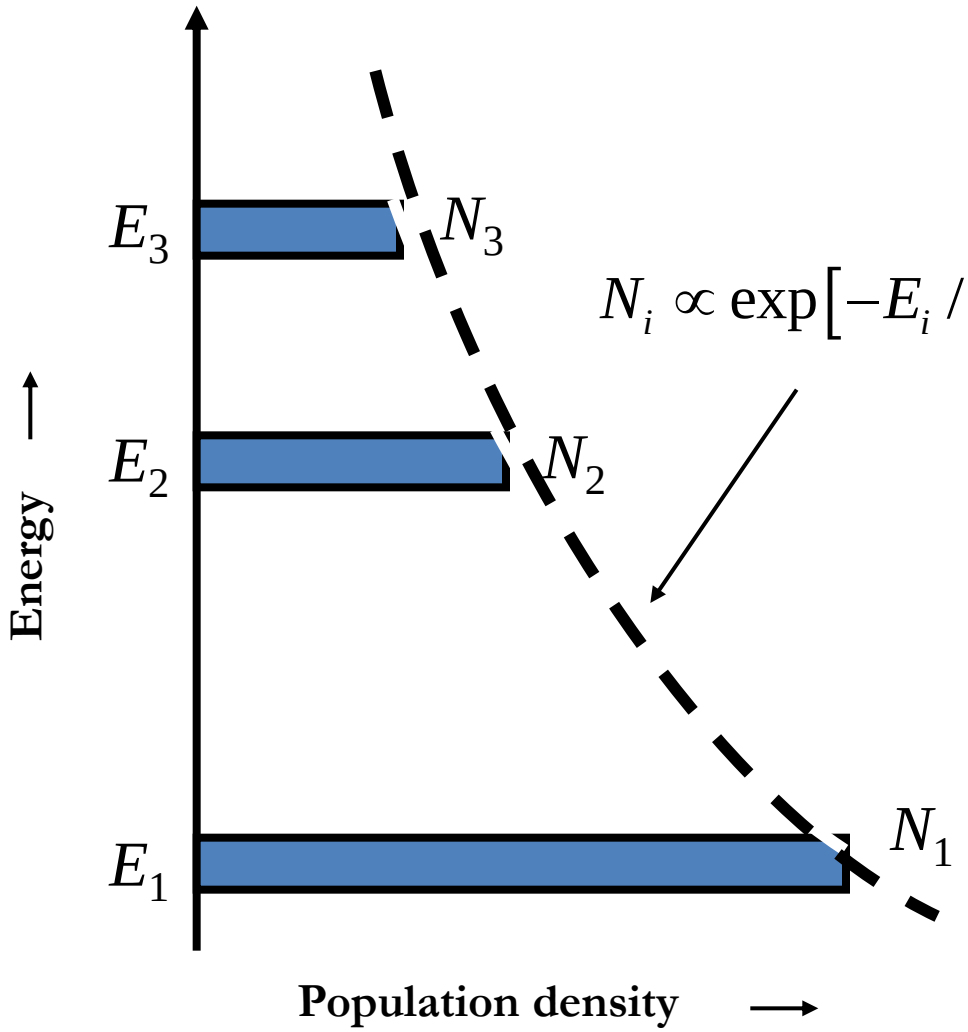
Population Inversion

- At **equilibrium**, absorption and spontaneous emission is **simultaneous**, but $\mathbf{N_1 > N_2}$
- A state in which a substance has been **energized**, or **excited** to specific energy levels.
- More atoms or molecules are in a higher excited state to obtain high percentage of stimulated emission.
- Non-equilibrium state in which population in $\mathbf{N_2}$ **exceeds to that of** $\mathbf{N_1}$ is generally known as **Population inversion**
- The **process of producing** a population inversion is called **pumping**.

