



Topic: - LASERS (Part B, Unit-5)

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Lasers and Holography

VTU Syllabus (2008-09)

Lasers

Principle and production. Einstein's coefficients (expression for energy density). Requisites of a Laser system. Condition for Laser action. Principle, Construction and working of He-Ne and semiconductor Laser. Applications of Laser – Laser welding, cutting and drilling. Measurement of atmospheric pollutants. Holography – Principle of Recording and reconstruction of 3-D images. Selected applications of holography.

6 Hours

Laser is an acronym for **LIGHT AMPLIFICATION BY STIMULATED EMISSION OF RADIATION**. The laser is the outgrowth of MASER, which is a device that amplifies microwaves. Laser made optical communication possible. Lasers are invented in 1959 and 1960.

Comparison of Ordinary Beam of Light and Laser Beam

Ordinary Beam	Laser Beam
1. It is not Monochromatic 2. It is Incoherent 3. It does not travel as a concentrated and parallel beam.	1. It is Monochromatic. 2. It is coherent 3. It travels as a concentrated

Coherence

The coherence between two sources of light is regarded as the existence of a constant phase relationship between them Coherence is of two types:

1. Temporal or time coherence
2. Spatial Coherence

Coherence Length and Coherence Time: When an excited atom returns to initial state, it emits a light pulse of short duration. The time interval is of the order of 10^{-10} seconds. The field remains sinusoidal for this time interval.

The average time interval for which the field remains sinusoidal is known as Coherence time. It is denoted by τ .

Temporal or Time Coherence: In a source like sodium lamp, two waves of slightly different wavelengths are given out. These waves have slightly different coherence times. A definite phase relationship exists between the two times of coherence. This is known as temporal coherence of the beam.

Spatial Coherence: A laser beam is said to possess spatial coherence if the phase difference of the waves crossing the two points on a plane perpendicular to the direction of propagation of the beam is time-independent.

Spatial coherence is also termed as transverse or lateral coherence.

Interaction of Radiation with Matter

A material medium is composed of identical atoms or molecules each of which is characterized by a set of discrete allowed energy states. An atom can move from one energy state to another when it receives or releases an amount of energy equal to the energy difference between those two states. It is termed as a quantum Jump or transition.

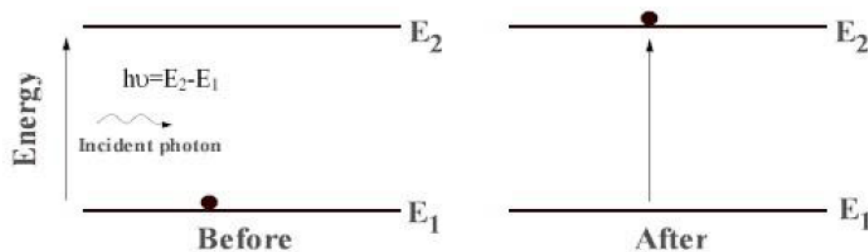
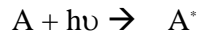
Let us consider two energy states E_1 and E_2 of an atom. E_1 is the lower energy state while E_2 is the excited state. As the constituent atoms of the medium are identical, the energy states E_1 and E_2 will be common to all atoms in the medium.

Let a monochromatic radiation of frequency ν be incident on the medium. The radiation may be viewed as a stream of photons, each photon carrying an energy $h\nu$. If $h\nu = E_2 - E_1$, the interaction of radiation with atoms leads to the following three distinct competing processes in the medium.

1. Stimulated Absorption
2. Spontaneous Emission
3. Stimulated Emission

1. Stimulated Absorption:-

An atom residing in the lower energy state E_1 may absorb the incident photon and jump to the excited state E_2 . The transition is known as Stimulated Absorption or induced Absorption. Corresponding to each transition made by an atom one photon disappears from the incident beam. It may be represented as



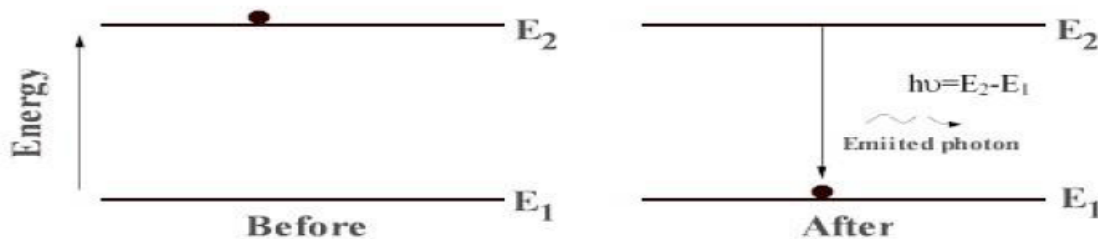
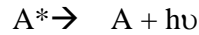
Where A is the atom in lower state and A^* is an excited atom. The probable rate of transition from $1 \rightarrow 2$ (State 1 to State 2) depends on the properties of states 1 and 2 and is proportional to the energy density $u(\nu)$ of the incident radiation of frequency ν .

$$P_{12} = B_{12} N_1 u(\nu)$$

B_{12} is a constant of proportionality, which depends on the properties of state 1 and 2. It is called Einstein's Coefficient for absorption of radiation.

