K.T.S.P. Mandal's

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As per the new syllabus

Subject- LASER

Physics Paper VI

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**Topic- INTRODUCTION TO LASER**

# Introduction to LASER

## 1) Ordinary Light and Lasers:

**Ordinary light** is a mixture of electromagnetic waves of different wavelengths. Laser light is monochrome. Ordinary light is non-directional and inconsistent, while laser light shows **directional** and **highly consistent** distribution. This is the **main difference** between ordinary light and laser light.

**Laser light** is a focused beam in which all photons move at the **same wavelength** and in the **same direction**. Laser lights are spectrally pure. Ordinary light, on the other hand, is a **wide spectrum** of light that moves irregularly at different wavelengths.

Both ordinary light and laser light are electromagnetic waves. Ordinary light is a mixture of electromagnetic waves of different wavelengths. Laser light is monochrome. Ordinary light is non-directional and inconsistent, while laser light shows directional and highly consistent distribution. This is the main difference between ordinary light and laser light.

## 2) Brief History of LASER

The laser would not have been possible without an understanding that light is a form of electromagnetic radiation. Max Planck received the Nobel Prize in physics in 1918 for his discovery of elementary energy quanta. Planck was working in thermodynamics, trying to explain why "blackbody" radiation, something that absorbs all wavelengths of light, didn't radiate all frequencies of light equally when heated.

In 1900, Max Planck deduced the relationship between energy and the frequency of radiation, essentially saying that energy could be emitted or absorbed only in discrete chunks — which he called quanta — even if the chunks were very small. In 1917, Einstein proposed the process that makes lasers possible, called stimulated emission. **April 26, 1951:** Charles Hard Townes of Columbia University in New York conceives his **maser** (microwave amplification by stimulated emission of radiation) idea while sitting on a park bench in Washington. **March 22, 1960:** Townes and Schawlow, under Bell Labs, are granted US patent number 2,929,922 for the optical maser, now called a laser. With their application denied, Gould and TRG launch what would become a 30-year patent dispute related to laser invention. December 1960: **Ali Javan, William Bennett Jr. and Donald Herriott of Bell Labs develop the helium-neon (HeNe) laser, the first to generate a continuous beam of light at 1.15 μm.**

Advances in LASER research are given below

1962: Hall R. – First Semiconductor laser (Gallium-Arsenic) at General Electric Labs.

**1962:** With Fred J. McClung, Hellwarth proves his laser theory, generating peak powers 100× that of ordinary ruby lasers by using electrically switched Kerr cell shutters.

1962: Johnson L.F.- Continuous wave solid-state laser

1964: Geusic J.E. – first development of Nd:YAG LASER at Bell Labs

1964: Patel C.K.N. – Development of $CO_2$ laser at Bell labs

1964: Bridges W. – Development of Argon Ion laser at Hughes labs

1965: Kasper J. V.V. – First chemical Laser at university of California, Berkley

1966: Fowles, G.- First metal vapour laser – Zn/Cd at University of Utah

1966: Sorokin P. – Demonstration of first Dye Laser action at IBM Labs

1977: McDemott W.E. – Chemical Oxygen Iodine Laser

2001: Lawrence Livermore National Laboratory – Solid State Heat Capacity Laser

**3) Interaction of Radiation with Matter**

The frequency υ and the wavelength λ of light are related to velocity of light c by the relation,

$$\mathbf{C} = \upsilon \lambda$$

When a beam of light passes through absorbing medium, then the decrease in intensity of light (dI) is proportional to intensity of light and thickness of the medium

$$dI = - \alpha I \, dx$$

α- coefficient of absorption

$$dI / I = - \alpha \, dx$$

Integrating on both sides,

$$\int_{I0}^{I} \frac{dI}{I} = \int_0^x - \alpha \, dx$$

$$I = I_0 e^{-\alpha x}$$

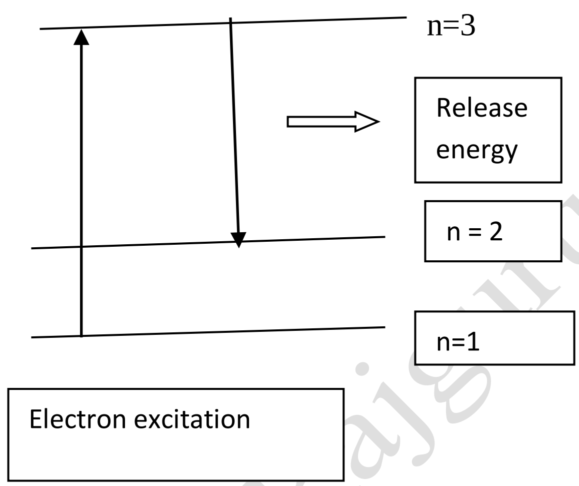
Equation indicates that, light intensity decreases exponentially with displacement in the medium.

4) **Energy Levels**

The energy that a photon carriers depends on its wavelength. Since photons absorbed or emitted by electrons jumping between the n = 1 and n= 2 energy levels must have 10.2 eV of energy. The wavelength and energy relation is,

$$E = \frac{hc}{\lambda}$$

E is photon energy; h is Plank's constant and c speed of light.
The electrons of individual atoms can be excited from a lower to higher energy state.




