Basic mechanism for production of LASER light

Laser stands for

Light Amplification by Stimulated Emission of Radiations

A Laser device produces coherent beam of optical radiation through optical amplification using stimulated emission of electro magnetic radiation.

The phenomenon of stimulated emission was predicted Albert Einstein in 1917.

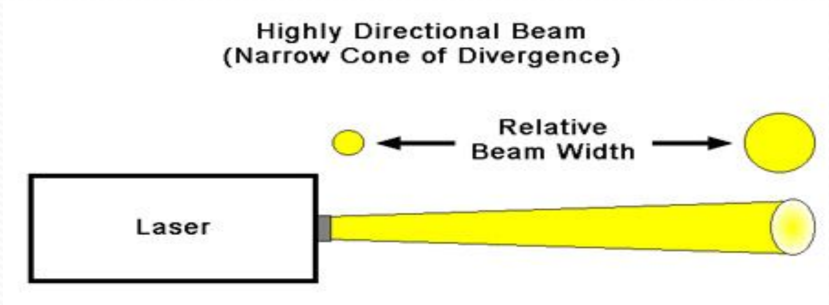
Properties of Laser

- The light produced by LASER is highly **monochromatic that is single** wavelength wheras ordinary white light is a combination of many colors (or wavelengths) of light.

- Lasers light is highly **directional**, that is, laser light is emitted as a relatively narrow beam in a specific direction whereas ordinary light is emitted in many directions away from the source.

- The light from a laser is perfectly **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.
- **Laser light is most intense means that it contains a lot of energy within a small area.**

Directionality



Conventional light source Divergence angle (θ_d)

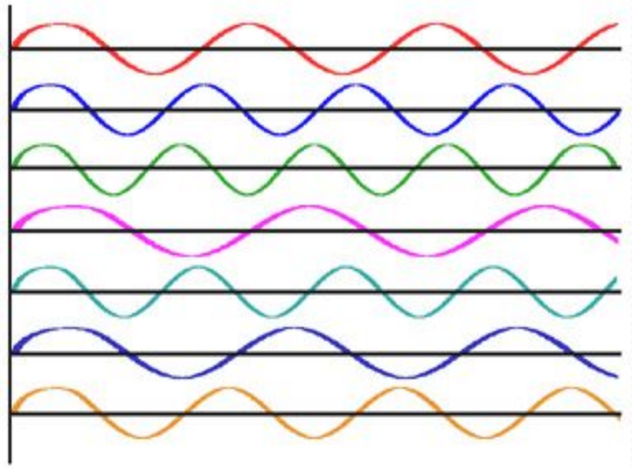
Beam divergence: $\theta_d = \beta \lambda / D$

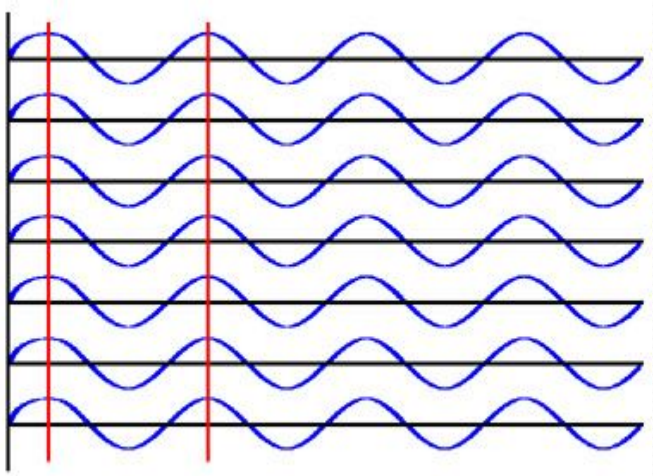
$\beta \sim 1$ = f(type of light amplitude distribution, definition of beam diameter)