2. Spontaneous Emission:-

Excited states with higher energy are inherently unstable because of a natural tendency to seek out the lowest energy configuration. The excited atom in the state E_2 may return to the lower state E_1 on its own, due to the tendency to attain minimum potential energy. During the transition the excess energy is released as a photon of energy $h\nu = E_2 - E_1$. This type of process in which photon emission occurs without any external impetus is called spontaneous emission. It may be represented as



The process of Spontaneous emission is essentially probabilistic. The instant of the transition, direction of emission of photon, the phase of the photon, the polarization state of the photon are all random quantities. There will not exist any correlation among the parameters of the innumerable photons emitted spontaneously by the assembly of atoms of the medium. The probability of Spontaneous emission $2 \rightarrow 1$ depends only on properties of state 1 and 2. According to Einstein's the probable rate of spontaneous emission is denoted by

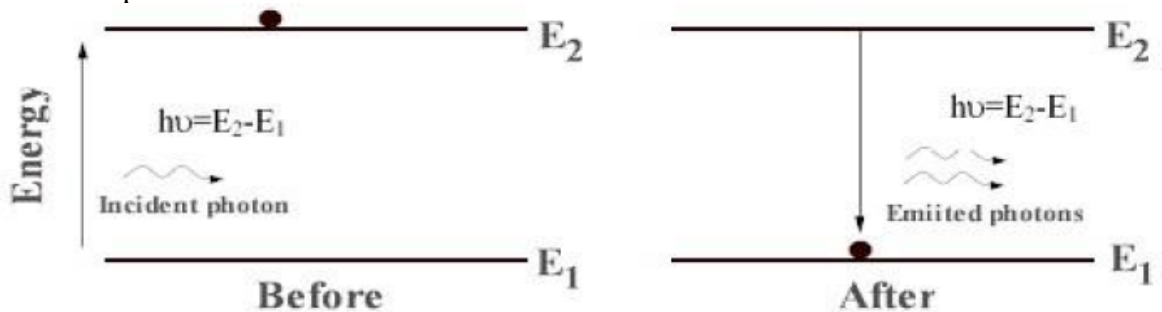
$$(P_{21})_{\text{spontaneous}} = A_{21} N_2$$

A_{21} is called Einstein's coefficient of spontaneous emission of radiation.

Note: The mean life time τ for spontaneous emission by excited atoms is of the order of 10^{-8} Seconds. However, there are some states for which τ is much longer, perhaps 10^{-3} seconds. These are called meta-stable states. These states play a major role in laser operation.

3. Stimulated Emission

An atom in the excited state need not wait for spontaneous emission to occur. There exists an alternate mechanism by which an excited atom can make a downward transition and emit light. A photon of energy $h\nu = E_2 - E_1$ can induce the excited atom to make a downward transition realizing the energy in the form of a photon. Thus, the interaction of a photon with an excited atom triggers the excited atom to drop to the lowest energy state giving up a photon. The phenomena of forced emission of photons are called induced emission or stimulated emission.



The process of stimulated emission is characterized by following features:

1. The emitted photon is identical to the incident photon in all respect. It has the same frequency ν as that of incidence photon. It will be in phase with the incident photon. Both the photon travels in the same direction. They will be in the same state of polarization.
2. The process is controllable from outside.
3. The most important feature is that multiplication of photons takes place in the process. One photon induces an atom to emit a second photon, these two traveling photons can cause another stimulated emission event, giving a total of four photons, which can cause additional stimulated emissions and so on. This is the “amplification “of the laser acronym. The probability of stimulated emission from energy state E_2 to energy E_1 depends on the energy density of incident radiation as well as on the properties of two energy states involved. It is given by

$$(P_{21})_{\text{stimulated}} = B_{21} N_2 u(\nu)$$

B_{21} is the Einstein’s coefficient of Stimulated emissions of radiations. The total probability of emission transition $2 \rightarrow 1$ is the sum of spontaneous and stimulated emission probabilities.

$$P_{21} = (P_{21})_{\text{spontaneous}} + (P_{21})_{\text{stimulated}}$$

$$P_{21} = A_{21} + B_{21} u(\nu)$$

Relation between Einstein’s Coefficients A and B:-

Let us consider an assembly of atoms in thermal equilibrium at temperature T with radiation of frequency ν and energy density $u(\nu)$. Suppose N_1 and N_2 are the number of atoms in energy states 1 and 2 respectively at any instant. The probability of absorption that the number of atoms in state 1 which can absorb a photon and rise to state 2 per unit time is given by

$$N_1 P_{12} = N_1 B_{12} u(\nu) \tag{1}$$

The total probability of emission (Spontaneous + Stimulated) that the number of atoms in higher state 2 can drop to lower state 1 by emitting a photon, per unit time is given by

$$N_2 P_{21} = N_2 [A_{21} + B_{21} u(\nu)] \tag{2}$$

At thermal equilibrium, the absorption probability is equal to the total emission probability.

$$\begin{aligned}
 N_1 P_{12} &= N_2 P_{21} \\
 N_1 B_{12} u(\nu) &= N_2 [A_{21} + B_{21} u(\nu)] \\
 N_1 B_{12} u(\nu) &= N_2 A_{21} + N_2 B_{21} u(\nu) \\
 N_1 B_{12} u(\nu) - N_2 B_{21} u(\nu) &= N_2 A_{21} \\
 u(\nu) [N_1 B_{12} - N_2 B_{21}] &= N_2 A_{21} \\
 u(\nu) &= \frac{N_2 A_{21}}{[N_1 B_{12} - N_2 B_{21}]} \\
 u(\nu) &= \frac{A_{21}}{\frac{N_1}{N_2} B_{12} - B_{21}} \\
 u(\nu) &= \frac{A_{21}}{B_{21} \left[\frac{N_1}{N_2} \frac{B_{12}}{B_{21}} - 1 \right]}
 \end{aligned}$$

