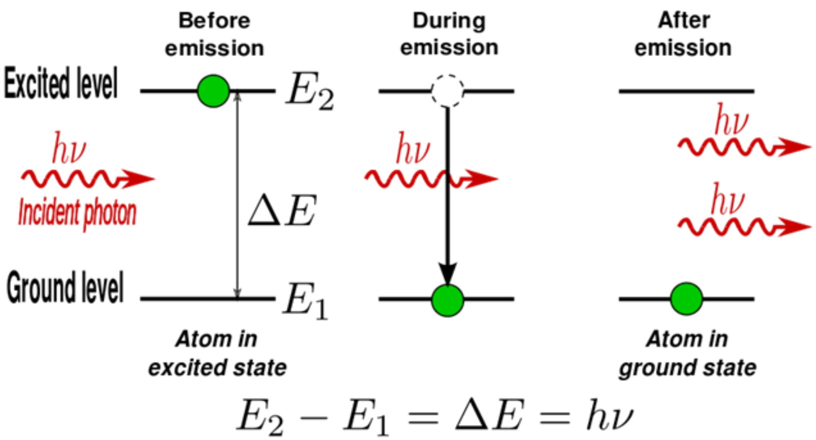
PHY 110 Engineering Physics

Lecture 1

UNIT 2 – laser

Lasers and applications:

- **Fundamentals of laser- energy levels in atoms**
- **Radiation matter interaction**
- **Absorption of light**
- **Spontaneous emission of light**
- **Stimulated emission of light**
- Population of energy levels
- Einstein A and B coefficients
- Metastable state
- Population inversion,
- Resonant cavity
- Excitation mechanisms
- Nd – YAG
- He-Ne Laser
- Semiconductor Laser
- lasing action
- Properties of laser
- Applications of laser: holography

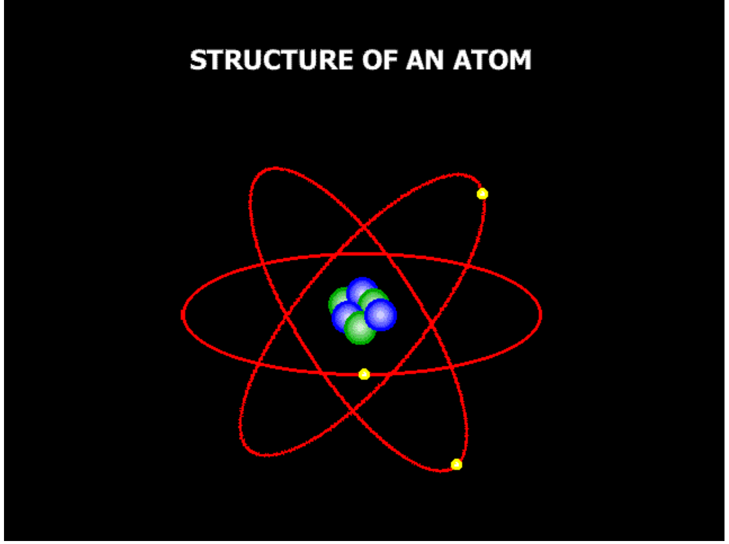


History:

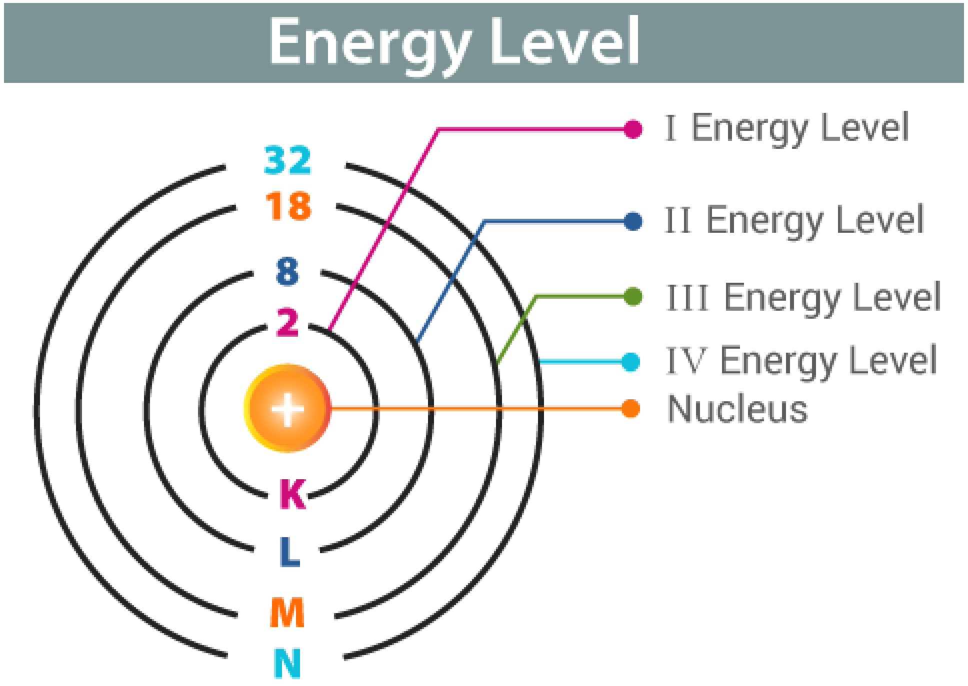
- **1917-** Einstein predicted the possibility of Stimulated emission.
- **1954-** C.H.Towens developed MASER (Microwave Amplification through Stimulated emission)
- **1958-** A.Schawlow and C.H.Towens extended principle of Maser to light.
- **1960-** T.H.Maiman built first laser.

