University of Mosul
College of science
Department of Physics
Third Stage
Lecture 2

Laser

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Lecture 1: Population Inversion

Preparation
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1) Population Inversion

Inversions and Two Level Systems: consider a hypothetical atom having just two levels u and l with an energy difference:

$$\Delta E_{ul} = E_u - E_l = h\upsilon_{ul} \qquad ....……………...19$$

Where υ_{ul} is frequency emitted from a radiative- transition.

The question is whether or not an inversion could be created between these two levels?

We assume a cell of dimension L containing atoms of total density N at room temperature.

γ_{ul} → the total decay rate from the upper level u to the lower level l (radiative and non radiative decay).

A_{ul} → the radiative decay from u to l.

Thus $\gamma_{ul} > A_{ul}$, depending upon whether collisions increase - the decay rate from u to l above the rate of radiative decay, as shown in fig. (4).

σ_{ul} ⟶ is the stimulated cross section

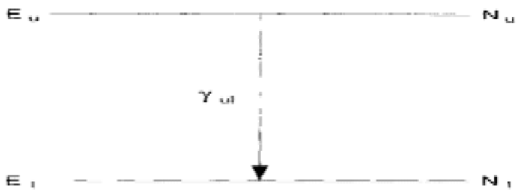

Fig. (4): Energy levels and decay rate of two level systems

Atoms in the cell at room temperature →i.e., according to Boltzmann distribution, nearly all of the atoms would be in the lower level l. We will attempt to "pump" these atoms from level l to level u by shining light of intensity I_o and frequency υ_{ul} into the cell and will then examine the intensity I emerging from the opposite side. The light would be absorbed by the atoms in level 1and atom would be promoted to level u, thus:

$$I = I_o e^{\sigma_{ul}(N_u - N_l)z} = I_o e^{\sigma_{ul}(N_u)z} \qquad \text{……………………. 20}$$

We have replaced the length z by the cell length L.

1) We see from this equation that, as we increase the input light intensity I_o, the energy absorbed would increase and thus, for very high intensities I_o we might expect all of the population to be transferred from level l to level u by absorption of photons from the beam. As soon as population is pumped up to level u, N_u becomes greater than zero. Since

$N = N_u + N_l \longrightarrow Nu = N - N_l$ ……………….21

notation

$I = I_o e^{\sigma ul(Nu-Nl)L} = I_o e^{\sigma ul(N-Nl-Nl)L} = I_o e^{\sigma ul(N-2Nl)L}$

Thus $I = I_o e^{\sigma ul\ (1-2(N1/N)\ N)}$ ……………….22

Hence, as the population leaves level l, the ratio N_l/N begins to drop from a value of unity, and when is reached 0.5, *no more energy will be absorbed because the value of the exponent will be reduced to zero*. If no more energy can be absorbed, there is no mechanism to increase the population in level u. If $N_l/N=0.5$ then $N_u = N_l$ and no further absorption can occur, N_u can never exceed N_l. Radiation decay will continually reduce the population in level u, which will also increase the population in level l and lead to more absorption.

2) If energetic electrons are present in the cell

$$N_u = N_l\, e^{-\Delta E_{ul}/KT_e} \qquad \text{………………..25}$$

Where T_e is the electron temperature, this ratio (N_u/N_l) can never have a value of unity except for an infinite electron temperature T_e.

3) The more atoms that are excite to level u, the more collisions electrons make with atoms in level u, returning them to level l.
4) We have not calculated the additional effect of the radiative decay rate A_{u1} which would only further decrease the ratio Nu/Nl. This in turn increases the ratio of Nl/N to greater than 0.5, accordingly, there would never be any gain.

We can thus conclude that it is **impossible to have a population inversion between two energy levels.**

Relative Decay Rates- Radiative Versus Collisional:

The radiative decay rate (spontaneous emissions) from any level 2 to a lower level 1 is proportional to υ_{21}^2. Since the energy difference between level 2 and level 1 is given by:

$$\Delta E_{21} = h\upsilon_{21} \qquad \text{………………26}$$

It follows that

$$A_{21} \alpha E^2_{21} \qquad \text{………………27}$$

This expression states that the radiative transition probability from state u increases very rapidly as the energy separation between level u and l increase.

The nonradiative decay (collisional) rate associated with electron collisions is given by:

$$k_{21} \propto \frac{1}{\Delta E_{21}} \qquad \text{..……………..28}$$

We can see that, the collisional rate is inversely proportional to the energy separation ΔE_{21}.

We show from the figure that, for rapid decay, radiative transitions like to have large energy separations between levels where as collisional transitions downward prefer a close energy separation.

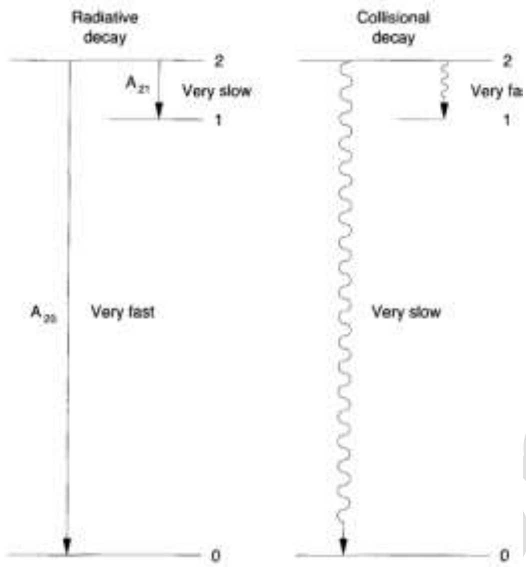

Fig. (5): comparisons between radiative and non radiative decay

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