According to Einstein's, the probability of stimulated absorption is equal to the probability of stimulated emission i.e. $B_{21}=B_{12}$.

$$u(\nu) = \frac{A_{21}}{B_{21} \left[\frac{N_1}{N_2} - 1 \right]} \quad (3)$$

According to the Boltzmann distribution law, the number of atoms N_1 and N_2 in energy states E_1 and E_2 in thermal equilibrium at temperature T are given by

$$N_1 = N_0 e^{-\left(\frac{E_1}{kT}\right)} \quad \text{and} \quad N_2 = N_0 e^{-\left(\frac{E_2}{kT}\right)}$$

Where N_0 is the total number of atoms and K is Boltzman's constant.

$$\begin{aligned}
 \frac{N_2}{N_1} &= \frac{e^{-\left(\frac{E_2}{kT}\right)}}{e^{-\left(\frac{E_1}{kT}\right)}} \\
 \frac{N_2}{N_1} &= e^{-\left(\frac{E_2}{kT}\right) + \left(\frac{E_1}{kT}\right)} \\
 \frac{N_2}{N_1} &= e^{-\left(\frac{E_2 - E_1}{kT}\right)} \\
 \frac{N_2}{N_1} &= e^{-\left(\frac{h\nu}{kT}\right)} \\
 \frac{N_1}{N_2} &= e^{\left(\frac{h\nu}{kT}\right)}
 \end{aligned}$$

From eq. (3)

$$u(\nu) = \frac{A_{21}}{B_{21} \left[e^{\left(\frac{h\nu}{kT}\right)} - 1 \right]} \quad (4)$$

According to Planck's law of radiation formula

$$u(\nu) = \frac{8\pi h \nu^3}{c^3} \frac{1}{\left[e^{\left(\frac{h\nu}{kT}\right)} - 1 \right]} \quad (5)$$

Comparing eq (4) and eq(5)

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

$$\frac{A_{21}}{B_{21}} \propto \nu^3 \quad \text{and} \quad B_{12} = B_{21}$$

The ratio of spontaneous emission and stimulated emission is proportional to ν^3

Active Medium

A medium in which light gets amplified is called an active medium. The medium may be solid, liquid or a gas, out of the different atoms in the medium, only a small fraction of atoms of a particular species are responsible for stimulated emission and consequent light amplification. They are called active centers. The remaining bulk of the medium plays the role of host and supports active centers.

Population

The number of active atoms occupying an energy state is called population of that state. Thus N_1 and N_2 are the populations of the lower (E_1) and upper (E_2) energy levels respectively.

Condition for light Amplifications

At thermal equilibrium, the ratio of the stimulated to spontaneous transitions is generally very small and the stimulated emission is negligible. The ratio is given by

$$\frac{\text{Stimulated .transitions}}{\text{Spontaneous .transitions}} = \frac{B_{21} N_2 u(\nu)}{A_{21} N_2} = \frac{B_{21} u(\nu)}{A_{21}} \quad (1)$$

The ratio of stimulated to absorption transition is given by

$$\frac{\text{Stimulated .transitions}}{\text{Spontaneous .transitions}} = \frac{B_{21} N_2 u(\nu)}{B_{12} N_1 u(\nu)} = \frac{B_{21} N_2}{B_{12} N_1}$$

$$= \frac{N_2}{N_1} \quad \therefore B_{21} = B_{12} \quad (2)$$

here $B_{21}=B_{12}$ as the probability of stimulated emission transition must equal the probability of stimulated absorption transition.

1. The eq (1) suggests that in order to enhance the number of stimulated transitions the radiation density $u(\nu)$ is to be made larger.
2. The eq (2) indicates that stimulated emission will be longer than absorption only when $N_2 > N_1$. As long as $N_1 > N_2$, the absorption dominates stimulated emission and the medium will absorb the incident light.

Population Inversion

To achieve high percentage to stimulated emission, an artificial situation known as population inversion is to be created.

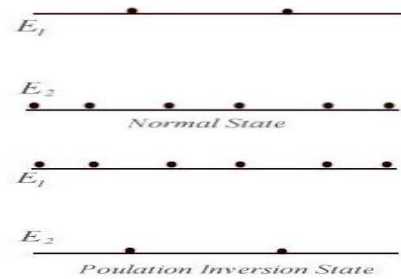
We know that

$$\frac{N_2}{N_1} = \exp[-(E_2 - E_1) / kT]$$

which shows that in a state of thermal equilibrium there are more atoms in lower level than in upper level

We also know that

$$\frac{\text{Stimulated transitions}}{\text{Spontaneous transitions}} = \frac{N_2}{N_1}$$



This shows that there must be more atoms in the upper level than the lower level in order to achieve stimulated emission exclusively. Therefore a non equilibrium state is to be produced in which the population of upper-energy exceeds to a larger extent in comparison to the lower energy level. When this situation occurs, the population distribution between the levels E_1 and E_2 is said to be inverted and the medium is said to have into state of population inversion.