λ = wavelength

D = beam diameter

Coherence

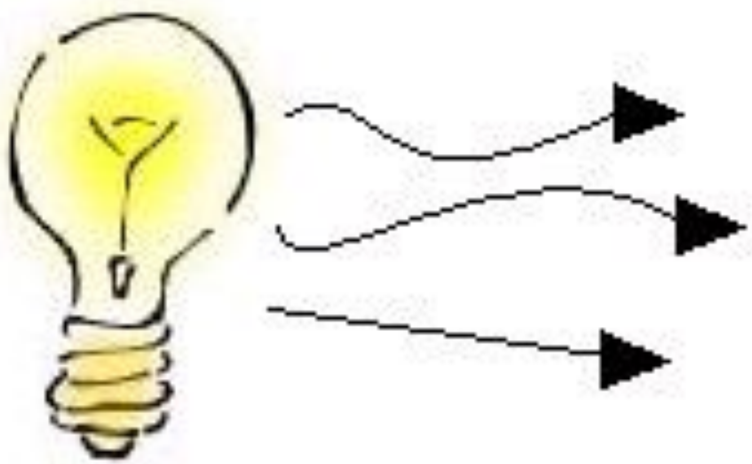


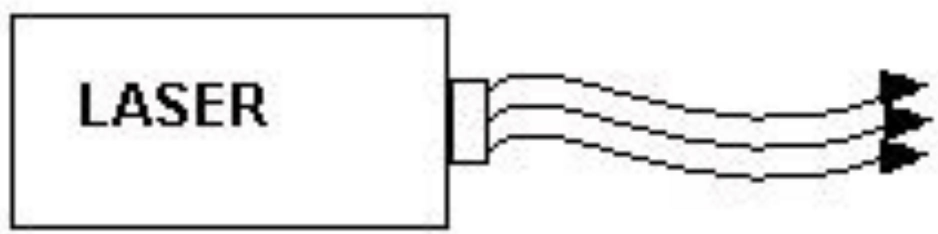


Incoherent light waves

Coherent light waves

Incandescent vs. Laser Light





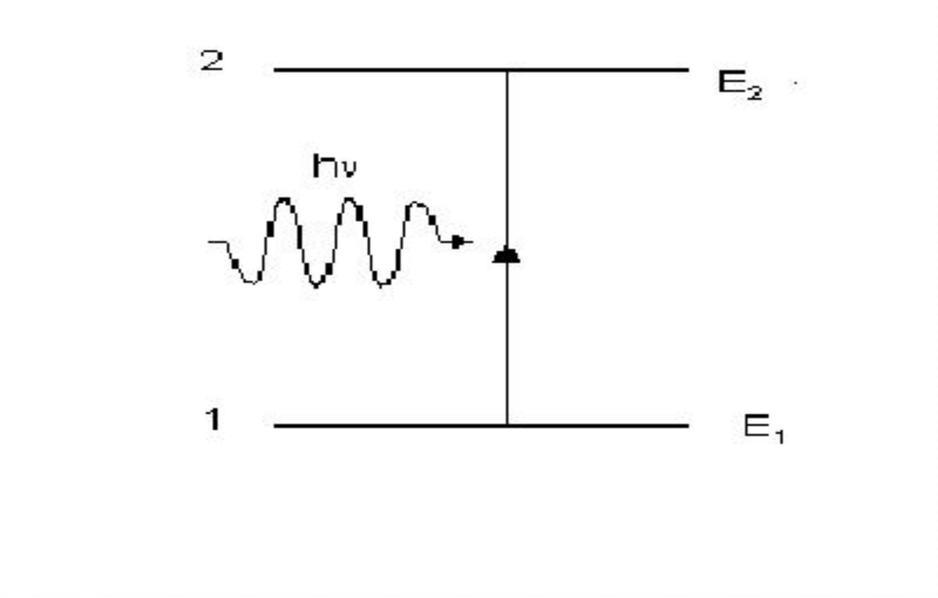
1. **Many wavelengths**
2. **Multidirectional**
3. **Incoherent**

