18PYB101J MODULE-5

LECTURE 1

- **LASERS INTRODUCTION**
- **BASIC PRINCIPLE**
- **EINSTEIN’S THEORY**

LASERS

A Brief History of Lasers

Laser is the acronym of Light Amplification by stimulated emission of Radiation. Laser is light of special properties.

- In 1704, Newton characterized light as a stream of particles. Maxwell’s electromagnetic theory explained light as rapid vibrations of EM field due to the oscillation of charged particles.

- It was until Plank introduced the ***"quantum"*** concept in 1900 when this was explained. Thus energy is not continuous, it is discrete and can only be the multiples of a small unit.

- Einstein proposed the concept of ***"photon"***, we can say light is composed of individual particles called photons which posses a discrete amount of energy or quanta.

- Einstein also predicted in 1917 that when there exist the population inversion between the upper and lower energy levels among the atom systems, it was possible to realize amplified stimulated radiation, i.e., laser light.

- Many people tried to find methods for amplified stimulated emission, but it was not realized until 1960, about half a century after Einstein’s prediction.

Basic Principle

Absorption

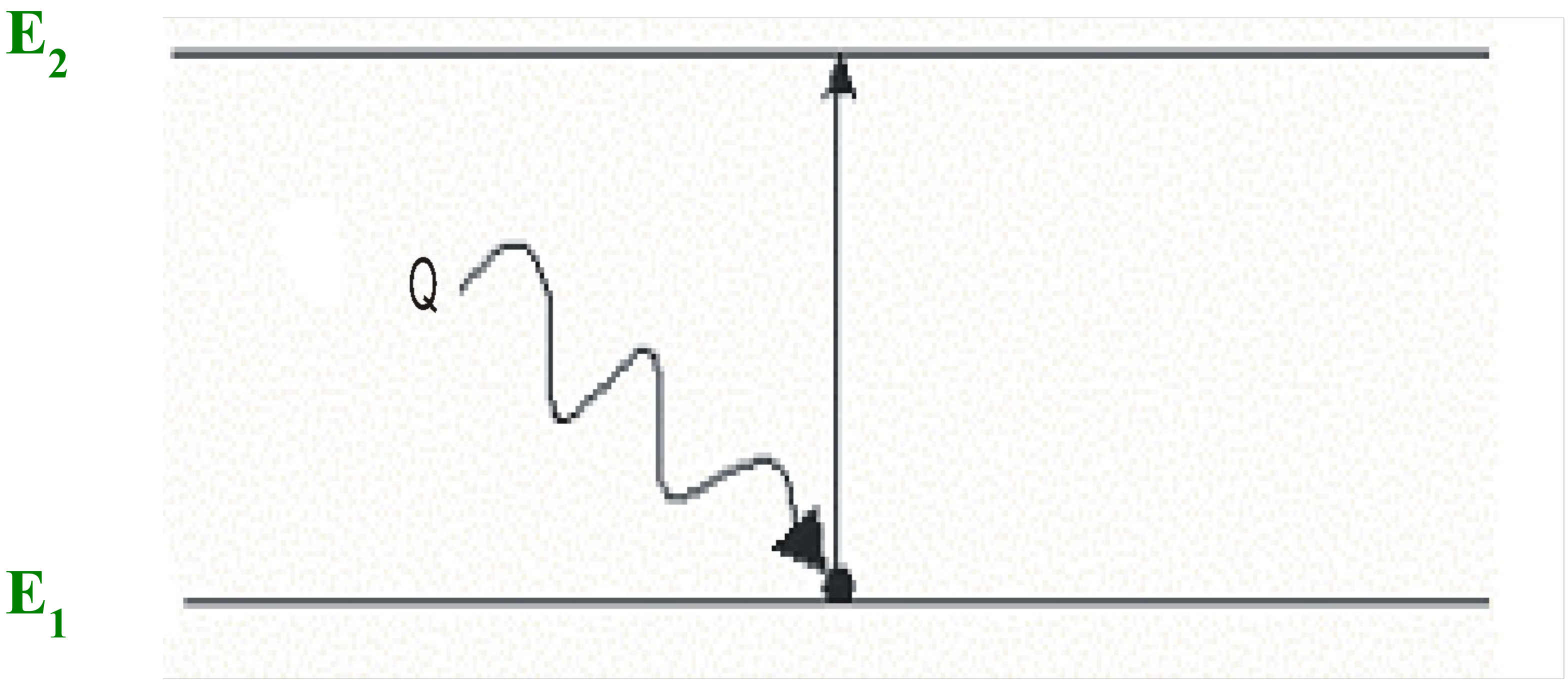
i. A system containing two energy levels namely the ground state and the excited state.

ii. The number of atoms in the ground state is more than the number of atoms in the excited state.

iii. For an atom to move from the ground state to the excited state it should absorb energy at least equal to the difference between the two energy levels.

iv. If E_1 is the energy of atoms in the ground state and E_2 the energy of atoms in the excited state.

v. The energy required for excitation should be greater than or equal to $E_2 - E_1$.



Absorption process

The process of raising the atoms from the ground state to the excited state is known as absorption.

The number of atoms, per unit volume undergoing absorption will be proportional to N_1, the number of atoms per unit volume in the ground state and Q, the energy density of the incident radiation.