Pumping

For realizing and maintaining the condition of population inversion, the atoms have to be raised continuously to excited state. It requires energy to be supplied to the system. The process of supplying energy to the medium with a view to transfer it into the state of population inversion is known as pumping.

Some Methods for Pumping:

(1) **Optical Pumping:** In this method, the medium is excited by supplying luminous energy from a light source. The energy is supplied in the form of short flashes of light. This type of pumping is used in **Ruby Laser**.

(2) **Electric Discharge:** This method of pumping is employed in gaseous ion lasers. A slowing electric field accelerates the electrons. The accelerated electrons collide with atoms of the medium. Consequently, the atoms are ionized and excitation is produced. Example:- **Argon ion Laser**.

(3) **Direct Conversion:** The electric energy is converted directly into light energy with the help of light emitting diodes (LED's). This method is used in **semiconductor laser**.

(4) **In-Elastic Atom-Atom Collisions:** The atoms excited by electrical discharge method collide in-elastically with other atoms. **Helium-Neon laser** is an example of this kind.

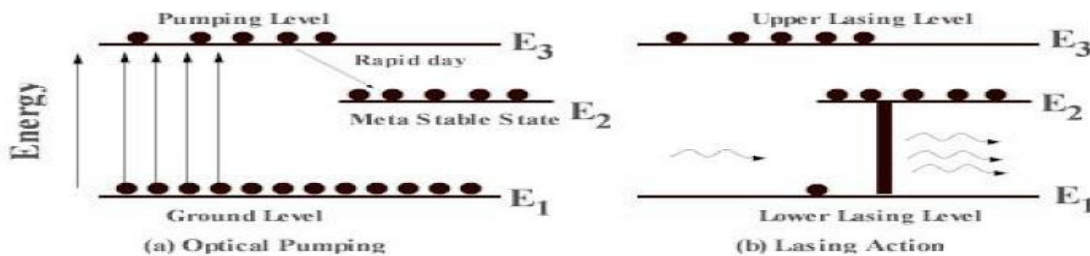
(5) **Chemical Pumping:** In chemically pumping, the energy for pumping is obtained from a chemical reaction. As an example, when hydrogen combines with fluorine to form hydrogen fluoride, enough heat is generated. This reaction is employed for pumping in a **CO₂ laser**.

The Principal Pumping Schemes

The transitions between the two levels that generate stimulated emission is called a lasing transition. The terminal level is called the lower lasing level and the upper level as upper lasing level. The upper most level is termed pumping level. Two important pumping schemes are widely employed.

1. Three-Level Pumping Scheme:

Let us assume that as atomic system has three energy levels. The State E_1 is the ground state and E_2 and E_3 are the excited states. In the scheme, the energy states are such that atoms are readily excited to uppermost state E_3 (known as pumping level), when light of frequency ν_p (known as pump frequency) $= E_3-E_1/h$ is incident on them. The pump level E_3 is not a stable state. Atoms do not stay at the E_3 level and undergo downward transitions either to E_1 or E_2 levels.



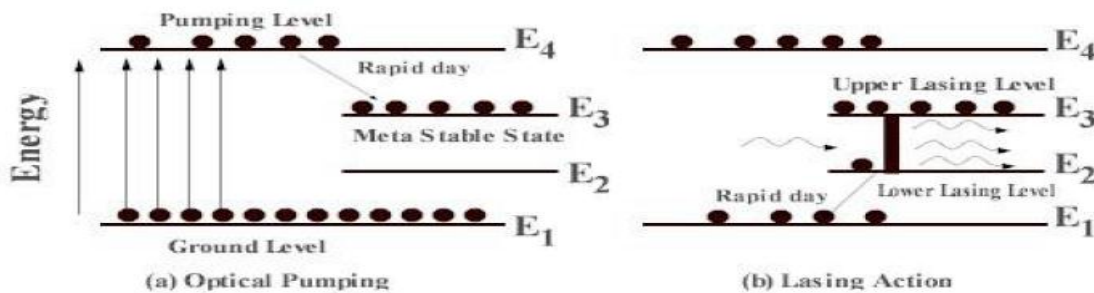
The probability of spontaneous transitions $E_3 \rightarrow E_1$ is comparable to that of $E_3 \rightarrow E_2$. The E_2 is a meta-stable state, since the probability of spontaneous transition $E_2 \rightarrow E_1$ is extremely small. When the medium is exposed to radiation of frequency ν_p , a large number of atoms will be excited to the higher energy level E_3 . Some of these atoms make spontaneous transitions to the lowest level E_1 . But many of them make spontaneous transitions to the meta-stable level E_2 through a non-radiative transition.

As spontaneous transitions from E_2 to E_1 occur rarely, the atom gets trapped in the state E_2 . The process continues because of pumping and after a short time there will be a large accumulation of atoms at E_2 . When more half of the ground state atoms accumulated at E_2 the population inversion is achieved between the states E_1 and E_2 .

Now a photon of energy $h\nu=(E_2-E_1)$ can trigger stimulated emission of atoms at E_2 .

2. Four-Level Pumping Scheme:

A typical four level pumping scheme is shown in fig. Pump frequency lifts the active centers from the ground level E_1 to the uppermost level E_4 . From the pump level E_4 the atoms rapidly falls to the meta-stable state E_3 . The population at this stage grows rapidly while the level E_2 is virtually empty. Therefore, population inversion is achieved between the states E_2 and E_3 . A photon of energy $h\nu=E_3-E_2$ can start a chain of stimulated emissions, bringing the atoms into the state E_2 . From there the atom undergoes non-radiative transitions subsequently to the ground state E_1 and will be available once again to participate in the process.