1. **Monochromatic**
2. **Directional**
3. **Coherent**

Basic concepts for a laser

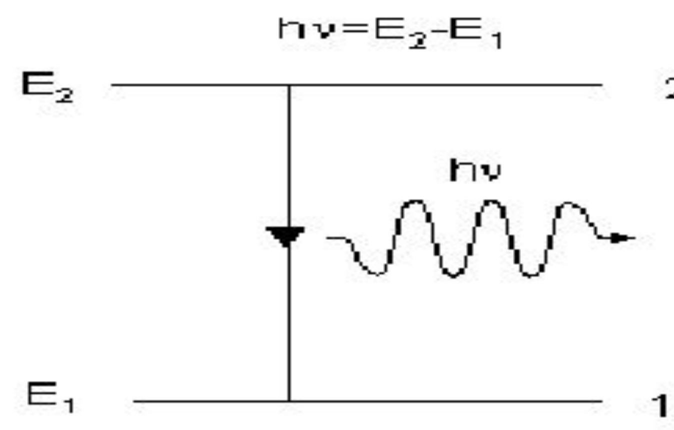
- Absorption
- Spontaneous Emission
- Stimulated Emission
- Population inversion

Absorption



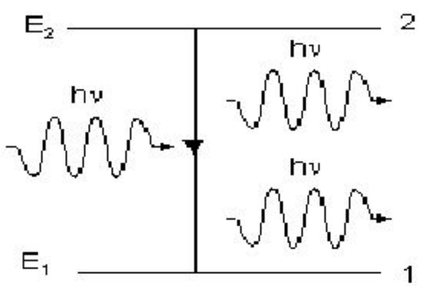
- When an atom absorbs energy, the electrons are excited into higher energy levels.

Spontaneous Emission



- As the higher levels are highly unstable,The atom decays from level 2 to level 1 instantly with the emission of a photon with the energy *hν,which is random in nature.*

Stimulated Emission



When the higher level is metastable, an incoming photon of resonant energy can stimulate it to move to ground state with the emission of another photon which is coherent with the incident photon

Stimulated Emission

The stimulated emission produces a copy of incident photon as it is

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

Population Inversion

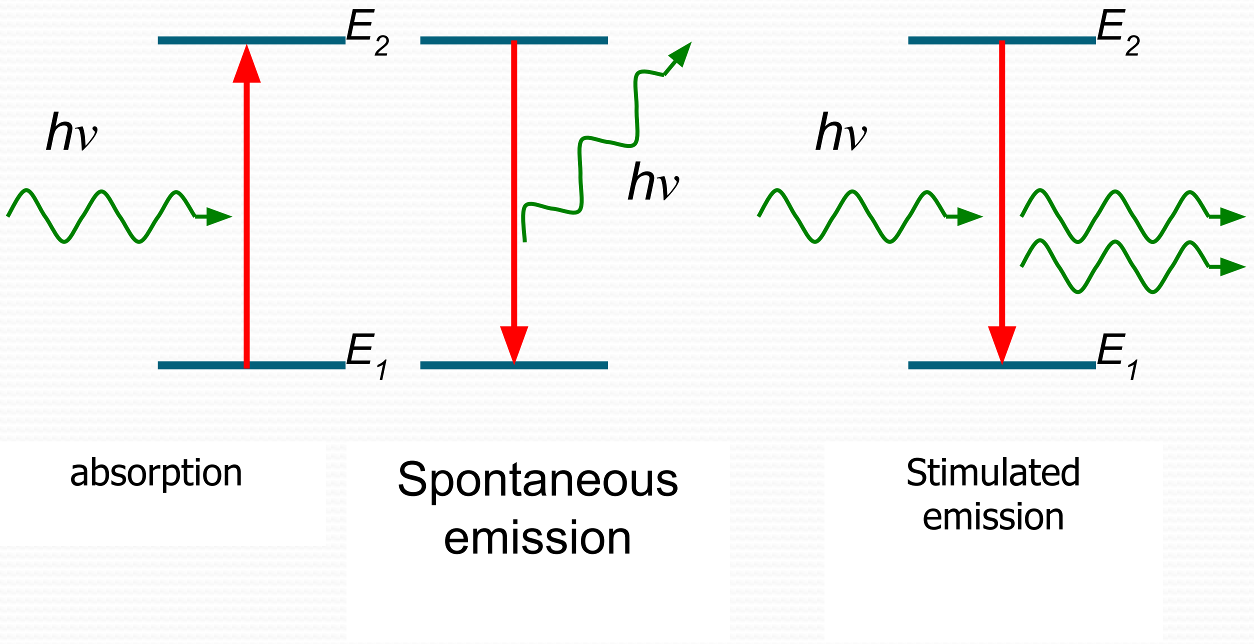
- More atoms or molecules are in a higher excited state than in ground state.
- The process of producing a population inversion is called pumping.
- Examples:

