Course: (CBCS) B.Sc. (H)-Physics [Section-A]

(32221402) Elements of Modern Physics

Part & Semester – II & IV

Lecture-6

Dear Students

Hope all of you are well and taking all the necessary precautions in this difficult time.

Now, I am going to discuss about the last unit of this course (LASER). Apart from this, all of you can contact me through Email, Whatsapp or Mobile for any quarry related to our course of Elements of Modern Physics.

Thanking you.

With Best Wishes
Dr. Manish Kumar
Assistant Professor
Dept. of Physics, ARSDC (DU)
Mob.: +91-9555977892
Email.: manishphy2007@gmail.com

(May 05, 2020)

LASER

The word **LASER** stands for "**L**ight **A**mplification by **S**timulated **E**mission of **R**adiation".

A Laser is the device used to produce a strong, monochromatic, collimated and highly coherent beam of light and depends on the phenomenon of 'stimulated emission'.

The most important feature of laser light are:

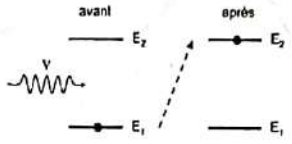
1. High Intensity
2. Extra ordinary Monochromatic
3. Unidirectional
4. Highly Coherent in nature

The emission process of Laser are of two types-

1. Spontaneous Emission
2. Stimulated Emission

Absorption: Generally an atom lies in ground state or a lower state 1. IT can rise to a higher state 2 by absorbing a quantum of photon or radiation of frequency v. Its energy is given by

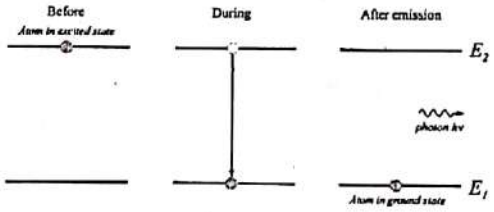
$\nu = \frac{E_2 - E_1}{h}$ here E_1 and E_2 are the energies of the atom in the state 1 and 2.



(Figure-1)

Spontaneous Emission:

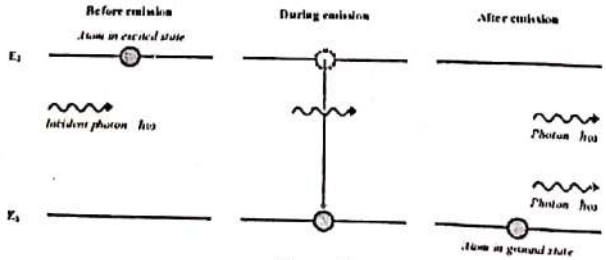
The atom in the excited state does not stay for longer time and it jumps to lower energy state 1 by emitting a photon of frequency v. This phenomenon is called spontaneous emission.



(Figure-2)

Stimulated Emission or Induced Emission:

An atom in an excited state may under the influence of the electromagnetic field of photon of frequency v incident upon it, jump to a lower energy state, emitting an additional photon of frequency v. Hence two goes from a normal state(ground) E_1 to an excited state photons one original and the other emitted move together. This stimulated emission of radiations.



(Figure-3)

The direction of propagation, phase, energy and state of emitted photon is exactly same as that of the incident stimulated photon, so the result is an enhanced beam of light.

Difference between Spontaneous emission and stimulated emission:

Spontaneous Emission	Stimulated Emission
1. This process takes place immediately during the transition of atom from higher to lower state.	1. This process take place due to the another photon having energy equal to emitted photon.
2. It is an incoherent radiation.	2. It is a coherent radiation.
3. The light is less intense.	3. The light is high intense.
4. This emission has many wavelength.	4. This emission has single wavelength.
5. This is less directionally and more angular spread.	5.This is high directional and less angular spread.

Characteristics of LASER Beam:

1. **High Intensity**: As we know that the intensity of the light is defined as the energy passing per unit area per second normally to the area of cross section. And the formula is given by-

$$I = \frac{P}{4\pi r^2}$$ where P is the power.

In the case of Laser the energy is concentrated in a very small region, that's why the intensity increases.

