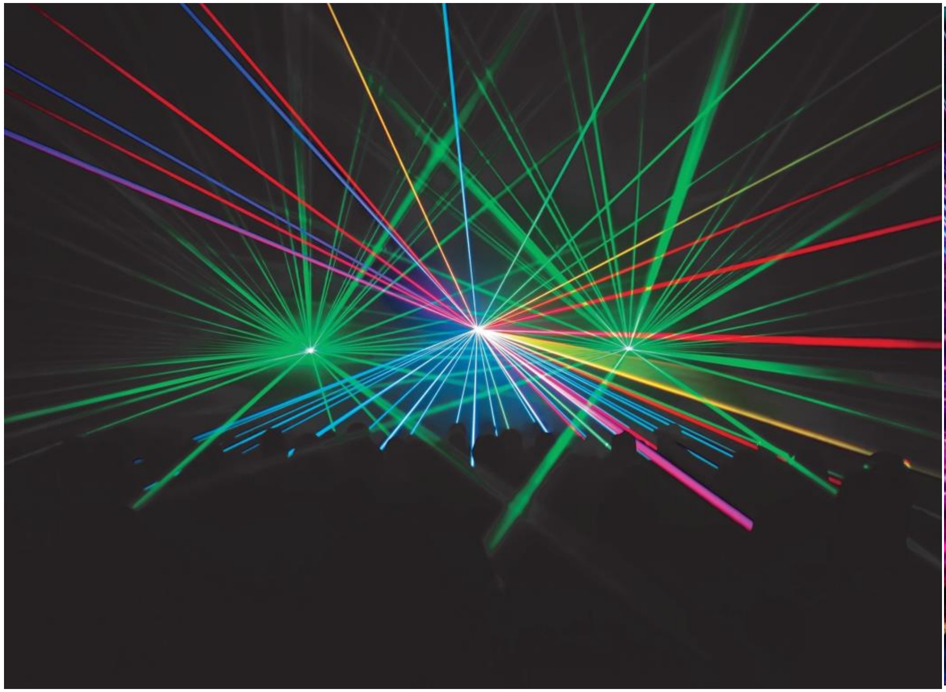
UNIT-IV: Optics with LASER and Optical Fibre

Chapter-15: Lasers and Holography
Lecture-1



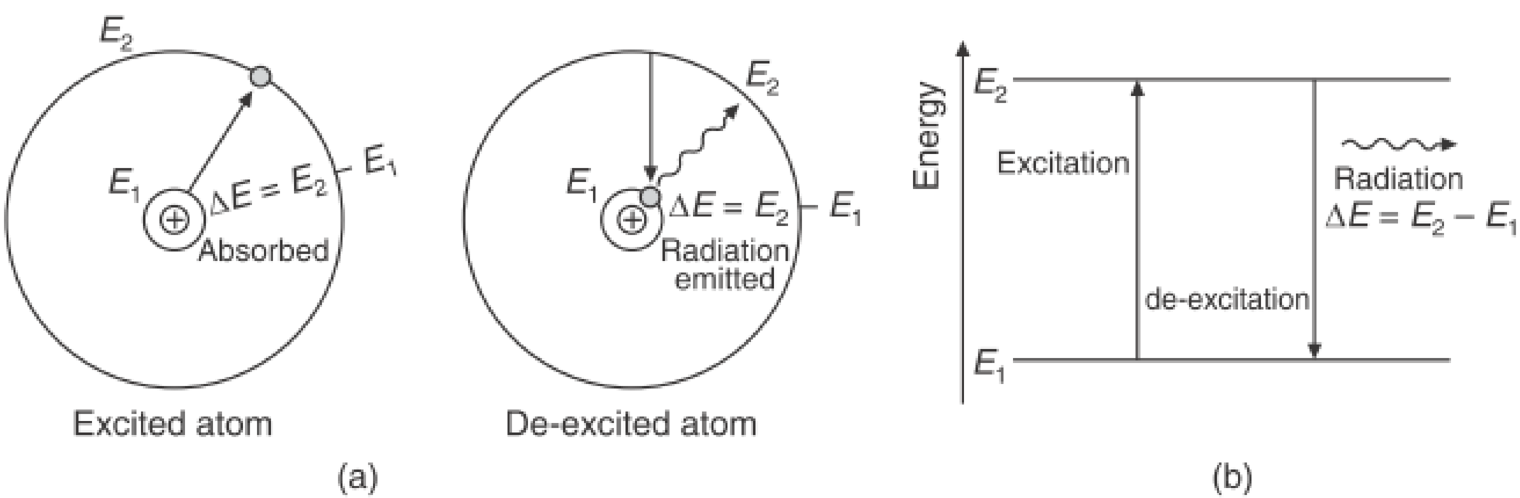

Content of Lecture

- LASER
- ATOMIC EXCITATION AND ENERGY STATES
- INTERACTION OF EXTERNAL ENERGY WITH THE ATOMIC ENERGY STATES
- ABSORPTION, SPONTANEOUS EMISSION
- IMPORTANT FEATURES OF SPONTANEOUS EMISSION
- STIMULATION EMISSION
- EINSTEIN COEFFICIENT and POPULATION INVERSION

ATOMIC EXCITATION AND ENERGY STATES

- According to the fundamentals of atomic structure, we know that in an atom, an electron in a ground state is stable and moves continuously in its orbit without radiating energy.