→by direct collisions

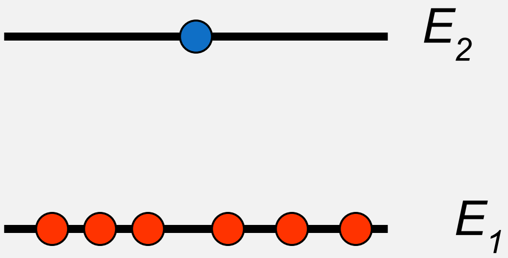
→by electrical discharge

Two level system

$h\nu = E_2 - E_1$



Einstein's coefficients



Probability of stimulated absorption $R_{1\text{-}2}$

$$R_{1\text{-}2} = \rho\,(\nu)\,B_{1\text{-}2}$$

Probability of stimulated and spontaneous emission :

$$R_{2\text{-}1} = \rho\,(\nu)\,B_{2\text{-}1} + A_{2\text{-}1}$$

assumption: n_1 atoms of energy ε_1 and n_2 atoms of energy ε_2 are in thermal equilibrium at temperature T with the radiation of spectral density $\rho\,(\nu)$:

$$n_1\,R_{1\text{-}2} = n_2\,R_{2\text{-}1} \qquad n_1\rho\,(\nu)\,B_{1\text{-}2} = n_2\,(\rho\,(\nu)\,B_{2\text{-}1} + A_{2\text{-}1})$$

$$\Rightarrow \qquad \rho\,(\nu) = \frac{A_{2-1}/B_{2-1}}{\frac{n_1}{n_2}\frac{B_{1-2}}{B_{2-1}} - 1}$$

According to Boltzman statistics:

$$\frac{n_1}{n_2} = \exp(E_2 - E_1)/kT = \exp(h\nu / kT)$$

⇓

- $$\rho(\nu) = \frac{A_{2-1}/B_{2-1}}{\frac{B_{1-2}}{B_{2-1}}\exp(\frac{h\nu}{kT}) - 1} = \frac{8\pi h\nu^3/c^3}{\exp(h\nu/kT) - 1}$$

Planck's law

⇓

$B_{1\text{-}2}/B_{2\text{-}1} = 1$

$$\frac{A_{2-1}}{B_{2-1}} = \frac{8\pi h\nu^3}{c^3}$$

The probability of spontaneous emission A_{2-1} /the probability of stimulated emission $B_{2-1}\rho(\nu)$:

$$\frac{A_{2-1}}{B_{2-1}\rho(\nu)} = \exp(h\nu / kT) - 1$$

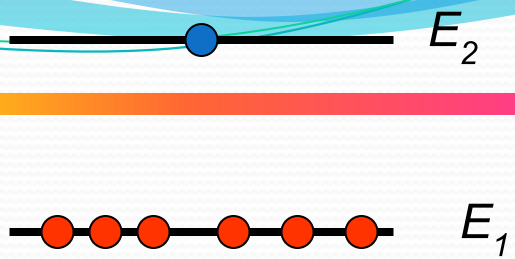
stimulated emission dominates solely when

$h\nu /kT << 1$!

The frequency of emission leads to the absorption:

if $h\nu /kT << 1$.

Condition for the laser operation



If $n_1 > n_2$

- radiation is mostly absorbed
- spontaneous radiation dominates.

if $n_2 >> n_1$ - *population inversion*

- stimulated emission prevails

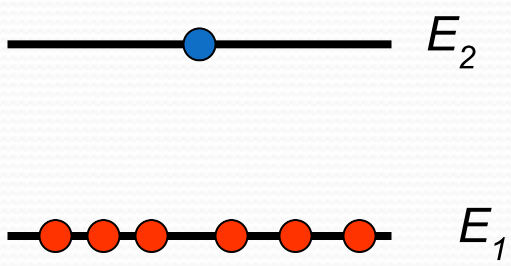
- light is amplified

Necessary condition:
population inversion

How to realize the population inversion?

Thermal excitation:

$$\frac{n_2}{n_1} = \exp\left(\frac{-\Delta E}{kT}\right)$$



impossible.

The system has to be „pumped”

Optically,
electrically.