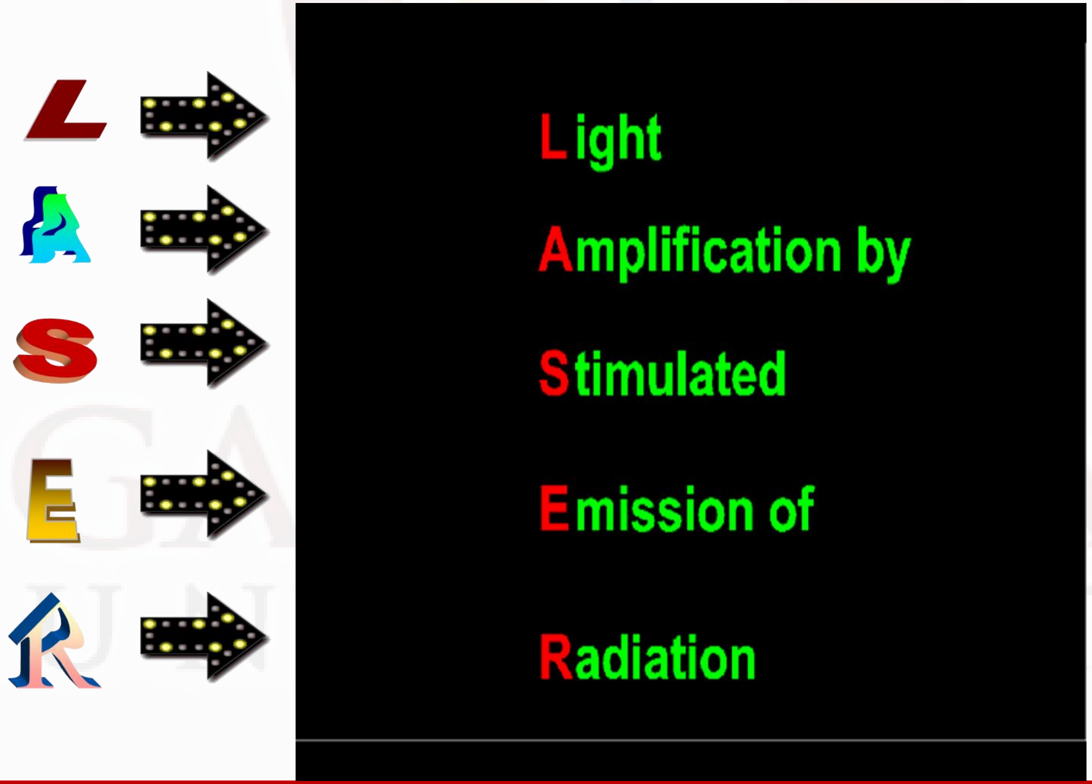
Laser Characteristics and Transitions

Abbreviation of laser



L → Light

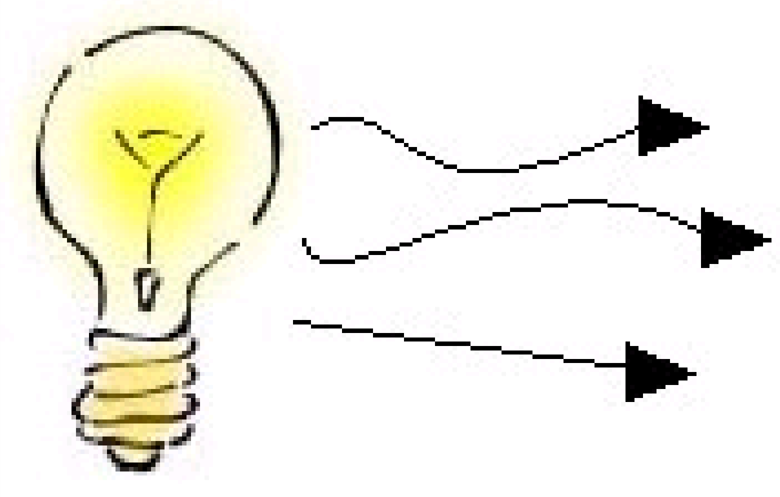
A → Amplification by

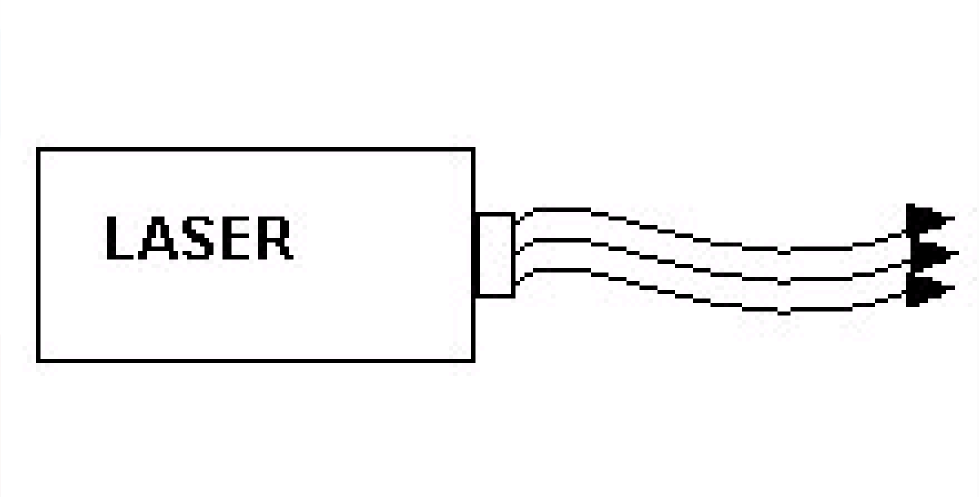
S → Stimulated

E → Emission of

R → Radiation

Incandescent vs. Laser Light





1. Many wavelengths
2. Multidirectional
3. Incoherent

1. Monochromatic
2. Directional
3. Coherent

Laser Characteristics

- The light emitted from a laser has a very high degree of **coherence** **whereas the light emitted from conventional light source is incoherent because the radiation emitted from different atoms do not bear any definite phase relationship with each other.**

- The light emitted from a laser is highly **monochromatic.** Degree of non-monochromaticity $\xi = \frac{\Delta \nu}{\nu_0}$