3. Two-Level Pumping Scheme:

The population inversion can be achieved only by the indirect routes. A two level pumping scheme is not suitable for obtaining population inversion. The Time Span Δt for which atoms have to stay at the upper level E_2 must be longer for achieving population inversion condition. According to Heisenberg's Uncertainty principle

$$\Delta E \cdot \Delta t \geq h$$

Δt will be longer if ΔE is smaller.

If ΔE is smaller the pumping frequency is smaller as a consequence of which less number of atoms are excited. Through the Sharp energy level supports the population inversion; enough population cannot be excited to level E_2 in view of small ΔE .

The result is that the upward transitions would be accomplished by premature downward stimulate transitions and the population in level E_2 would not accumulate to the required extent.

Three Components of Laser Devices

1) The Pump:

It is an external source, which supplies energy to obtain population inversion. The pump can be optical, electrical or thermal. In the ruby laser, we use optical pumping. In the He-Ne laser, we use electric discharge. The energy supplied by the pump excites the atoms to higher energy levels and through spontaneous emission or through non-radiative processes, the population inversion occurs.

2) The laser Medium:

It is a material in which the laser action is made to take place. It may be solid, liquid or gas. Many lasers are named after their material used e.g. ruby laser, He-Ne laser, CO₂ laser etc. The most important characteristic requirement for the laser medium is that we should be able to obtain the

population inversion in it. According to Boltzmann condition if N_1 and N_2 be the number of atoms in the energy states E_1 and E_2 , then

$$\frac{N_2}{N_1} = e^{-\frac{h\nu}{kT}}$$

Where $h\nu = E_2 - E_1$. Therefore, N_2 is in general less than N_1 . Because of this reason, rigorous pumping may be required for sustaining the population inversion and so only certain pairs of energy levels with appropriate lifetime can be invented.

3) The Fabry-Perot Resonator:

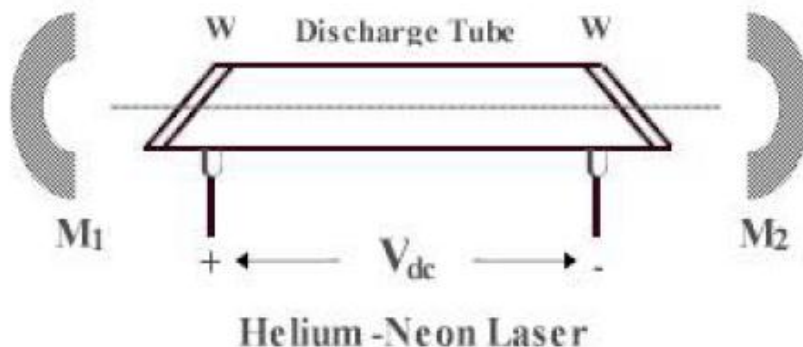
It consists of a pair of plane or spherical mirrors having common principal axis. The reflection coefficient of one of the mirrors is very near to 1 and that of the other is kept somewhat less than 1. It enables a part of the intensity reflected beam to escape out as a large beam. The resonator is basically a feedback device, that directs the photons back and forth through the laser medium and in the process the number of photons is multiplied.

Helium-Neon Laser

Helium-Neon (He-Ne) laser was first successful gas laser. It was built by Ali Javan, W. Bennett and D. Herriot in 1961.

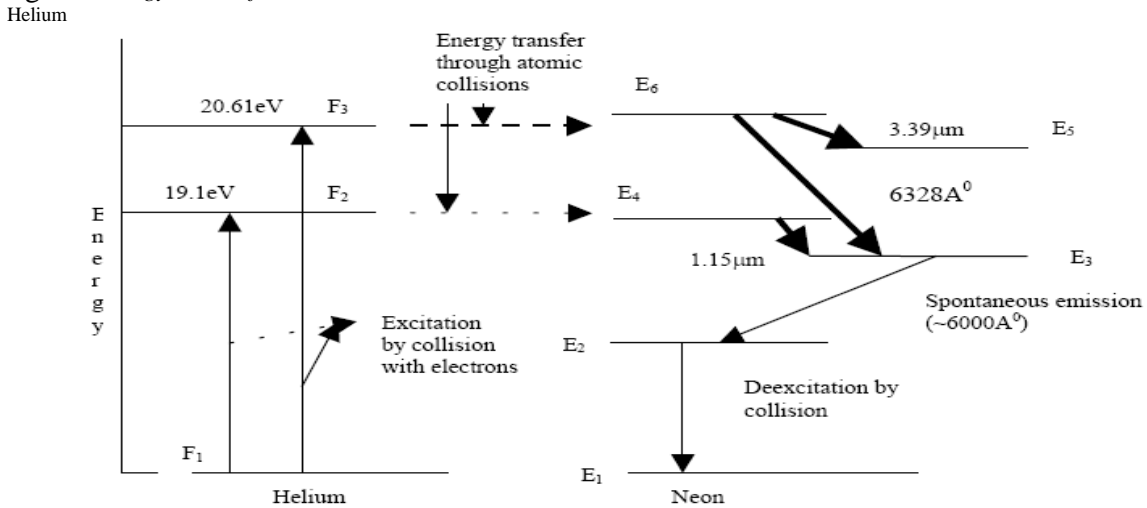
(1) Construction :

It consists of along discharge tube of length about 50 cm and diameter 1 cm. The tube is filled with a mixture of Helium and Neon gases in the ratio of 10:1. Helium is the pumping medium and Neon is the lasing medium. Electrodes are provided to produce a discharge in the gas and they are connected to a high voltage power supply. The tube is hermetically sealed by inclined windows arranged at its two ends. On the axis of the tube, two reflectors are fixed which form the Fabry – Perot resonator. The distance between the mirrors is adjusted such that it equals $m\lambda/2$ and supports the standing waves pattern.



