimulated photons travel in the same direction as the incoming photon.
- Spontaneous emission does not require the presence of a photon.
- Instead a molecule in the excited state can relax to the ground state by spontaneously emitting a photon. Spontaneously emitted photons are emitted in all directions.
- When light travels through an absorbing medium, the medium absorbs the light; the amount of light absorbed is determined by Beer’s Law.
- For a medium to operate as a lasing medium, the transmitted light intensity should be greater than the intensity of light incident on the material.

Coherence

- Coherence is a measure of the correlation between the phases measured at different (temporal and spatial) points on a wave.
- The interactions of two EM waves that have only slightly different frequencies, or that originate from points only slightly separated spatially.
- For example, two closely located but separate laser beams or a single beam illuminating two closely positioned apertures.



Incoherent light waves



Coherent light waves

Temporal Coherence

- The case of temporal coherence refers to the relative phase or the coherence of two waves at two separate locations along the propagation direction of the two beams.
- It sometimes referred to as longitudinal coherence.
- If we assume that the two waves are exactly in phase at the first location, then they will still be at least partially in phase at the second location up to distance l_c, where l_c is defined as the coherence length.
- The coherence length can be determined to be

$$\boldsymbol{l_c = \lambda\left(\frac{\lambda}{\Delta\lambda}\right) = \frac{\lambda^2}{\Delta\lambda}}$$

Spatial coherence

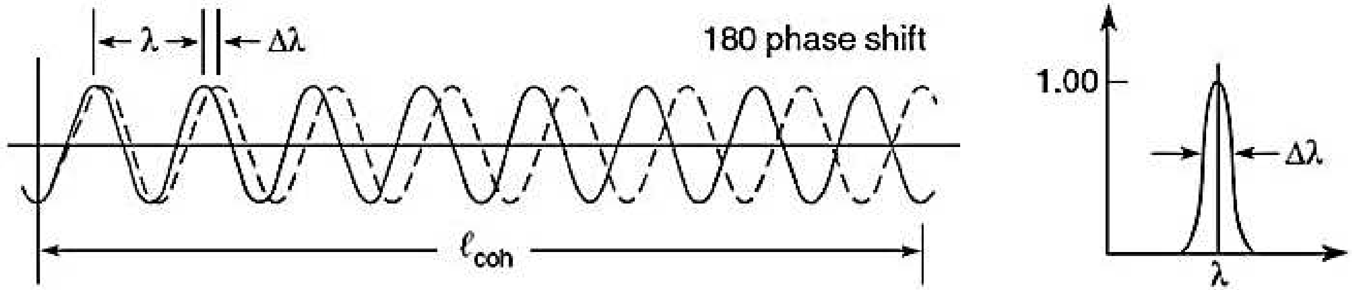
- Spatial coherence, also referred to as transverse coherence, describes how far apart two sources, or two positions of the same source, can be located in a direction transverse to the direction to the direction of observation and still exhibit coherent properties over range of observation points.
- This is sometimes referred to as the lateral coherence. More specially, we will ask by what distance l_t can two points separated in the transverse direction at the region of observation and still have interference effect from the source region over a specific lateral direction of the source.
- The transverse coherence length can be calculated by the following relation.

$$l_t = \frac{r\lambda}{s} = \frac{\lambda}{\theta_s}$$

Temporal & Spatial Coherence

Temporal Coherence

Ability of a light beam to form fringes with a delayed version of itself



Spatial Coherence

Ability of spatially separated points in a wavefront to form fringes.