Laser Characteristics contd…

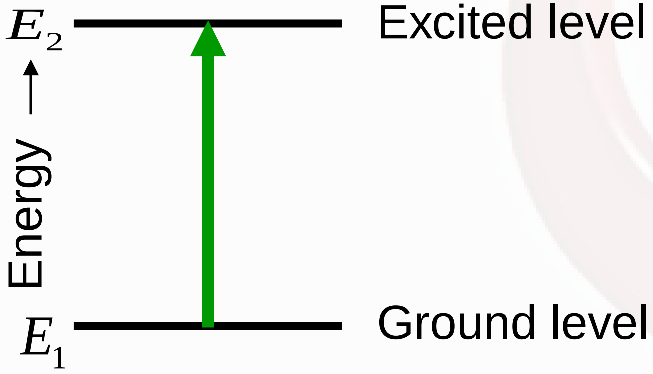
- Lasers emit light that is highly **directional**, that is, laser light is emitted as a relatively narrow beam in a specific direction. Ordinary light, such as from a light bulb, is emitted in many directions away from the source.

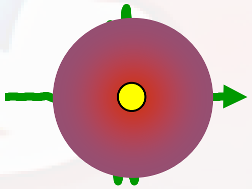
- The intensity of Laser light is tremendously high as the energy is concentrated in a very narrow region and stays nearly constant with distance. The intensity of light from conventional source decreases rapidly with distance.

In 1916, Einstein considered the various transition rates between molecular states

Absorption:

When an atom encounters a photon of light, it can absorb the photon's energy and jump to an excited state.





This is, of course, absorption.