- When the electron receives an amount of energy equal to the difference of the energy of the ground state and one of the excited states, it absorbs energy and jumps to the excited state.



LASER:

- Laser stands for “light amplification by stimulated emission of radiation”.

- Laser produces a highly directional and high-intensity light with a narrow frequency range.

ATOMIC EXCITATION AND ENERGY STATES :

❖In an atom, an electron in a ground state is stable and moves continuously in its orbit without radiating energy.

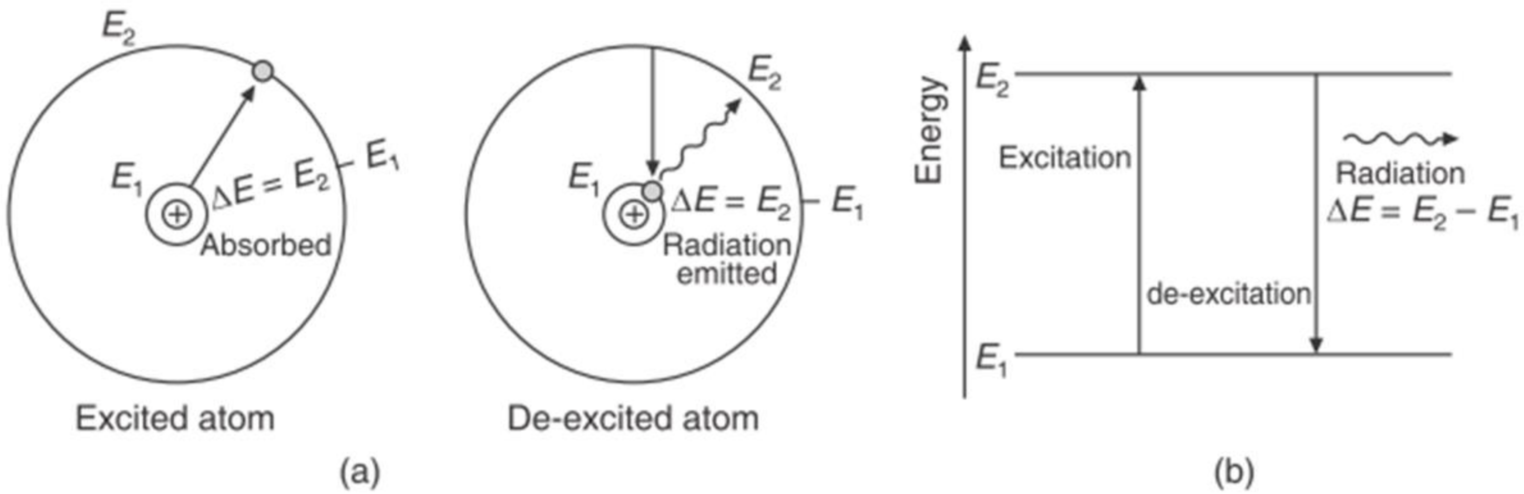
❖When the electron receives an amount of energy equal to the difference of the energy of the ground state and one of the excited states, it absorbs energy and jumps to the excited state.

❖The electron can stay for a very short lifetime (10^{-8} s) in the excited state, but sometime may stay in the metastable state having relatively longer lifetime of 10^{-3} s.

ATOMIC EXCITATION AND ENERGY STATES :

❖Let us consider in an atom, an electron absorbs an energy equal to the difference of the ground state (E_1) and the first excited state (E_2), i.e., $\Delta E = (E_2 - E_1)$.

❖When this excited electron comes to the ground state by the process of de-excitation, then it releases a radiation of energy $\Delta E = (E_2 - E_1)$. The process of excitation and de-excitation of atom is shown in Fig.1

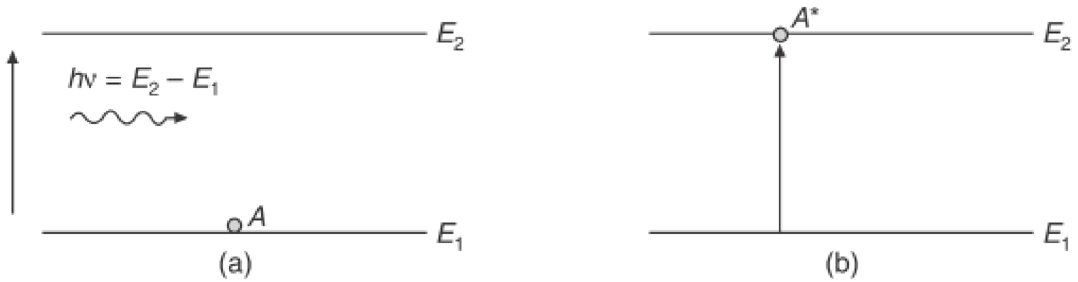


INTERACTION OF EXTERNAL ENERGY WITH THE ATOMIC ENERGY STATES:

- There are three kinds of interactions of the external energy with the atomic energy states.

