Population Inversion and 3-level & 4-level Laser System

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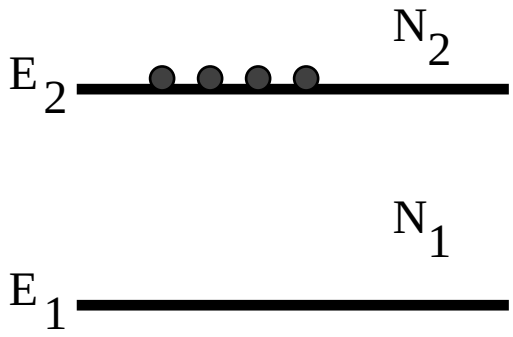
Population inversion

In order to get amplification we need to create a population inversion i.e.



$N_2 > N_1$

We create the population inversion by **pumping.**

We need to find a way in which we can overcome the thermal distribution of states.

One way in which we could try to increase the population of state 2 is to illuminate the medium with light of frequency ν, where:

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

However, since $B_{12} = B_{21}$ this light will just as likely cause stimulated absorption as stimulated emission. In the steady state we see from [5]:

$$B_{12}\,\rho_\nu\,N_1 = A_2\,N_2 \;+\; B_{21}\,\rho_\nu\,N_2$$

that for any value of ρ_ν:

$$N_2 \leq \frac{g_2}{g_1} N_1$$

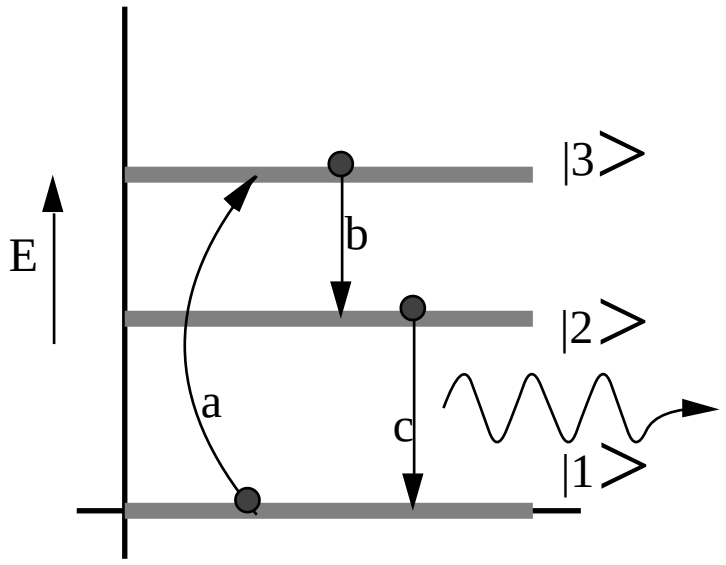
and hence, at best the medium will be transparent

Making the medium transparent by an intense optical pumping is called **bleaching.**

To achieve a population inversion we need to use media with more than two energy states. All practical laser systems can be simplified to three or four energy levels.

These are called
Three level laser systems
or **Four level laser systems**

Three level Laser



a) Pump from state 1 to state 3

The pump transfers population from the ground state to higher energy levels. (State 3 may be a collection of different levels)

b) Non radiative decay from state 3 to state 2

In a good laser medium, the lifetime of state 3 is short and all the population in state 3 rapidly decays to state 2

c) Stimulated emission from state 2 to state 1

In a good laser medium the lifetime of state 2 is long so that the population will grow and an inversion can be created with respect to state 1. Once an inversion is obtained, stimulated emission will give optical gain.

Three level system, getting an inversion

Under thermal equilibrium, nearly all the population resides in state 1. To get an inversion we need to pump at least half the total population via state 3 into state 2.

If the total population is N_{Tot}, then for an inversion we need:

$$N_2 \geq \frac{N_{Tot}}{2}$$

However, the population in state 2 will decay due to spontaneous emission. To maintain the inversion we need to pump at:

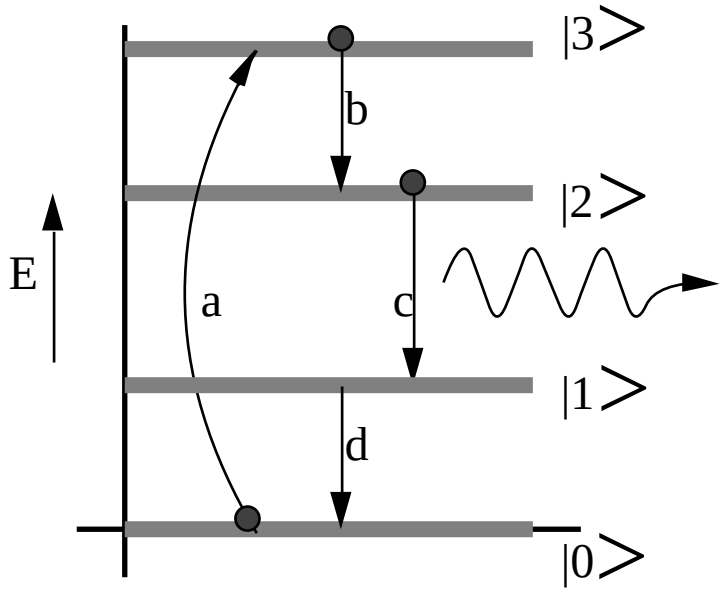
$$R_{th\text{-}3\ level} = \frac{N_{Tot}}{2}\ \frac{1}{\tau_2} \qquad [24]$$

where

R_{th} = threshold pump level, excitations per sec, per unit vol.

τ_2 = lifetime of state 2

Four level Laser



a) Pump from state 0 to state 3

The pump transfers population from the ground state to higher energy levels. (State 3 may be a collection of different levels)

b) Non radiative decay from state 3 to state 2

In a good laser medium, the lifetime of state 3 is short and all the population in state 3 rapidly decays to state 2

c) Stimulated emission from state 2 to state 1

In a good laser medium the lifetime of state 2 is long so that the population will grow and an inversion can be created with respect to state 1. Once an inversion is obtained, stimulated emission will give optical gain.

d) Non radiative decay from state 1 to state 0

In a four level laser, terminal state of the laser transition is **not** the ground state and therefore a population inversion is easier to maintain.