The number of atoms undergoing absorption per unit volume per unit time can be expressed as

$$N_{ab} = B_{12} N_1 Q \qquad (1)$$

B12 is called the proportionality constant, which depends on the energy levels E_1 and E_2.

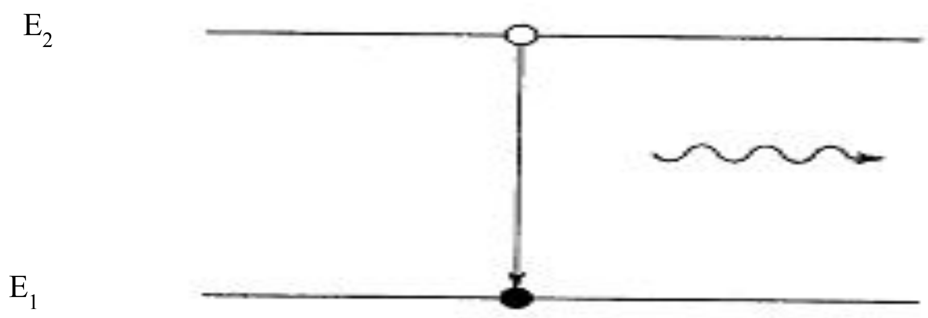
Emissions

An atom after absorbing energy goes to the excited state and does not stay there indefinitely.

They make transition to the ground state E_1.

Spontaneous Emission

- The spontaneous emission does not require any external energy.
- After its lifetime from the excited state atom goes back to the ground state.
- The average lifetime of carriers in the excited state is 10^{-8} sec, thus they go back to the ground state by emitting energy.



The number of atoms making spontaneous emission per unit volume per unit time can be expressed as

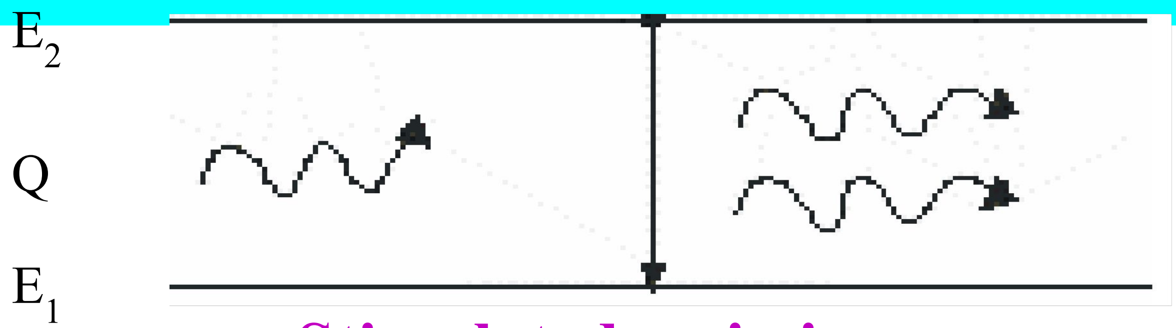
$$N_{sp} = A_{21} N_2 \qquad (2)$$

A_{21} is proportionality constant, which depends on the energy levels.

Stimulated emission

- The atom in the excited state is given an external energy and is forced to go to the ground state.

- The atom in the excited state is not allowed to stay for its lifetime.



Stimulated emission

The number of transitions per unit volume per unit time can be expressed as

$$N_{st} = B_{21} N_2 Q \qquad (3)$$

B_{21} is a constant, which depends on the energy levels.
A_{21}, B_{12} and B_{21} are called as Einstein's coefficients.

Einstein's theory of spontaneous and stimulated emission

At thermal equilibrium, the number of upward transition should be equal to the number of downward transitions per unit volume per unit time.

$$B_{12}N_1Q - B_{21}N_2Q = A_{21}N_2 \qquad (4)$$

$$B_{12}N_1Q - B_{21}N_2Q = A_{21}N_2$$

(or)
$$Q = \frac{A_{21}}{\left(\frac{N_1}{N_2}\right)B_{12} - B_{21}} \qquad (5)$$

From Boltzmann's distribution law, at a given temperature *T*, the ratio of the population of two levels is given by

$$\frac{N_1}{N_2} = e^{(E_2 - E_1)/kT} \qquad (6)$$

(or) $$\frac{N_1}{N_2} = e^{h\nu/kT} \quad (7)$$

where k is Boltzmann constant. Substituting the value of N_1/N_2 in this Eqn

$$Q = \frac{A_{21}}{\left(\frac{N_1}{N_2}\right)B_{12} - B_{21}}$$ we get,

$$Q = \frac{A_{21}}{B_{12}e^{h\nu/kT} - B_{21}} \quad (8)$$

According to Planck's black body radiation theory, we have

$$Q = \frac{8\pi hc}{\lambda^5} \frac{1}{(e^{h\nu/kT} - 1)} \qquad (9)$$

Here c is the velocity of light.

If $B_{12} = B_{21} = B$, Eqn (8) can be expressed as

$$Q = \frac{A_{21}}{B_{21}(e^{h\nu/kT} - 1)} \qquad (10)$$

Comparing the above Eqns we get

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$$\frac{A_{21}}{B_{21}} = \frac{8\pi hc}{\lambda^5} \qquad (11)$$

This eqn gives the ratio between spontaneous and stimulated coefficients. *A* and *B* are called Einstein's coefficients.