❑**Absorption:** In absorption suitable amount of energy is absorbed by the atoms of the ground state to get excited to the higher energy states. This is shown in figure.

❑This process of transition is known as induced or stimulated absorption, or simply absorption.



ABSORPTION

❖The rate of absorption transition is defined as the number of atoms per unit volume per second which are raised from the lower energy level to the excited energy level. It is expressed as

❖$R_{ab} = -\frac{dN_1}{dt}$

❖Where, $-dN_1/dt$ is the rate of decrease of population at the lower energy level E_1.

❖If dN_2/dt is the rate of increase of population at the higher energy level (E_2), then the absorption transition rate can also be expressed as

❖ $$R_{ab} = \frac{dN_2}{dt}$$

❖From the above expression, we may conclude that

❖$R_{ab} \quad -\frac{dN_1}{dt} = \frac{dN_2}{dt}$

ABSORPTION

❖It is clear that the rate of absorption transition is proportional to the population of atoms in the lower energy state and the energy density of incident light [(ρ(ν)]. Hence, the rate of absorption transition can be given as

$$R_{ab} = B_{12}\,\rho(\nu)\,N_1$$

Where B_{12} is known as the Einstein coefficient for induced absorption transition, which represents the probability of induced transition from level 1 → 2.

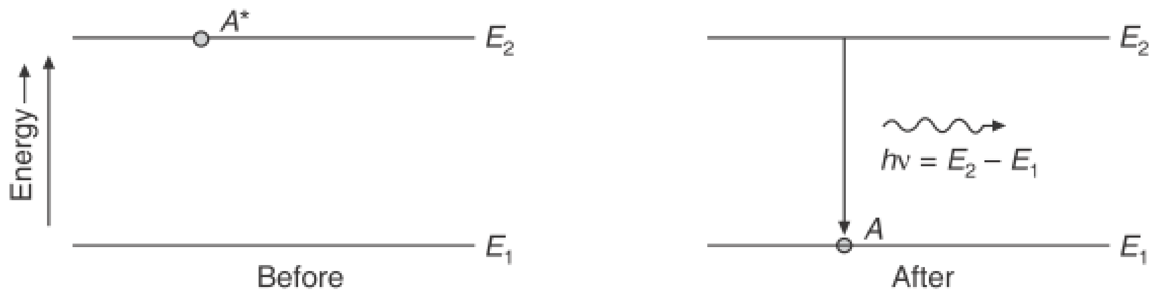
Spontaneous emission

- In spontaneous emission the excited atoms emit photon to come back in the lower energy state without any external impetus.

- The process in which an excited atom emits a photon itself without any external impetus is known as spontaneous emission.

- If A* is the excited atom which is releasing the energy hν to approach the lower energy state E_1, then the process can be represented as

- $$A^* \rightarrow A + h\nu$$



❖ The rate of spontaneous transitions R_{sp} *is given as*

$$R_{sp} = \frac{-dN_2}{dt} = \frac{N_2}{T_{sp}} \qquad (3)$$

Where T_{sp} *is the spontaneous transition lifetime.*

❖Number of photons generated during the process of spontaneous transition will be proportional to the number of excited atoms only. It may be expressed as

$$R_{sp} = A_{21} N_2 \qquad (4)$$

❖ Where A_{21} *is known as Einstein coefficient for spontaneous emission.* It gives the probability of spontaneous transition, from level 2 → 1. Comparing Eqs. (3) and (4), we get

$$A_{21} = \frac{1}{T_{sp}} \qquad (5)$$

❖ Thus, the reciprocal of the coefficient A_{21} *represents the lifetime of the spontaneous emission.*

Important features of spontaneous emission

- It is very difficult to control the process of spontaneous emission from outside.

- It is essentially probabilistic in nature.

- The emitted photons (radiation) during the process of spontaneous emission have different direction of propagation, initial phase, and plane of polarisation.

- The light emitted in the spontaneous emission is incoherent and non-monochromatic.