2. **High Directionality:** Generally the ordinary source of light radiates the light in all possible direction but the Laser beam emits the radiation in one direction.
3. **Divergence:** The light emitted from the ordinary source diverges in the forward direction but the divergence light from Laser is extremely small.
4. **Coherence:** The Laser beam is completely coherence.
5. **Monochromatically:** The light from ordinary source is never monochromatic but the light from the Laser, it is nearly monochromatic.

Some important definitions related to LASER:

Population Inversion (Inverted Population):

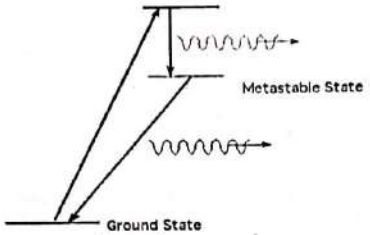
To start the stimulated emission the large number of atoms are made available in the higher/excited energy level ($N_2 > N_1$). This process of achieving the larger number of atoms in the higher energy level than lower energy is known as population inversion. The term population Inversion describes the assembly of atoms in which the majority is in energy levels above the ground state (lower) level. And a system in which the population inversion is achieved is called **active system or active medium.**

The process/method to achieve population inversion is known as 'pumping' of atoms. Most commonly used methods for 'pumping' are as-

1. **Optical pumping (used in Ruby LASER)-** In this method the atoms are exposed to light radiations/photons . The atoms in lower energy state absorb these photons and get excited.
2. **Electrical discharge (used in He-Ne LASER)-** In this method the electrons are produced in an electric discharge tube and accelerated to high velocities by strong field. The accelerated electrons then collide with gas atoms and transfer their energy to the atoms and thus atoms get excited.
3. **In-elastic atom-atom collisions-** In this method a combination of two types of gases are used such that both have the same or nearly same coinciding excited states. The atoms of first gas are excited due to collision with electrons. The excited atoms of first gas collide with the atoms of second gas in lower state and transfer their energy to the atoms of second gas. So the atoms of second gas are excited and the atoms of first gas return to the ground/lower state.
4. **Direct conversion (used in semi-conductor LASER)-** In this method the electric energy is applied to direct band gap semiconductor. The combination of electrons and hole take place.
5. **Chemical reaction (used in CO_2 LASER)-** Due to some chemical reactions the atoms may be raised to the excited state.

Metastable state:

When the atom is in excited state, its time to come from excited state to ground state is very small ie 10^{-8} sec, so in order to achieve the population inversion , we must have energy state which has a long lifetime . Such an energy state is called metastable state. These levels lie in the forbidden band gap of the host of the crystal.



(Figure-4)

Principle of LASER-

The following steps are taken in Laser action-

Pumping ⟶ Population Inversion ⟶ Stimulated Emission

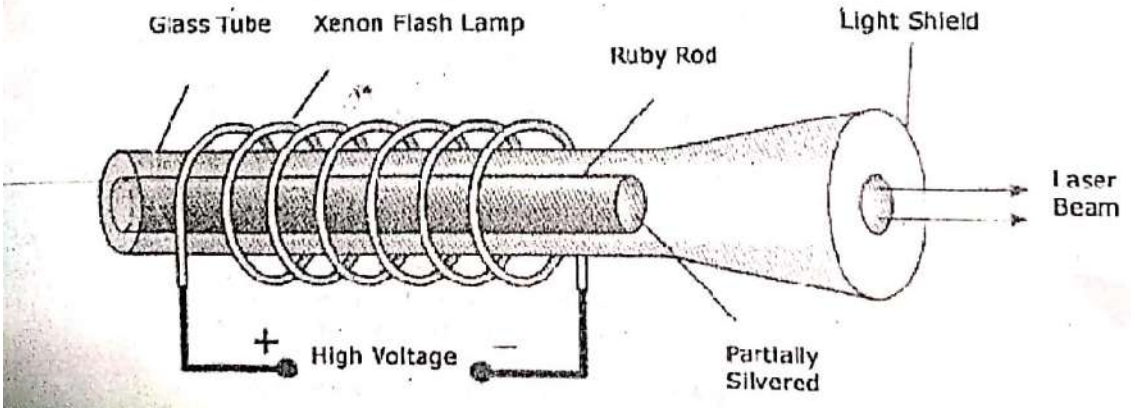
Main parts of a Laser:

