Module: 1 LASER

Q.1 Explain the quantum processes? (3m)

OR

Q.2 Differentiate between spontaneous and stimulated emission. (3m)

1.2.1 Absorption

- An atom in lower energy state E_1 may absorb the incident photon and may be excited to E_2 as shown in Fig. 1.2.1. This transition is known as stimulated absorption corresponding to each transition made by an atom one photon disappears from the incident beam.

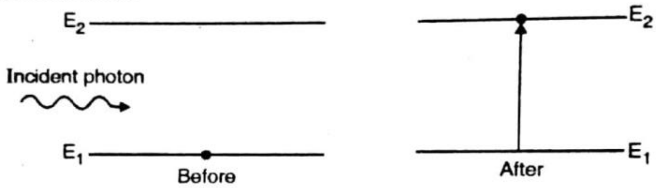


Fig. 1.2.1 : Induced absorption

The transition may be written as

$$A + h\nu = A^* \qquad ...(1.2.1)$$

Where A = Atom in lower energy state

A^* = Atom in excited state

The number of atoms N_{ab} excited during the time Δt is given by

$$N_{ab} = B_{12} N_1 Q \Delta t \qquad ...(1.2.2)$$

Where N_1 = Number of atoms in state E_1

Q = Energy density of the incident beam

B_{12} = Probability of an absorption transition.

[redacted] Spontaneous Emission

- Excited state with higher energy is inherently unstable because of a natural tendency of atoms to seek out lowest energy configuration. Therefore excited atoms do not stay in the excited state for a relatively longer time but tend to return to the lower state by giving up the excess energy $h\nu = E_2 - E_1$ in the form of spontaneous emission or stimulated emission.
- The excited atom in the state E_2 may return to the lower state E_1 on its own out of natural tendency to attain the minimum potential energy condition.
- 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 agency is called **spontaneous** or **naturalemission.** Fig. 1.2.2 represents natural emission and shows the transition.

$$A^* \rightarrow A + h\nu \qquad ...(1.2.3)$$

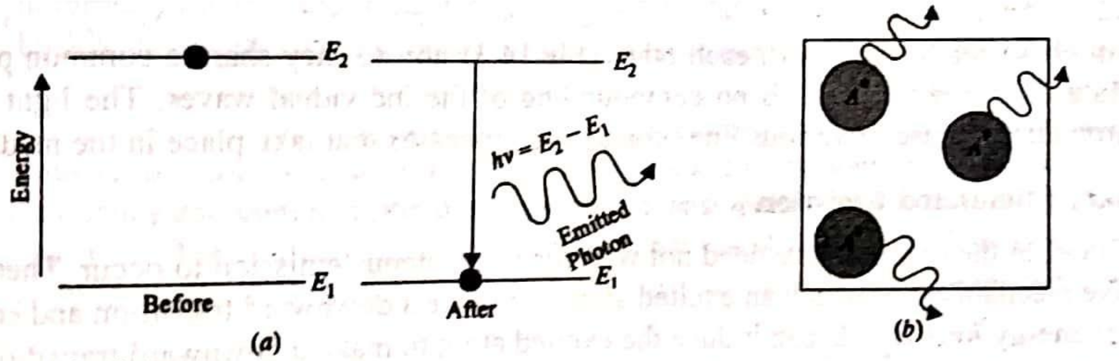
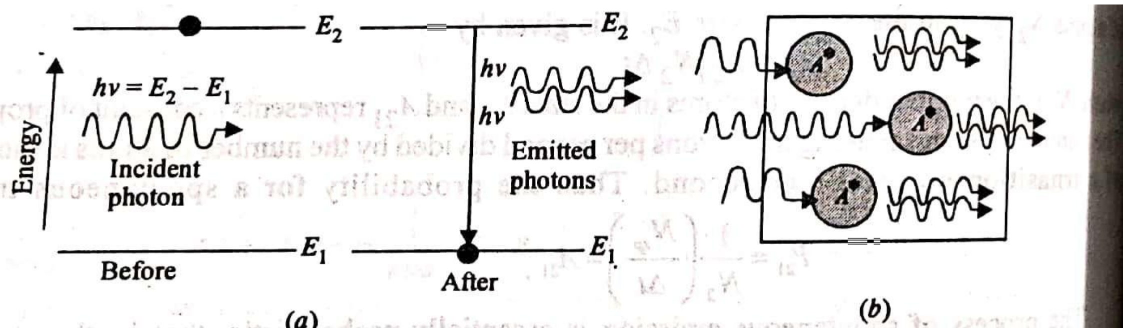