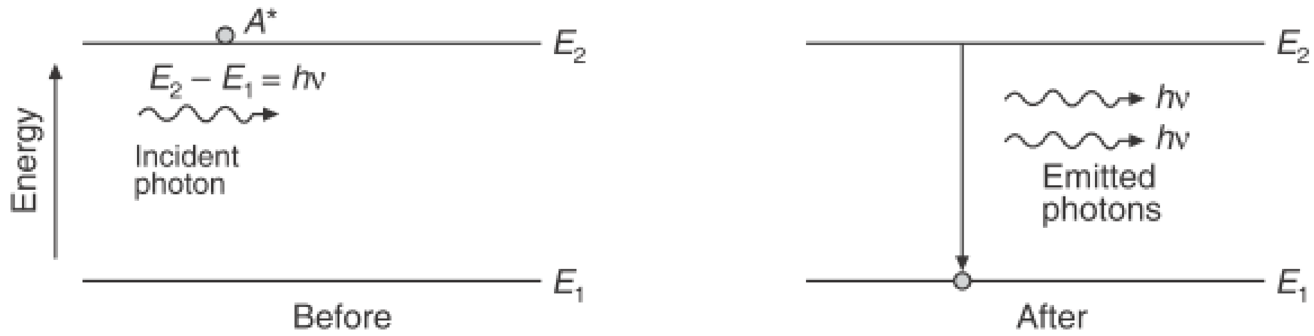
- The intensity of light decreases rapidly with distance from the source.

- The emitted light during the process of spontaneous emission is incoherent.

Stimulated emission

- In stimulated emission, with the influence of suitable energy impetus, excited atom is triggered to the lower energy state, with the release of appropriate energy.

- A photon with suitable energy ($h\nu = E_2 - E_1$) interacts with an excited atom. This photon c triggers the excited atom for the transition from higher energy level (E_2) to lower energy level (E_1) by emitting another photon as shown in Fig.4



Stimulated emission

- The rate of stimulated emission of radiation can be given as

$$R_{st} = B_{21}\,\rho(\nu)N_2$$

- Where $\mathbf{B_{21}}$ is known as **Einstein coefficient for stimulated emission,** which indicates the stimulated emission from level 2 → 1.

- Some important features of stimulated emission are as follows:
- The process of stimulated emission can be controlled from outside.
- The emitted photon and incident photon have same direction, phase, frequency, and plane of polarisation.
- The light produced during stimulated emission is coherent and monochromatic.

EINSTEIN COEFFICIENTS

- Einstein's A and B coefficients give the idea about the relation between spontaneous and stimulated emission probabilities.

- Let us consider that under thermal equilibrium, N_1 and N_2 are the mean population of atoms in the lower energy level E_1 and the upper energy level E_2, respectively. For the condition of equilibrium, the number of transitions from E_2 to E_1 must be equal to the transitions from E_1 and E_2 .

- If ρ(ν) is the photon density, then the number of atoms absorbing photons per unit time per unit volume is given as

$$B_{12}\,\rho(\nu)\,N_1$$

- The number of atoms emitting photons per unit volume per unit time can be given as the sum of spontaneous emission and stimulated emission as

$$A_{21}\,N_2 + B_{21}\,\rho(\nu)\,N_2$$

EINSTEIN COEFFICIENTS

❖At the condition of equilibrium, transitions from E_1 to E_2 must be equal to the transitions from E_2 to E_1. Thus, we can write

$$B_{12}\,\rho(\nu)\,N_1 = A_{21}\,N_2 + B_{21}\,\rho(\nu)\,N_2$$

❖The ratio of the populations in these two states, N_1/N_2, is called the relative population, which is expressed as $\frac{N_1}{N_2} = e^{h\nu/kT}$

❖By putting the value of N_1/N_2 ,we get

- $$\rho(\nu) = \frac{A_{21}}{B_{12}}\left[\frac{1}{e^{h\nu/kT} - (B_{21}/B_{12})}\right] \qquad (6)$$

❖ From the Planck's radiation law, we know that

- $$\rho(\nu) = (8\pi h\nu^3/c^3)\,\frac{1}{e^{h\nu/kT} - 1} \qquad (7)$$

EINSTEIN COEFFICIENTS

Comparing Eq.(6) and (7) we get

$$B_{21} = B_{12} \tag{8}$$

$$\frac{A_{21}}{B_{12}} = \frac{8\pi h\nu^3}{c^3} \tag{9}$$

$$B_{12} = B_{21} = \frac{c^3}{8\pi h\nu^3} A_{21} \tag{10}$$

❖Equations (8) and (9) are known as Einstein relations and Eq. (10) gives the relationship between Einstein's A and B coefficients.

Assignment Based on this Lecture

- Explain The Atomic Excitation And Its Energy States.

- Discuss the interaction of external energy with the atomic energy states.

- Explain the phenomena of absorption and spontaneous emission
- Mention the important features of spontaneous emission
- Explain the process of stimulation emission

- What do you mean by Einstein coefficient derive the relation between them.

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