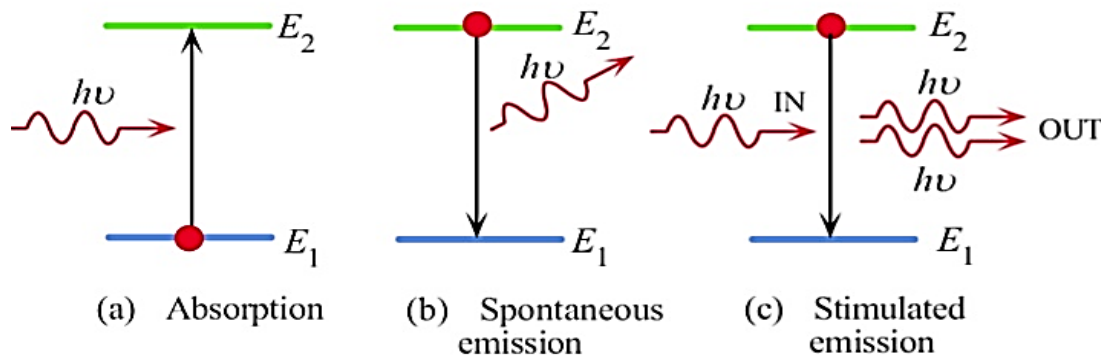




4. The interaction of electromagnetic radiation with matter

At the beginning of the 20th century, Einstein set the theoretical basis for laser production, but practical application was only achieved 40 years later. It has been concluded that three different mechanisms can occur for material atoms as shown in Fig.1-1:

- a- Absorption:** An atom in a lower level absorbs a photon of frequency $h\nu$ and moves to an upper level.
- b- Spontaneous emission:** An atom in an upper level (Without external effect) can decay spontaneously to the lower level and emit a photon of frequency $h\nu$ if the transition between E_2 and E_1 is radiative. This photon has a random direction and phase.
- c- Stimulated emission:** An incident photon causes an upper level atom to decay, emitting a “stimulated” photon whose properties are identical to those of the incident photon. The term “stimulated” underlines the fact that this kind of radiation only occurs if an incident photon is present. The amplification arises due to the similarities between the incident and emitted photons.



Fig(1-3): three different mechanisms can occur for material atoms

4.1 spontaneous emission

Suppose that there is a two-level atomic system of energy, $E_2 > E_1$ as in Fig (1-3). To easily assume that E_1 is the ground level, and that the atom at the beginning lies at level (2). Because the energy level (2) is greater than the energy level (1), the atom naturally (automatically) is trying to decay to level (1) and thus releases $E_2 - E_1$ energy in the form of random electromagnetic wave. This phenomenon is called Spontaneous emission. Since, it is



a natural process that occurs without any external stimulus. The resulting wave frequency is given in terms of Planck's law.

$$\nu = \frac{E_2 - E_1}{h}$$

If the volume unit contains a number of N_2 atoms at level (2) (population of upper level) at time t , the decay rate $\left(\frac{dN_2}{dt}\right)_{sp}$ will be proportional to N_2 , i.e.:

$$\left(\frac{dN_2}{dt}\right)_{sp} = -AN_2$$

Where A : is representing the probability of spontaneous emission (Einstein coefficient) and its units (sec^{-1}). A represent the inverse of the time of the survival of the atom in the excited level (average time of spontaneous emission time τ_{sp})

$$A = \frac{1}{\tau_{sp}}$$

There are two types of spontaneous emission:

1. Radioactive decay accompanied by the emission of electromagnetic wave.
2. Non-Radioactive decay is not accompanied by emission of electromagnetic wave. Where the atom loses the energy by colliding with the surrounding atoms (or particles) or by colliding with the inner walls of the vessel.

4.2 Stimulated Emission

Suppose that there is a two-level atomic system of energy, $E_2 > E_1$ as in Fig (1-3), the atom is also present at level (2) but this time with the presence of electromagnetic radiation, its energy ($h\nu$) is exactly equal to $(h\nu_2 - h\nu_1)$ the difference between energy levels (1) and (2). When the frequency of the falling radiation is equal to the atomic transition frequency, there is a limited probability of this radiation that stimulates the atom at level (2) and forces it to move to the lowest level (1). In this case, the difference in the energy of the atom is released in the form of coherent electromagnetic wave.



If the volume unit contains a number of N_2 atoms at level (2) at time t , the decay rate $\left(\frac{dN_2}{dt}\right)_{st}$ will be proportional to N_2 , i.e.:

$$\left(\frac{dN_2}{dt}\right)_{st} = -W_{21}N_2$$

Where W_{21} is the probability of stimulated emission and its units (sec^{-1}). W is not the same as A , where W is not only dependent on the transition between levels (1) and (2) but also depends on the intensity of falling radiation.

$$W_{21} = \sigma_{21} F$$

Where F represents the photonic flow of the falling wave. The proportionality constant σ_{21} is a quantity that has the dimensions of the area and it's called the stimulated emission section, σ_{21} depends only on the given transition characteristics.

4.3 Absorption

Now suppose that the atom is at the lowest ground level of energy (level 1), it will remain there unless it is exposed to an external stimulant. When the medium is exposed to electromagnetic radiation with energy ($h\nu$) is exactly equal to the $(E_2 - E_1)$, There is a limited probability of the atom moving to the upper level (2). The falling electromagnetic wave feeds the atom by the energy difference $(E_2 - E_1)$ needed to complete the transition process. It is called the absorption process, note Fig (1-3).

If we assume that the volume unit contains a number of atoms N_1 at level (1) in time t (population of lower level N_1), the rate of absorption $\left(\frac{dN_1}{dt}\right)_{ab}$ will be

$$\left(\frac{dN_1}{dt}\right)_{ab} = -W_{12}N_1$$

Where W_{12} is the probability of absorption and its units (sec^{-1}). It also depends on the intensity of the electromagnetic radiation falling as well as the atomic transition between the two levels



$$W_{12} = \sigma_{12} F$$

Where F represents the photonic flow of the falling wave. The proportionality constant σ_{12} is a quantity that has the dimensions of the area, it's called the absorption section and depends only on the given transition characteristics.

Einstein was able to prove that

$$\sigma_{12} = \sigma_{21}$$

This means that the

$$W_{12} = W_{21}$$

Therefore, it is possible to write only the symbol σ as well as the symbol W to indicate the transition section or its probability respectively. It can be said that the stimulated emission process is a negative absorption process (or vice versa).