1. **Active Medium-** The basic material in which atomic transition takes place. The active medium may be solid, liquid and gas. In ruby laser the active medium is solid ie ruby crystal, in He-Ne Laser and Co_2 Laser the active medium is Helium-Neon gas and Co_2 gas.
2. **Energy Source:** The energy source raise the system to the excited state where the population inversion takes place.
3. **Optical Resonator:** The function of optical resonator is to increase the intensity of the Laser beam. The optical resonator consists two plane reflecting mirror. The first mirror is fully reflecting while the second mirror is partially reflecting. The active medium is placed between these two mirrors.

RUBY LASER

The Laser which is made by introducing impurity atoms into a crystal. Ruby was the first solid material which was used in the production of Laser and is still widely used. Ruby laser is based on three energy level and this laser consists of pink ruby cylindrical rod. The ruby rod is basically aluminum oxide (Al_2O_3) crystal doped with 0.05% (by weight) of chromium oxide (Cr_2O_3). The Al^{3+} ions are replaced by Cr^{3+}. These impurity in ruby crystal is responsible for pink colour.

The different parts of Ruby Laser are shown in the figure-



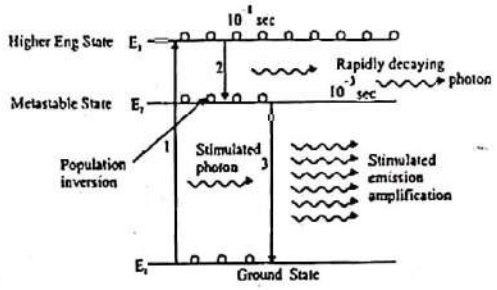
(Figure-5)

Construction:

It contains main three main parts-

1. An active working material- A rod of ruby crystal laser.
2. Energy Source/Exciting System- A helical xenon flash tube with power supply source.
3. Optical Resonator/The resonant Cavity- It is made of fully reflecting plate on the left of ruby crystal and a partially reflecting plate at the right of the ruby crystal.
4. Cooling System- Water circulating system in a glass tube surrounding it.

The Working of Ruby Laser: The energy level diagram of ruby laser is shown in the figure. There are three energy levels. Upper energy level E_3 is short lived state, Level E_1 is a ground state and, E_2 is a metastable state in which the time period is 3×10^{-3} sec. and it lies between E_1 and E_2 of chromium ions.



(Figure-6)

Normally most of the Cr^{+3} ions are in the ground state, when a flesh (λ=5500Å) falls upon the ruby rod the photons are absorbed by the Cr^{+3} ions. They get excited and reach in E_3 levels. Now the excited ions give a part of their energy to the crystal lattice and decay to the metastable state E_2, so this transition is radiation less. Now the maximum number of chromium ions reach to the metastable state while the number of Cr^{+3} ions start decreasing in ground state E_1, so the population inversion is established between E_1 and E_2.

A spontaneous photon emitted by a Cr^{+3} ion at E_2 level initiates the stimulated emission by the other Cr^{+3} ions in the metastable state E_2. The wavelength of the photon is 6943 Å. This photon travels through the ruby rod and moves along the axial direction and repeatedly reflected by the resonator. This results in amplified strong laser beam of wavelength 6943 Å.

Characteristics of Ruby Laser-

1. Ruby Laser is a three level solid state Laser.
2. Ruby rod is used as active medium.
3. The output power is 10^4 to 10^6W.
4. The wavelength/ frequency of output beam is 6943Å/4.32×10^{14}Hz.
5. The nature of output is pulsed beam of light.
6. Two mirrors are silver polished at the ends of ruby rod and act as optical resonator.
7. The type of pumping is optical pumping in this Laser.