Fig. 14.2. Spontaneous emission (a) Emission process (b) Material emits photons haphazardly.

Stimulated Emission:

- An atom in excited state need not wait for spontaneous emission to occur. There exists an additional possibility according to which an excited atom can make a downward transition and emit a radiation.
- A photon of energy $h\nu = E_2 - E_1$ can induce the excited atom to make a downward transition releasing 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 lower energy state giving up a photon.
- This phenomenon is called **forcedemission** or **stimulatedemission** as shown in Fig. 1.2.3. The process may be represented as

$$A^* + h\nu = A + 2h\nu \quad ...(1.2.5)$$



Stimulated emission. (a) Emission process. (b) Material emits photons in a coordinated manner.

Q.3 What is a population inversion state? Explain its significance in the operation of LASER.(3m)

OR

Explain the population inversion.(3m)

Ans:

1) A **population inversion state** refers to a condition in a system where more particles (atoms or molecules) occupy an excited energy state than the lower energy state.
2) This is the opposite of thermal equilibrium, where the majority of particles would normally reside in the lower-energy state at equilibrium conditions.
3) In a typical system without external intervention, particles tend to occupy lower energy states (ground states or nearby low-energy states) due to Boltzmann distribution.
4) A population inversion is necessary for achieving certain quantum processes such as **stimulated emission**, which is the key mechanism in the operation of a LASER.

Significance in LASER operation:

1) **Stimulated emission** occurs when an incident photon causes an excited atom or molecule to drop to a lower energy state, releasing another photon of the same frequency, phase, polarization, and direction as the incident photon. For stimulated emission to dominate over absorption, a system must have more particles in the excited state than in the lower energy state. This is achieved by creating a **population inversion**.
2) In a laser, the process of creating a population inversion ensures that stimulated emission can outcompete absorption, allowing light to build up and form a coherent beam of photons in a controlled manner.
1) Without a population inversion, the rate of absorption would prevent a chain reaction of stimulated emissions, and the system would not produce coherent, amplified light.

Q.4 What is an optical resonator? What is it's role in lasing? (3m)

OR

What is resonant cavity? Explain its use in the generation of laser beam.(3m)

Ans:

1) It is a structure that confines light through multiple reflections between two or more mirrors to enable the amplification of light through **stimulated emission**.

2) The optical resonator allows the photons emitted by stimulated emission to build up in number by repeatedly passing through the gain medium, thereby producing the coherent, monochromatic light characteristic of a laser.

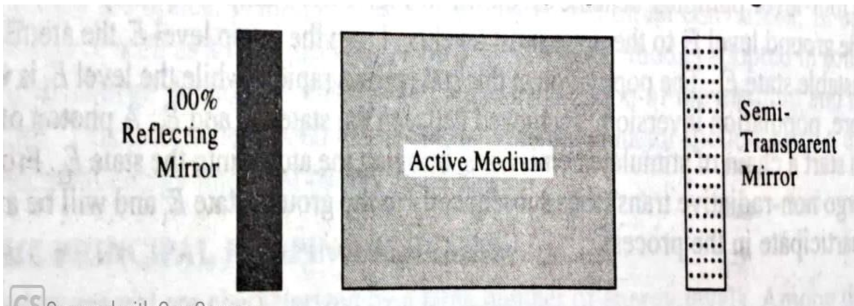


Fig. 14.10. Fabry-Perot optical resonator.

a) A photon emitted by stimulated emission travels through the gain medium and reflects between the mirrors.

b) Each time the photon passes through the gain medium, it stimulates additional emissions from excited atoms or molecules, amplifying its intensity.

c) The repeated reflections create a standing wave condition in the optical resonator. Standing waves are patterns formed by the superposition of traveling waves reflecting back and forth between the mirrors.

d) When the light reaches a sufficient intensity, a fraction of it exits through the partially reflective mirror as the **laser output beam**.