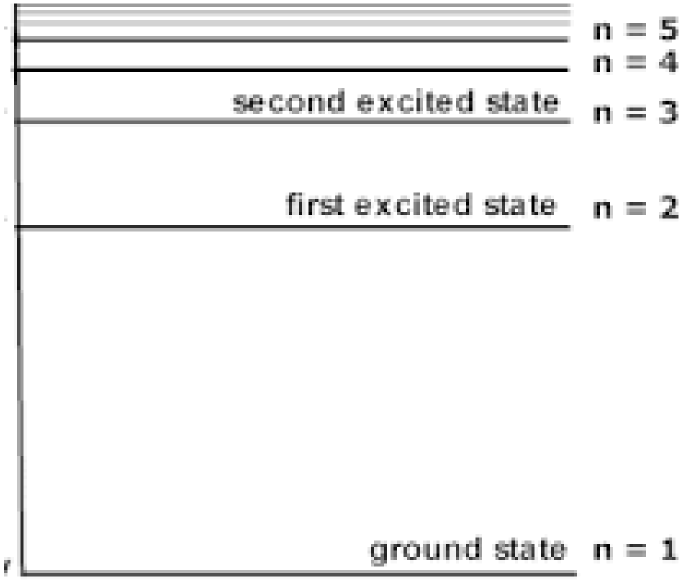
LASER(**L**ight **A**mplification through **S**timulated **E**mission of **R**adiation)

Energy levels in an atom:



Every atom has a ground level with minimum energy (Ground state, n=1). All the levels above it is called excited states.





Radiation-Matter interaction

In physics, **radiation** is the emission or transmission of energy in the form of waves or particles (photon) through space or through a material medium

light is nothing but radiation, thus will act as either a wave or a particle (photon); both of which are important in its interaction with **matter**.

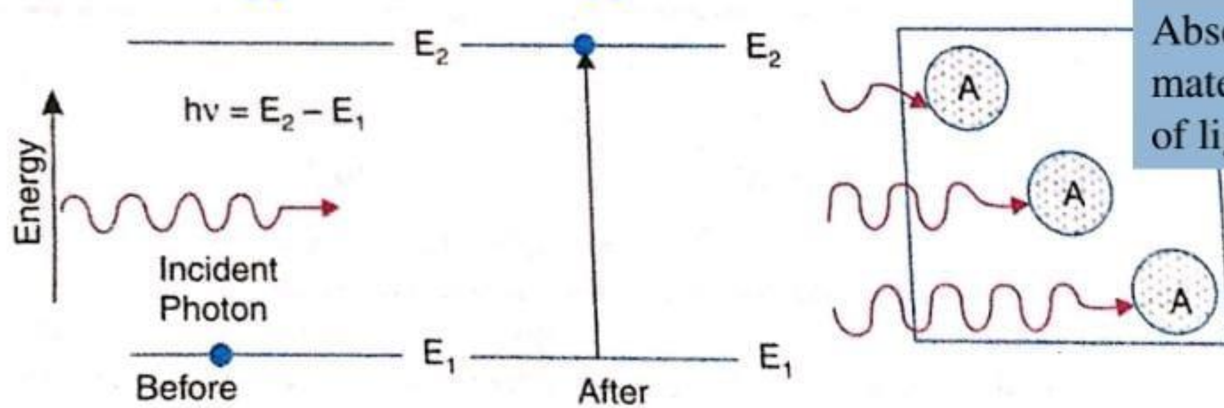
matter consists of various types of particles, each with mass and size. The most familiar examples of material particles are the *electron, the proton and the neutron*. Combinations of these particles form atoms; bonding of atoms molecules and that extend we have matter…

When a photon travel through a material three different processes occur, namely, **absorption, spontaneous emission and stimulated emission**. We study these 3 processes now…