Drawbacks of Ruby Laser-

1. The Ruby Laser requires high pumping power.
2. The Laser output is in pulse form not continuous.
3. Its efficiency is very small.

Applications and Uses of Ruby Laser-

1. It is used in soldering and welding.
2. It is used in laboratory.
3. It is used to test the quality of materials.
4. It is used to drill in brittle materials.
5. It is used in the treatment of retina.
6. It is used in light detection and ranging (LIDAR).

He-Ne (Helium-Neon) LASER-

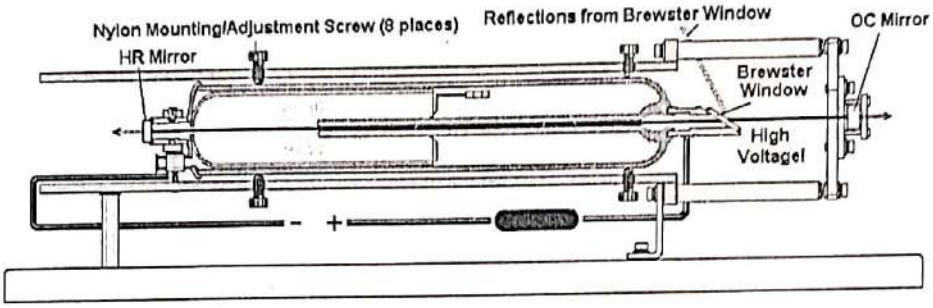
The output of Ruby Laser is not continuous, so to remove this drawback He-Ne gas Laser was represented in 1961. It is a gas based Laser.

Main Parts of Laser:

Its construction is shown in the figure below. It contains main following main parts-

1. Active Medium- Mixture of helium and neon gas in the ratio of 7:1 acts as an active medium in this Laser.
2. Optical Resonator/The resonant Cavity- The reflecting mirrors M_1 and M_2 outside the tube act as the resonant cavity.
3. Pumping Mechanism- Electric discharge Method is used.

Construction: The working diagram of He-Ne Laser is shown in the figure-



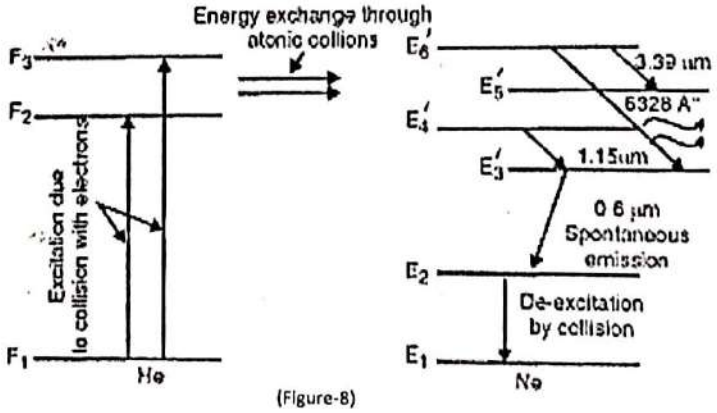
Anode-End One-Brewster HeNe Laser Tube Mounted in Test Fixture

(Figure-7)

This gas Laser consists a fused quartz tube 1.5 cm in diameter and 80 cm in length. This tube is filled with the mixture of helium and neon gas in the ratio of 7:1 at a pressure of 1 mm mercury column (1 torr).

The end faces of the tube are inclined at the angle of polarization so that the light becomes ppl. This tube is placed between the two mirrors (act as an optical resonator), one of the mirror is perfect reflector while the second one is partially reflector and these reflecting surfaces.

The active material is excited by means of a high frequency generator and its input is about 50 watt. When a discharge passes through the mixture the He atoms are excited and reach in level E_2 and E_3 (metastable state, but from these state no transition is allowed), this is termed as pumping. Due to no allowed transition the helium atoms collide with Ne atoms at ground level and transfer energy, due to which the Ne-atoms are excited and jump to the levels E'_5, E'_4 and E'_3 (metastable state) and population inversion takes place. After the collision the He atoms return to the ground state.



(Figure-8)