Types of optical resonators:

a) Fabry-Pérot Cavity

b) Spherical or Confocal Resonators

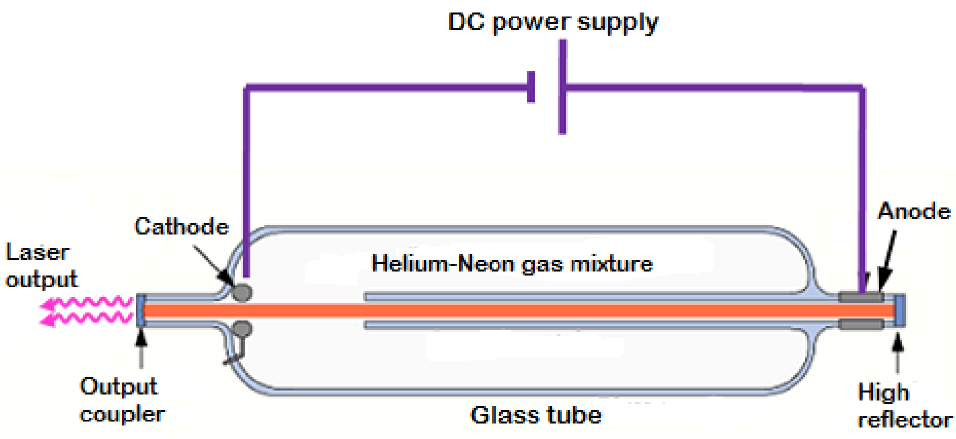
c) Ring Resonators

Q.5 With a neat energy level diagram describe the construction and working of He-Ne laser.(5m)

Ans:

The **Helium-Neon (He-Ne) laser** is one of the most well-known types of gas lasers. It operates on the principle of **stimulated emission of radiation** and produces a coherent, monochromatic light, typically at a wavelength of **632.8 nm**, which is in the red part of the visible spectrum.

Construction:



The main components of a typical He-Ne laser are:

a) **Gas Discharge Tube**:

- A sealed glass tube containing a mixture of **helium (He)** and **neon (Ne)** gases.
- The usual mixture is around **80% He and 20% Ne** by pressure.

b) **Electrodes**:

- Electrodes are attached at either end of the gas discharge tube to apply an electric field.
- The electric field ionizes the gas and excites helium atoms to a higher energy state.

c) **Optical Resonator (Cavity)**:

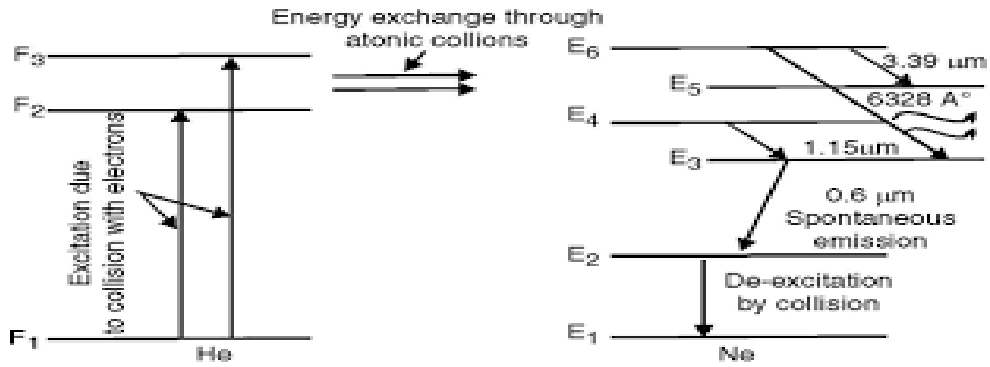
- Two mirrors are placed at the ends of the gas discharge tube.
  - One is a **highly reflective mirror**, and the other is a **partially reflective mirror**.