1. ABSORPTION

Suppose an atom is the lower energy level E_1. A photon of energy $h\nu = (E_2 - E_1)$ interact with the atom and gets annihilated. So atom actually absorb that photon and go the next allowed level E_2 and this transition is called absorption transition or induced absorption

$$A \longrightarrow A^*$$



Absorption in the material..attenuation of light in the medium

$A + h\nu = A^*$ Where A is an atom in the ground state and A* is an excited

1. ABSORPTION

The **probability** of an absorption transition (P_{12}) is proportional to photon density $\rho(\nu)$

$$P_{12} \alpha \rho(\nu) \qquad P_{12} = B_{12}\,\rho(\nu)$$

B_{12} is known as the Einstein coefficient for induced absorption, and indicates the probability of occurrence of an induced transition from $1 \rightarrow 2$. B_{12} characteristics of an atom as per the properties of E1 and E2.

If N_1 and N_2 are the population of atoms at E_1 and E_2 levels in the material, then **Rate of absorption transitions** (R_{abs}) is defined as

$$R_{abs} = -\frac{dN_1}{dt} = \frac{dN_2}{dt}$$

1. ABSORPTION

R_{abs} is also equal to the product of probability of absorption transition and number of atoms at the energy level 1

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

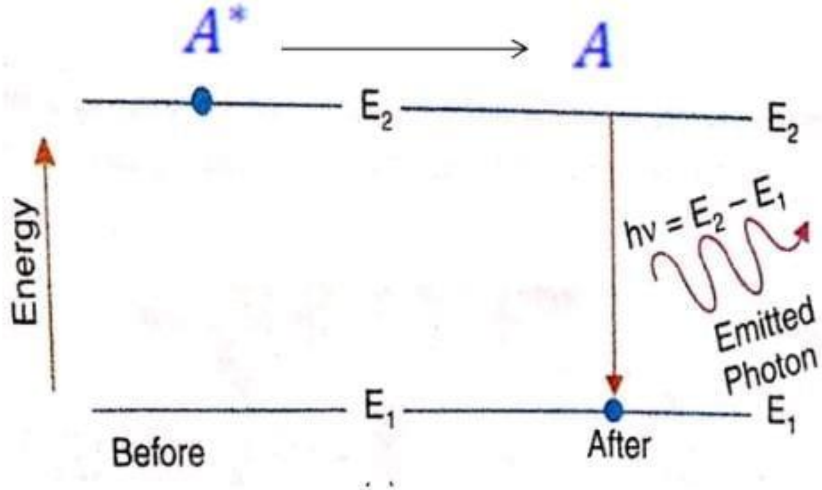
i.e. absorption transition rate, R_{abs} when the N_1 is more or photons density is more, absorption transitions from level 1 $\rightarrow$level 2 are. more

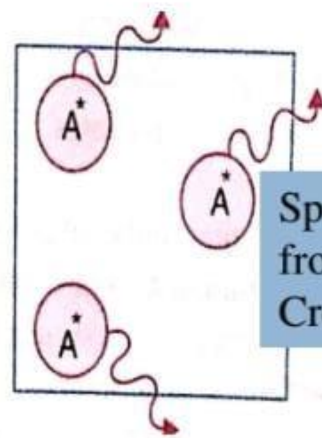
As it is expected, due to this absorption transition N_1 decreases and N_2 increases. But under normal conditions N_2 can not be greater than N_1…

That we will see later in Population inversion for lasing action

2. SPONTANEOUS EMISSION

For this to happen there should be atoms in the excited state E_2





But in the excited state E_2, atoms cannot stay longer. In about 10^{-8} seconds atoms come back to the lower level E_1 by releasing a photon of energy $h\nu=(E_2\text{-}E_1)$. This photon emission without any external aid is called spontaneous emission.

2. SPONTANEOUS EMISSION

Spontaneous emission is the reverse process of induced absorption transition and can expressed as $A^* \rightarrow A + h\nu$

Spontaneous emission is independent of the photon density and depends only on E_2 and E_1 properties. Hence probability of spontaneous transition $(P_{21})_{Spont}$ from 2→1

$$(P_{21})_{Spont} = A_{21}$$

Where A_{21} is known as the Einstein coefficient for Spontaneous emission, characteristic of the atom. Rate of spontaneous transition R_{sp}

$$R_{sp} = P_{21}N_2 = A_{21}N_2$$

2. SPONTANEOUS EMISSION

In other words, A_{21} is a measure of the lifetime of atoms at E_2 state against the spontaneous emission and subsequent transition of atom to the E_1. Note; spontaneous transition is not possible from E_1 to E_2 so

$$A_{12} = 0$$

Characteristics of the Spontaneous Emission

1. **No way to control** the process from outside
2. Direction of propagation, phase and plane of polarization of emitted photons are random - **Incoherent**
3. Light emitted are **polychromatic** not monochromatic
4. The intensity of the emitted radiation **is proportional to the number radiating atoms(N)..** i.e excited atoms at level E_2

$I_{tot}=N\ I$, where I is the intensity of light emitted by one atom.