Population Inversion

Some of the Boltzmann population factors,

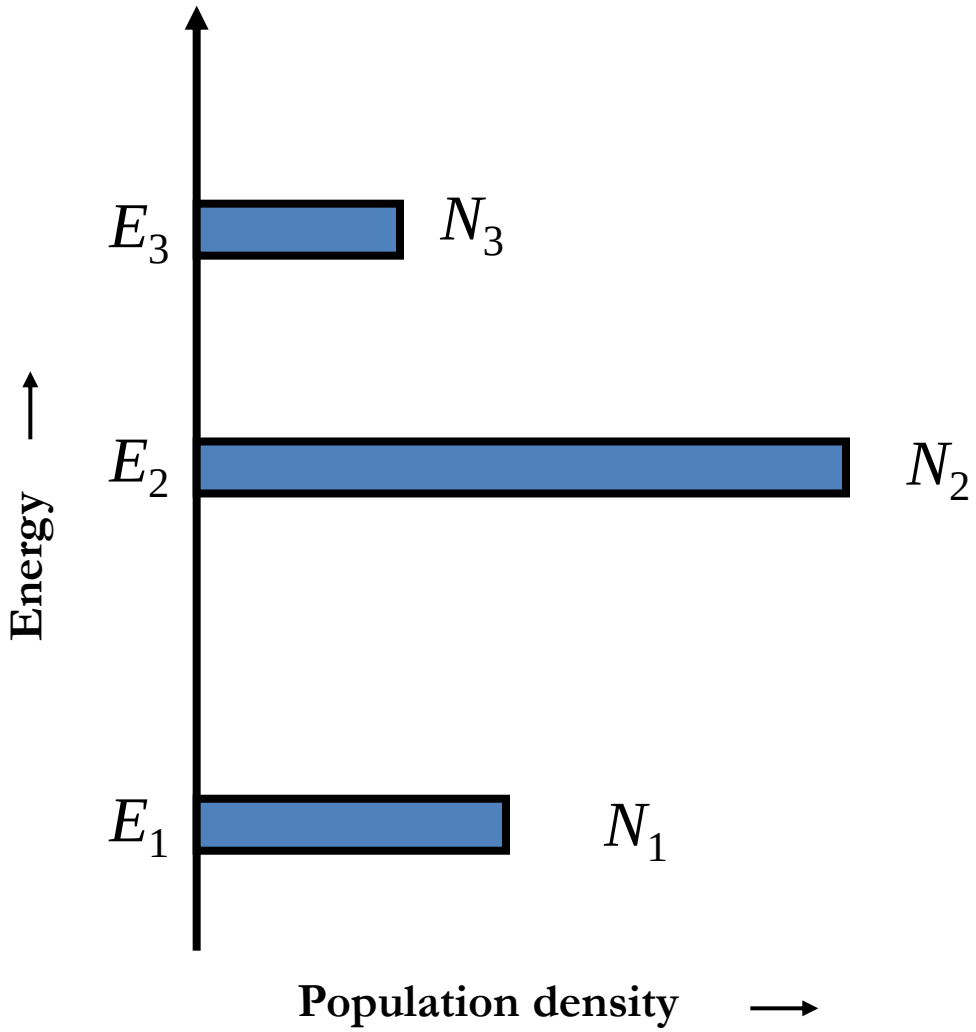


$$N_i \propto \exp\left[-E_i / k_B T\right]$$

$$N_3 < N_2 < N_1$$

Population Inversion

Some of the Boltzmann population factors,



$\mathbf{N_2 > N_1}$

Pumping

- A medium in which **population inversion** is achieved is called **active medium**.
- The population inversion can be achieved usually by **exciting the active medium** with suitable form of energy – pumping.
- Most commonly used methods for pumping are
    - Optical pumping
    - Direct electron excitation
    - Inelastic atom-atom collisions
    - Chemical reactions
    - Direct conversion

Pumping

Optical pumping

- **Light source is used** – this energy comes in the form of short flash of light
- Suitable for any laser medium which is transparent to pump light.

Electric discharge

- Preferred in **gases** – high voltage causes **electrons** emitted by the cathode to be **accelerated** towards anode. These accelerated electrons **collide** with the atoms in the active medium, **ionize** the medium and raise it to excited state causing population inversion.

Pumping

Inelastic atom-atom collisions

- Excitation by **electric discharge** provides the initial excitation which raises **one type of atoms** to their excited state.
- These atoms **collide inelastically** with **another type of atom** the later atoms provides population inversion.

$$A + e \rightarrow A^* + e$$

$$A^* + B \rightarrow A + B^*$$

Direct conversion

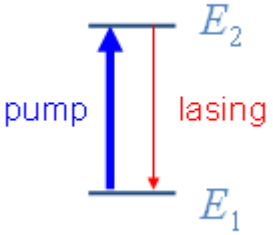
- In semiconductor lasers direct conversion of **electrical energy** into **light energy** takes place.