(2) Working: -

Helium-Neon laser employs a four level pumping scheme. The energy level diagram is shown in figure. *Energy levels of helium and neon atoms and transitions between the levels.*



Energy levels of helium and neon atoms and transitions between the levels.

Pumping is accomplished by setting up an electrically induced gas discharge in the helium neon-mixture. Electrons and ions in this discharge occasionally collide with helium atoms raising them to a level F₃. The Helium atoms are more readily excitable than neon atom because they are lighter. The energetic electrons excite helium atoms through collisions to state F₃=20.61 eV. Spontaneous emission to the ground state level F₁ is very rare. So during collisions between Helium and Neon atoms, the excitation energy of the Helium can be easily transferred to the Neon. Level F₃=20.61 eV in Helium is by chance very close to level F₆=20.66 eV in Neon. Though a radiative transition is forbidden, the excited Helium atoms can return to ground state by transferring their energy to neon atoms through collisions. Such an energy transfer takes place when the two colliding atoms have identical energy states. Therefore, Neon atoms acquire energy and go to the excited state on collision with Helium atoms, which returns (He atoms) to the ground state after transferring the energy. **The kinetic energy of Helium atoms provides the additional 0.05% for exciting the Neon atom. This is the main pumping scheme of He-Ne system.** Neon atoms are active centers. At ordinary temperatures, the E₅ and E₃ levels of neon atom are sparsely populated and the state of population inversion is achieved between E₆ and E₅, E₃ levels and between E₄ and E₃ levels. Consequently, three laser transitions can occur. They are

- E₆ E₃ transition: - This transition generates a laser beam of red colour of wavelength 6328Å
- E₄ E₃ transition: - It produces infrared laser beam at a wavelength of 115000Å(1.15µm).
- E₆ + E₅ transition:- A laser beam of wavelength 3.39 µm in the far infrared region arises due to this transition. As the lower lasing levels depopulate faster than the upper metastable states, it is easier to maintain the state of population inversion between the lasing levels throughout the time of laser operation.

- E₂ level is a metastable state. Therefore, neon atoms tend to accumulate at this level once again. However, when they drift toward the surrounding discharge tube wall and collide with it, they give up their energy and return to the ground state. These atoms are to be brought to the ground state quickly; otherwise the number of atoms available at the ground state will go on diminishing and the laser output decreases. To increase the probability of atomic collisions with the walls, the discharge tube is made narrow. The He-Ne laser operates in CW mode as the neon atoms are excited to upper levels continuously through collisions.

Semiconductor Laser

Semiconductor junction diodes can also be used as a laser device. The semiconductors have a filled valence band and above it an empty conduction band with a small energy gap, of the order of 1eV. At room temperature, a few of its electrons in the valence band have sufficient energy of thermal motion to cross the narrow energy gap and enter the conduction band above it. If a light photon of energy greater than the energy gap happens to interact with the electrons, one of the following two processes may occur.

- 1) The photon may be absorbed by a valence band electron which would be excited to the conduction band;
- 2) the photon may stimulate an already excited conduction band electron which would drop to the valence band, emitting a fresh photon in coherence with the stimulating photon.

The second process will occur only when the large numbers of electrons are made available in conduction band as compared to the valence band. This situation can be achieved by population inversion. In semiconductor laser the pumping is done by an electrical battery across the junction, which goes on feeding electrons to the conduction band. The necessary population inversion is brought about by forward biasing the junction. Once population inversion is achieved, the photons go on multiplying by repeated stimulated emission and a strong, intense, monochromatic and highly coherent beam of light emitted from the semiconductor. The first semiconductor laser was made from gallium arsenide (GaAs). At room temperature, GaAs laser emits light at a wavelength of 9000 Å in IR region. A GaAsP laser radiates at 6500 Å in the visible red region. The extreme simplicity to semiconductor lasers makes them very attractive. The light output can easily be modulated by varying the applied voltage, so that the signal can be transmitted on the light beam. Semiconductor lasers can therefore be used for communications, either by transmitting through an air or through the guiding action of glass fibers.

Applications of Laser

1. Laser Drilling: -

Drilling of holes is achieved by subjecting the material to powerful light pulses. The pulses will be of 10⁻⁴ to 10⁻³s duration. The intense heat generated over a short duration by the pulses evaporates the material locally, thus leaving a hole. Nd-YAG laser is used to drill holes in metals, where as a CO₂ laser is used in case of both metallic and nonmetallic materials.

Advantages: -

- The tools wear out while drilling by conventional method whereas that problem does not exist with laser set-up.
- Drilling can be achieved at any oblique angle through the material whereas it could be done only to a limited extent in conventional methods.
- Very fine holes to the dimensions of even 0.2 to 0.5 mm diameter could be drilled with a laser beam. The holes may be even adjacent to each other.
- Very hard materials or brittle materials could be subjected to laser drilling since there is no problem of mechanical stresses with a laser beam.