5) **Population Density**

Number of atoms per unit volume present in an energy level is called its population density. Population inversion occurs when a system exists in a state with more members in an excited state than in lower energy state.

6) **Boltzmann Distribution**

The distributions of atoms between the levels are given by Boltzmann law.
Two levels such that, ground state, with energy $E_1$ or the excited state with energy $E_2$;

$$E_2 > E_1$$

The number of atoms is $N_1$ for ground state and $N_2$ for excited state

$$N = N_1 + N_2$$

The energy difference between the two states

$$\Delta E = E_2 - E_1 = h\,\upsilon_{12} \quad \text{for frequency of light}$$

Maxwell- Boltzmann distribution that the ratio of the number of atoms in each state is given by,

$$N2 = N_1\, e^{-((E_2 - E_1)/KT)}$$

T is thermodynamic temperature of the groups of atoms. And K is Boltzmann constant.

7) **Transition Lifetimes**

A Laser is a transition of some laser active ion between two electronic levels is called as amplifier transition. A long upper-state lifetime in a laser gain medium means that a significant population inversion can be measured with a relatively low pump power.

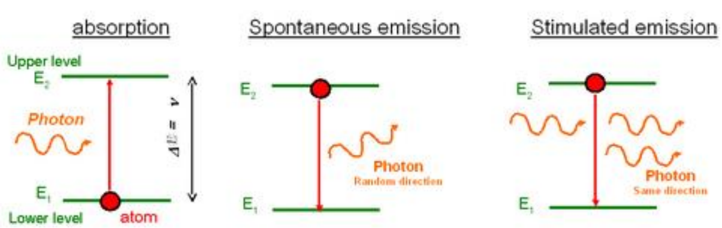
**8) Allowed and Forbidden Transitions**

Laser operation is the radiative absorption and emission of light by the laser materials. Laser ions undergoing transitions between electronic energy levels through the absorption and emission of photons. It can be used to classify absorption or emission of radiation between specific energy levels as allowed or forbidden transitions.

**9) Principle of Laser ( Absorption and emission)**

The three different mechanisms are shown below (Figure 2):

1. **Absorption**: An atom in a lower level absorbs a photon of frequency hν and moves to an upper level.
2. **Spontaneous emission**: An atom in an upper level can decay spontaneously to the lower level and emit a photon of frequency hν if the transition between E2 and E1 is radiative. This photon has a random direction and phase.
3. **Stimulated emission**: An incident photon causes an upper level atom to decay, emitting a "stimulated" photon whose properties are identical to those of the incident photon. The term "stimulated" underlines the fact that this kind of radiation only occurs if an incident photon is present. The amplification arises due to the similarities between the incident and emitted photons.




**10) Einstein's Coefficients and Einstein's Relations**

In steady-state (at thermal equilibrium), the two emission rates (spontaneous and stimulated) must balance the rate of absorption.

Thus $R_1=R_2+R_3$

Using equations (1,2, and 3) ,we get

$N_1B_{12}E=N_2A_{21}+N_2B_{21}E$

Or $N_1B_{12}E - N_2B_{21}E=N_2A_{21}$

Or $(N_1B_{12}-N_2B_{21})\, E =N_2A_{21}$

Or $E= N_2A_{21}/N_1B_{12}-N_2B_{21}$

$= N_2A_{21}/N_2B_{21}[N_1B_{12}/N_2B_{21} -1]$

[by taking out common $N_2B_{21}$from the denominator]

Or $E=A_{21}/B_{21}\ \{1/N_1/N_2(B_{12}/B_{21}-1))$ (4)

Einstein proved thermodynamically,that the probability of stimulated absorption is equal to the probability of stimulated emission.thus

$B_{12}=B_{21}$

Then equation(4) becomes

$E=A_{21}/B_{21}(1/N_1/N_2-1)$ (5)

From Boltzman's distribution law, the ratio of populations of two levels at temperature T is expressed as

$N_1/N_2=e^{(E_2-E_1)/KT}$

$N_1/N_2=e^{hv/KT}$

Where K is the Boltzman's constant and h is the Planck's constant.

Substituting value of $N_1/N_2$in equation (5) we get

$E=\ A_{21}/B_{21}(1/e^{hv/KT}-1)$ (6)

Now according to Planck's radiation law, the energy density of the black body radiation of frequency v at temperature T is given as

$E=\ \ 8\pi hv^3/c^3(1/e^{hv/KT})$ (7)

By comparing equations (6 and 7), we get

$A_{21}/B_{21}=8\pi hv^3/c^3$

This is the relation between Einstein's coefficients in laser.

**Significance of Einstein coefficient relation**: This shows that the ratio of Einstein's coefficient of spontaneous emission to the Einstein's coefficient of stimulated absorption is proportional to the cube of frequency v. It means that at thermal equilibrium, the probability of spontaneous emission increases rapidly with the energy difference between two states.