Chemical reactions

- The molecules undergo **chemical changes** in which one of the product of the reaction is a molecule or an atom that is **left** in an **excited state** under appropriate conditions.

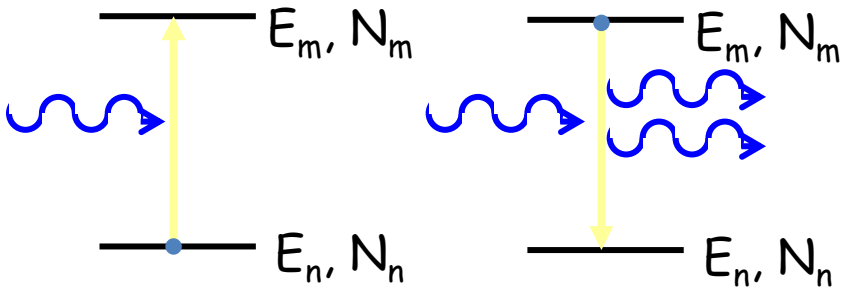
Types of Lasers

Lasers can be classified based on the factor, namely **number of levels involved** and the **type of active medium**.



Two – Level Laser

- **Not suitable** for attaining population inversion
- **Difficult to keep** the collection of **atoms** in the **excited state** until they are stimulated to emit photons

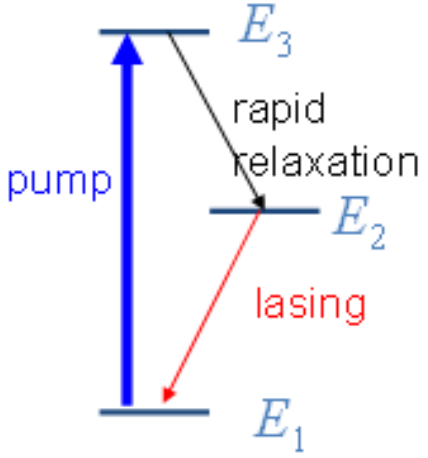


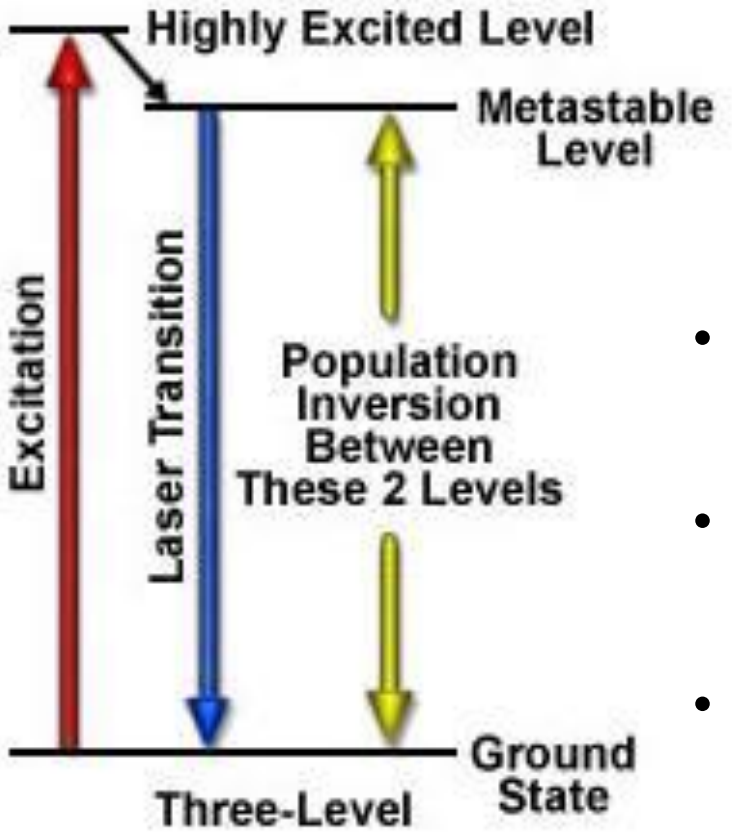
Even with very a intense pump source, the best one can achieve with a two-level system is