2. Measurement of pollutants in the Atmosphere: -

There are various types of pollutants in the atmosphere which include oxides of nitrogen, carbon monoxide, sulphur dioxide and a number of particulate matter under which category come dust, smoke, fly-ash etc. In conventional techniques, samples of the atmosphere are collected at desired heights and then chemical analysis is carried out to find the composition of the pollutants. But, since the local atmosphere is subjected to slow but continuous variation, the data obtained after the analysis pertains only to the conditions prevalent at the time of collection i.e., it is not real time data. This limitation is overcome when measurements are done using laser. The laser senses the atmospheric density variation by scanning the required local region and the electronic data processor yields the data, which is a real-time data. In the application of laser for measurement of pollutants, laser is made use of the way as radar system is used. Hence it is often referred as a lidar (light detection and ranging). A lidar can be employed to evaluate the distance, altitude and angular coordinates of the object. In the lidar system, the transmitting part consists of a pulsed (such as ruby laser) the receiving part consists of

1. a concave mirror which receives the reflected wave.
2. a photodetector which converts optical energy to electrical energy.
3. a narrow-band filter which cuts off the background noises and extraneous light.
4. a data processor which gives out the information regarding distance, dimensions of the object etc.,

While measurements are carried out, the laser beam undergoes scattering at places in the atmosphere where there is congestion (highly populated) due to higher concentration of particulate matter. The back scattered light is received by the concave mirror. The distance of congestion from the measuring station is calculated on the basis of time-delay between the pulse emission and the reception of the back scattered light. By scanning the space around the station, the concentration of pollutants can be mapped for different vertical sections of the atmosphere. But this measurement falls short of knowing about the nature of scattering particles. However the following two methods which involve the use of laser can be employed to know the composition of the pollutants. In both the methods, it needs the collection of sample of the atmosphere at the desired region. Then the sample is subjected to investigation by using laser.

1) **Absorption technique:** - The laser beam is passed through the sample collected from the atmosphere. The transmitted beam is recorded with a detector. While the beam passes through the sample it undergoes absorption of varying degrees depending upon the presence of exact type of chemical substance that the pollutant comprises of. Depending on the characteristic absorption pattern observed in the recording the composition of the atmospheric pollutants could be determined.

2) **Raman Back-scattering**: - Since laser is highly monochromatic we expect to see only one line in spectrum. But due to Raman scattering in the spectrum, several lines are seen. Among these lines there will be a line of high intensity corresponding to the incident lights wavelength as expected. The other lines of low intensity lie symmetrically to this line. Their wavelength values will be close to that of the incident light. These additional spectral lines are called side bands and their frequencies result when the oscillating frequencies of the molecules of the gas are added to or subtracted from the incident lights frequency. Since the oscillating frequencies of different types of molecules will be different, different gases produce different sidebands. The shifts in frequencies are termed Raman shifts. Thus by observing Raman spectra of the back-scattered light in the gas sample one can assess the composition of the pollutants.

Holography

In 1947 Dennis Gabor outlined a radically new technique of photographing objects. According to his technique both the phase and intensity attributes of the wave are recorded and when viewed the photograph shows a three dimensional image of the object. This technique is named holography. The below figure illustrates the principle of holography.

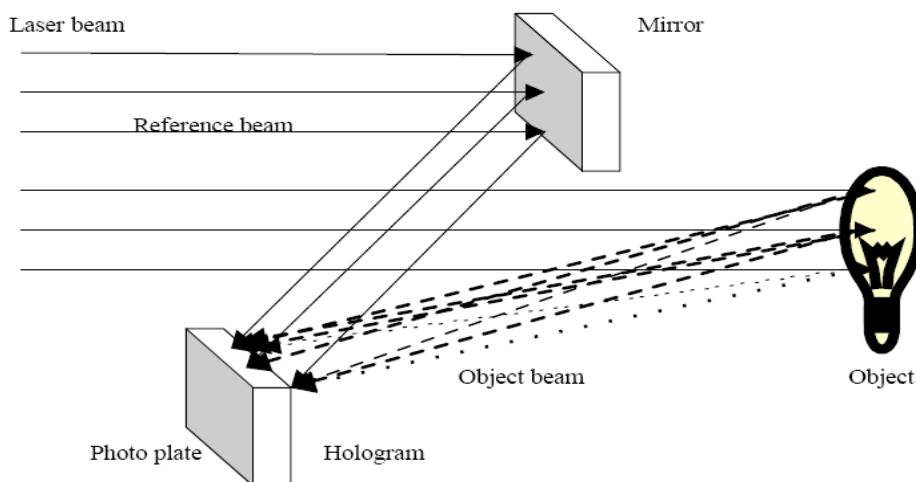
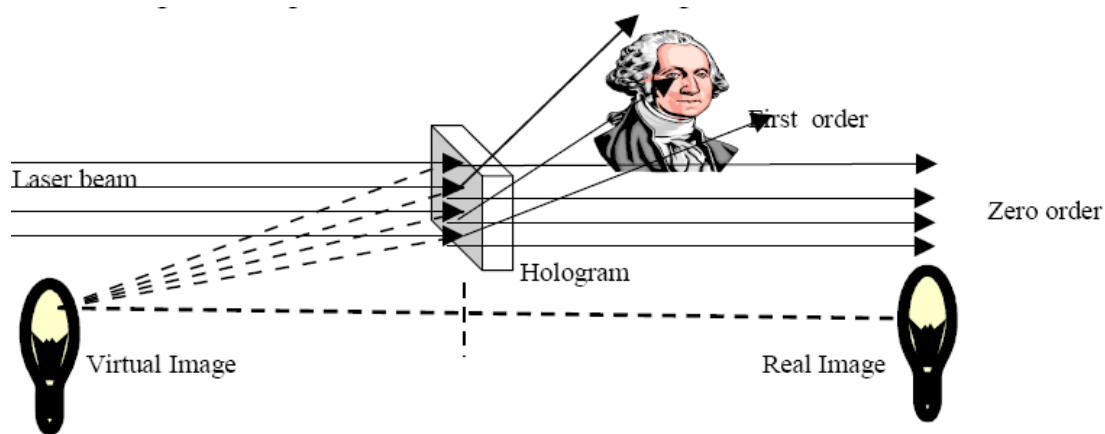