Spontaneous emission is what we see in conventional light sources.

3. STIMULATED EMISSION

From the previous discussions it is clear rate of absorption transition (R_{abs}) is higher compared to rate of spontaneous transition (R_{spont}) and due to that N_2 can be higher than N_1 with passage of time. But **this wont happen** and an equilibrium is maintained. **But we can make it☺, population inversion, surely not by normal means**

So to account this Einstein came up with the brilliant idea that say that a photon can stimulate an atom in the excited state E_2 to release a photon and come back to the lower energy state E_1. This mechanism is called stimulated emission and is depended on the photon density present in the medium. And like before can be expressed as $A^* + h\nu \rightarrow A + 2h\nu$

3. STIMULATED EMISSION

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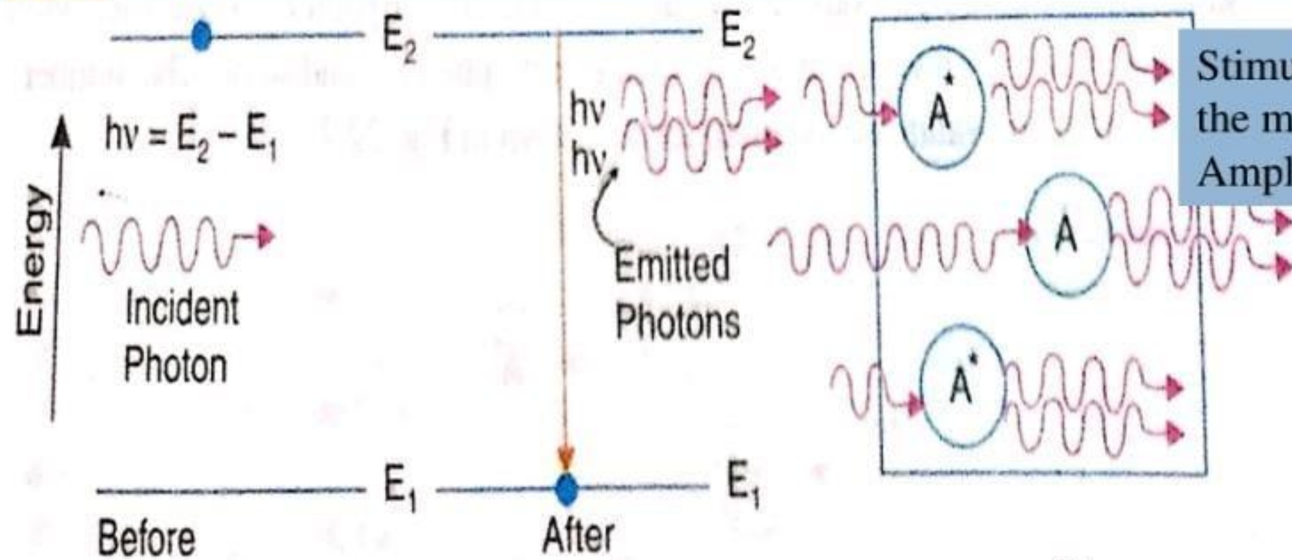

Stimulated emission from the material.
Amplification of light

Atoms in the excited state interact with the photon in the material medium and without consuming that photon, it get the stimulation to produce another identical one. As a result two photon are generated now. A different light source with more intensity.

3. STIMULATED EMISSION

The probability with which a stimulated transition occurs is given by

$$(P_{21})_{stimu} \propto \rho(\nu)$$

$$(P_{21})_{stimu} = B_{21}\,\rho(\nu)$$

B_{21} is known as the Einstein coefficient for **induced/stimulated** transition, and indicates the probability of occurrence of an induced transition from $2 \rightarrow 1$. B_{21} characteristics of an atom as per the properties of E_1 and E_2.

Similarly, Rate of stimulated emission **(R_{st}**) is expressed in terms of photon density and the number of atoms (**N_2**)at the excited state

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

CHARACTERISTICS OF THE STIMULATED EMISSION

1) The process **is controllable from out side-** control it through the photon interaction
2) Induced and inducing photon propagate in the **same direction**
3) Identical to incident photon-**coherent**
4) **Multiplication of the photon**
5) **Light amplification**
6) Net intensity of light is proportional to the square of the number of atoms (N) radiating light..

$I_{tot}=N^2 I$, where I is the intensity of light emitted by one atom.