Number of Absorption per unit time per unit volume = $B_{12} N_1 u(\nu)$

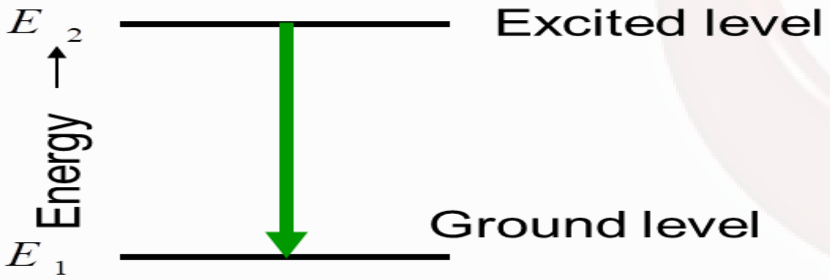
where N_i is the number of atoms (per unit volume) in the i^{th} state,

U(ν) dν radiation energy per unit volume within frequency range ν and ν+dν

B_{12} the coefficient of proportionality and is a characteristic of the energy levels

Spontaneous emission

When an atom in an excited state falls to a lower energy level, it emits a photon of light.



Rate of Spontaneous emission (per unit volume) $= A_{21} N_2$

where A_{21} is the proportionality consatant

Molecules typically remain excited for no longer than a few nanoseconds.

Stimulated Emission:

Einstein first proposed stimulated emission in 1916.

When a photon encounters an atom in an excited state, the photon can induce the atom to emit its energy as another photon of light, resulting in two photons.

Stimulated emission rate = $B_{21} N_2 u(v)$

A_{21} ,B_{12} B_{21} are known as Einstein’s A,B Coefficient.

Relation between Einstein's A, B Coefficient

- In thermal equilibrium, the rate of upward transitions equals the rate of downward transitions:

$$B_{12} N_1 u(v) = A_{21} N_2 + B_{21} N_2 u(v)$$

$$u(\nu) = \frac{N_2 A_{21}}{N_1 B_{12} - N_2 B_{21}} = \frac{A_{21} / B_{21}}{\frac{B_{12}}{B_{21}} \frac{N_1}{N_2} - 1} \text{..........} (1)$$

In equilibrium, the ratio of the populations of two states is given by

The Maxwell-Boltzman distribution

- $N_2 / N_1 = \exp(-\Delta E/kT)$, where $\Delta E = E_2 - E_1 = h\nu$, k is the Boltzmann Constant
- As a result, higher-energy states are always less populated than the ground state

Planck's blackbody radiation formula

$$u(\nu)=\frac{8\pi h\nu^3}{c^3}\frac{1}{e^{\frac{h\nu}{KT}}-1}\dots\dots\dots\dots(2)$$

$$Comparing\, Eqns\,(1)\, and\,(2)$$

$$B_{12}=B_{21}\dots\dots\dots\dots\dots\dots(3)$$

$$\frac{8\pi h\nu^3}{c^3}B_{21}=A_{21}\dots\dots\dots\dots\dots\dots(4)$$

$$\frac{Number\, of\, Spontaneous\, Emission}{Number\, of\, Stimulated\, Emission}=\frac{A_{21}}{B_{21}u(\nu)}=e^{\frac{h\upsilon}{KT}}-1$$

At thermal equilibrium two cases can arise

$$\text{Case 1}: \text{If } h\nu << KT, \frac{\text{Number of Spontaneous Emission}}{\text{Number of Stimulated Emission}} \approx \frac{h\upsilon}{KT}$$

$$\text{Case 2}: \text{If } h\nu << KT, \frac{\text{Number of Spontaneous Emission}}{\text{Number of Stimulated Emission}} \approx e^{\frac{h\upsilon}{KT}} - 1$$

$$\text{For normal optical source}, T \sim 10^3 K, \lambda = 6000\text{Å}, \frac{h\nu}{kT} \approx 23$$

$$\frac{\text{Number of Spontaneous Emission}}{\text{Number of Stimulated Emission}} = 10^{10}$$

At optical frequencies Spontaneous Emission is predominant.

Reference:

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2. K. Thyagarajan, A. K. Ghatak, Lasers: Theory and Applications. New Delhi: Macmillan India Ltd

3. L. Allen, Essentials of Lasers. Oxford: Pergamon Press.