Figure to illustrate generation of Hologram.

A weak but broad beam of laser light is split into two beams namely a reference beam and object beam. The reference beam is allowed to reach the photographic plate directly while the object beam illuminates the object. Part of the light scattered by the object travels towards the photographic plate. The photographic plate carrying the interference pattern is called a hologram. Hologram means complete recording. A hologram does not contain a distinct image of the object. It is only a record of the interference pattern formed by the superposition of two coherent light beams. The interference pattern on a hologram consists of a complex pattern of alternate regions of dark and bright fringes. The hologram is also called a Gabor zone plate. Whenever the object can be viewed by illuminating the hologram as shown in the below figure.



A laser beam identical to the reference beam is used for the reconstruction of the object. The reconstruction beam illuminated the hologram at the same angle as the reference beam. The hologram acts as a diffraction grating and secondary waves from the hologram interfere constructively in certain directions and interfere destructively in other directions. They form a real image in front of the hologram and a virtual image behind the hologram at the original site of the object. An observer sees light waves diverging from the virtual image. An image of the objects appears where once stood and that image is identical to what our eyes would have perceived in all its details. If the observer tilts his head other objects behind the first one or new details of the object, which were not noticed earlier, would be observed. Holography is thus a two-stage process. In the first stage a hologram is recorded in the form of interference pattern. In the second stage the hologram acts as a diffraction grating for the reconstruction beam and the image of the object is reconstructed from the hologram.

Applications of Holography

1. In hologram each part contains information about the entire object. Therefore, destruction of part of a hologram does not cause a loss of information about the entire object. From even a small part of the hologram the entire image can be reconstructed if only with a reduced clarity and definition of the image. Therefore, a hologram is a reliable medium for data storage.
2. Several images can be recorded on a hologram. Therefore, the information holding capacity of a hologram is extremely high.
3. The most significant improvement in the field of holography is that now holograms can be viewed with white light. Thus the necessity for a reconstruction of laser beam is dispensed away.
4. It is easy to produce coherent sound waves. Sound waves readily propagate in solids. Therefore, a three dimensional acoustical hologram of an opaque object can be made. By viewing such hologram in visible light the internal structure of the object can be observed. Such techniques will be highly useful in the fields of medicine and technology.

Questions:-

1. What is a laser? Explain how the basic lasing action is achieved.
2. Distinguish between spontaneous emission and stimulated emission.
3. Explain with diagram absorption, spontaneous emission and stimulated emission of radiation. **Or** explain in detail the interaction of radiation with matter.
4. What are Einstein's coefficients? Derive Einstein's relation.
5. What is population inversion? How it is achieved by optical pumping?
6. Why is population inversion necessary to achieve lasing?
7. Discuss the four-level (Pumping) scheme for laser action?
8. What is optical resonant cavity (Fabry-Perot resonator)? Explain in short its importance in producing a laser beam.
9. Explain with the help of an appropriate energy level diagram, how stimulated emission results from electron impact pumping in He-Ne gas laser.
10. Explain how lasing action is achieved in a semiconductor laser.
11. What are the important characteristics of laser? Explain in brief.
12. Give in brief any one engineering application of laser.
13. What is laser? How does it differ from an ordinary source of light? Mention a few engineering applications of laser.

Numericals: -

- 1) Find the intensity of a laser beam of 10mW power and having a diameter of 1.3mm. Assume the intensity to be uniform across the beam.

Solution: - Given data: - Power P 10 mW= 10×10^{-3} watt.

Diameter, $d=1.3 \text{ mm}=1.3 \times 10^{-3} \text{ m}$

Formula: - Intensity, $I = P/A = 4P/\pi d^2 = 7534 \text{ W/m}^2$

The intensity of the given laser beam is 7534 W/m^2 .

- 2) In a helium-neon laser the two plane mirrors forming the resonant cavity are distanced 0.5m. What is mode separation of longitudinal cavity in terms of frequency?

Solution: - Difference between the frequencies of consecutive modes is

$$\Delta \nu = \frac{c}{2L} = \frac{3 \times 10^8 \text{ m/s}}{2 \times 0.5 \text{ m}} = 300 \text{ MHz}$$

The mode separation of longitudinal cavity in terms of frequency is 300MHz.



End

