Stimulated light amplifications

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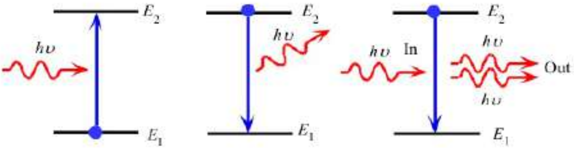
Absorption and emission

- An electron in an atom can be excited from an energy level E_1 to a higher energy level E_2 by the absorption of a photon of energy $h\nu = E_2 - E_1$.
- When an electron at a higher energy level transits down in energy level transits down in energy to an unoccupied energy level, it emits a photon. There are essentially two possibilities for the emission process. The electron can undergo the downward transition by itself quite spontaneously, or it can be induced to do so by another photon.

Absorption and emission

Fig.1 : Stimulated emission and photon amplification



(a) Absorption (b) Spontaneous emission (c) Stimulated emission

Absorption, spontaneous (random photon) emission and stimulated emission.

Spontaneous emission

- In spontaneous emission, the electron falls down in energy from level E_2 to E_1 and emits a photon of energy $h\nu = E_2 - E_1$ in a random direction. Thus a random photon is emitted. (Fig 1.(b)).
- The transition is spontaneous provided that the state with energy E_1 is not already occupied by another electron.
- The emission process during the transition of the electron from E_2 to E_1 can be thought of as if the electron is oscillating with a frequency ν.

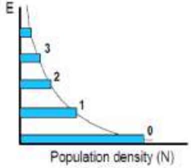
Stimulated emission

- In stimulated emission, an incoming photon of energy $h\nu = E_2 - E_1$ stimulates the whole emission process by inducing the electron at E_2 to transit down to E_1.
- The emitted photon is in phase with the incoming photon, it is in the same direction, it has the same polarization and it has the same energy since $h\nu = E_2 - E_1$.

Stimulated emission is the basis for obtaining photon amplification since one incoming photon results in two outgoing photons which are in phase. $(Fig1.(c))$

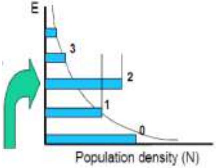
Population Inversion

Usually the no. density of atoms of an atomic system in the ground state remains larger than in the excited state. If by proper pumping, we obtain a situation so that the number density of atoms in the excited state becomes larger than that of the lower or normal state, population inversion is said to be achieved.



$$N_2 - N_1 = \exp\left(-\frac{E_2 - E_1}{k_B T}\right)$$

$$N_2 - N_1 < 0$$



$$\Delta N = N_2 - N_1 > 0$$

$$\Delta E = h\gamma = hc/\lambda$$

Population inversion

- To amplify the beam, we require that the rate of stimulated emission transitions exceeds the rate of absorption.
- This condition is satiesfied when

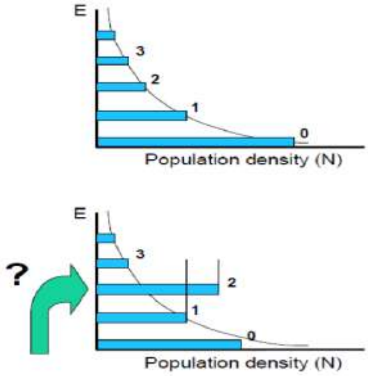
$$B_{12}N_2U(\nu) > B_{12}N_1U(\nu).$$

- which gives $N_2 > N_1$ for non-degenerate levels.
- This is highly non-equilibrium situation, and is called **population inversion**.

Population Inversion

It should be apparent that with only two energy levels we can never achieve population at E_2 greater than that at E_1 because, in the steady state, the incoming photon flux will cause as many upward excitations as downward stimulated emissions.

One solution of this problem is to use three energy energy levels.



Principle of LASER

We consider a three level system. [S.O. Kasap Page 161]

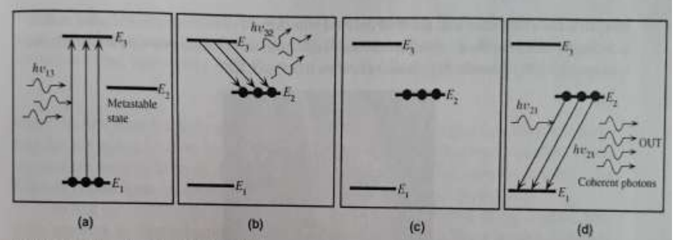


FIGURE 4.2 The principle of the LASER. (a) Atoms in the ground state are pumped up to the energy level E_3 by incoming photons of energy $h\nu_{13} = E_3 - E_1$. (b) Atoms at E_3 rapidly decay to the long-lived state at energy level E_2 by emitting photons or emitting lattice vibrations; $h\nu_{32} = E_3 - E_2$. (c) As the states at E_2 are long-lived, they quickly become populated and there is a population inversion between E_2 and E_1. (d) A random photon (from a spontaneous decay) of energy $h\nu_{21} = E_2 - E_1$ can initiate stimulated emission. Photons from this stimulated emission can themselves further stimulate emissions leading to an avalanche of stimulated emissions and coherent photons being emitted.

Further Reading

- Lasers; Theory and Applications, K. Tyagrajan and A. K. Ghatak
- Optoelectronics and Photonics: Principles and Practices, S.O. Kasap

Assignment:

- Find the ratio of the probability of spontaneous emission to stimulated emission at $300^{\circ} K$ (a) for a microwave photons $(h\nu/kT \gg 1Hz$ and (b) optical photons $(\nu = 10^{13} Hz)$.
- Describe with energy level diagrams, the phenomenon of spontaneous emission, stimulated absorption and stimulated emission in a two level system.
- Calculate the ratio of stimulated to spontaneous emission for the wavelength $5893 \mathring{A}$ at $27^{\circ} C$? Given $k_B T = 0.025 eV$.