- The optical cavity allows photons to bounce back and forth through the neon gas multiple times, passing through the gain medium and undergoing stimulated emission.

d) **Power Supply**:

- A power supply is connected to create an electrical discharge through the gas tube, which excites the helium atoms.

Energy Level Diagram and Working:



a) The power supply generates an electric discharge that excites helium atoms to a higher energy state.

b) Excited helium atoms collide with neon atoms in the gas mixture, transferring their excitation energy to the neon atoms.

c) This process creates a population inversion in the neon gas because more neon atoms are excited to a higher energy state (E2E_2E2) than are in the ground state (E1E_1E1).

d) A photon passing through the neon gas can stimulate excited neon atoms to drop to the lower energy state (E1E_1E1), releasing photons of wavelength **632.8 nm**.

e) The optical resonator (formed by two mirrors) allows photons to reflect back and forth through the gain medium, amplifying the number of photons by repeated stimulated emissions.

f) A portion of the amplified photons exits through the partially reflective mirror as a coherent and monochromatic laser beam.

The **He-Ne laser** works by exciting helium atoms using electrical discharge, which transfer energy to neon atoms. The excited neon atoms emit light at **632.8 nm** through stimulated emission facilitated by a resonator (optical cavity). The **population inversion**, optical feedback, and repeated stimulated emission in the optical cavity lead to the production of a stable, coherent laser beam.

Q.6 Explain application of LASER in industry and medical field. Discuss any one of them in detail. (5m)

Ans:

Lasers have found a wide range of applications across various industries and the medical field due to their unique properties such as coherence, monochromaticity, and directionality.

(1) For welding and melting

- In very short time metal can be melted and then it will be evaporated. Thus, accurate welding and melting of the hard material can be done very easily. Using laser, perfect and non-porous joints of metals are possible. The typical laser welding machine is as shown in the Fig. 1.14.3.
- Due to increased power output it is possible to use this as a welding tool. Generally, CO_2 gas laser is used as cutting tool. Thus due to laser welding very high welding rate is possible.
- It is possible to weld dissimilar metals. Complex counters can be welded using easy turning of laser beam.
- Working material is not stressed because of non-contact method.

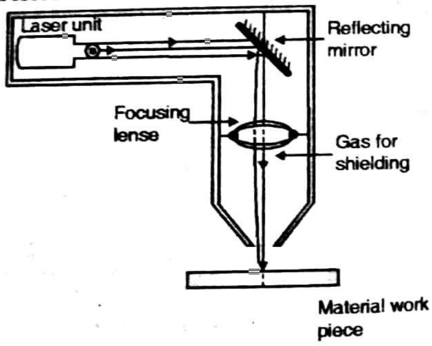


Fig. 1.14.3 : Laser welding machine

Laser application in medical field:

Among the various applications, **Laser Vision Correction**, specifically **LASIK (Laser-Assisted in Situ Keratomileusis)**, stands out as one of the most impactful uses of laser technology in the medical field.

a) LASIK is a surgical procedure that corrects refractive vision problems like **myopia (nearsightedness)**, **hyperopia (farsightedness)**, and **astigmatism**. It uses a specialized excimer laser to reshape the cornea of the eye, allowing light entering the eye to focus correctly on the retina.
b) In refractive vision problems, the shape of the cornea (the transparent front part of the eye) does not properly bend light to focus on the retina.
c) LASIK aims to reshape the cornea so that light focuses correctly.
d) A surgical instrument (microkeratome or femtosecond laser) is used to create a thin, hinged flap in the cornea.

e) The excimer laser is used to ablate (remove) a small amount of corneal tissue in a precise, controlled manner to reshape the cornea.

f) The corneal flap is placed back into its original position to heal naturally.

g) The **excimer laser** is a type of ultraviolet laser that provides high precision and can be programmed to remove very exact amounts of tissue from the cornea.