excited state population = ground state population

Types of Lasers

Three – Level Laser

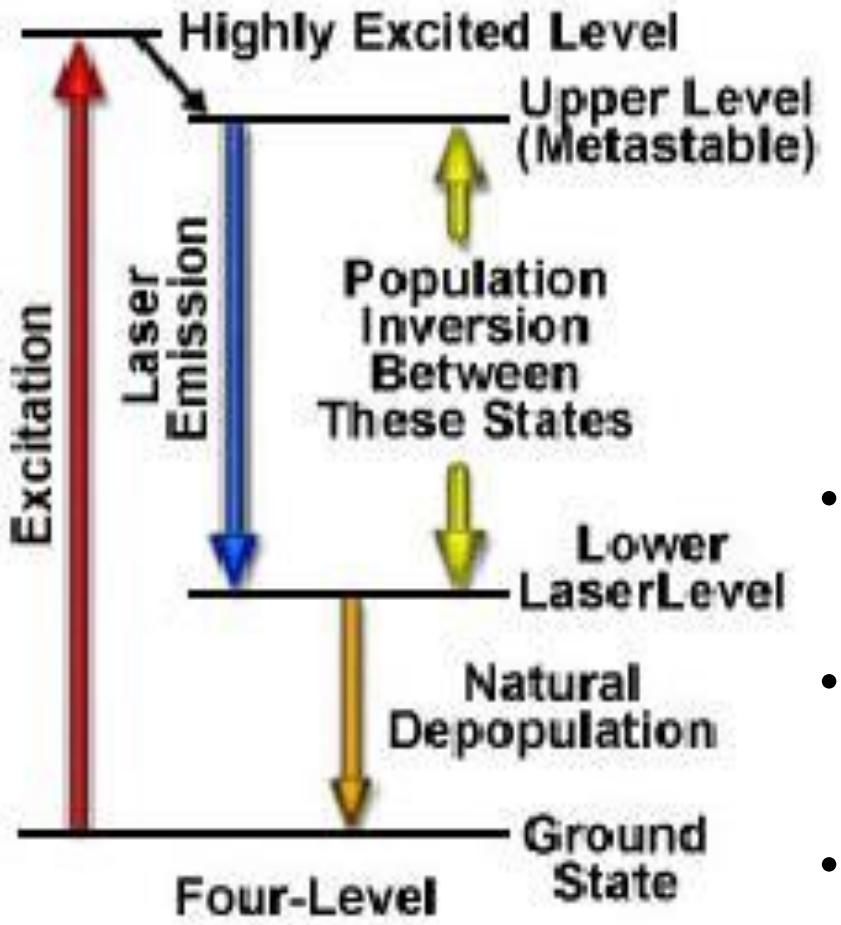


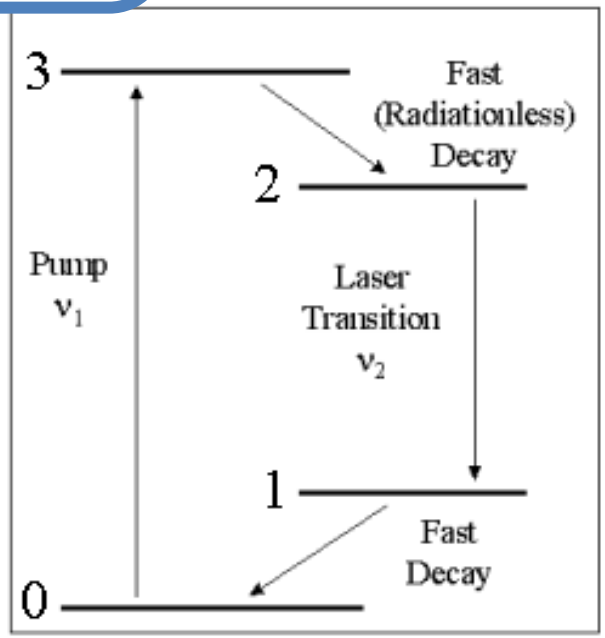


- Initially excited to a **short-lived high-energy state** .
- Then **quickly decay** to the intermediate **metastable level**.
- Population inversion is created between **lower ground state** and a **higher-energy metastable state**.

Types of Lasers

Four – Level Laser





Four Level Scheme

- Laser transition takes place between the **third** and **second excited states**.
- Less pumping energy than three level laser
- Can operate in a **continuous mode**.