Population inversion :-

The transition probability for induced emission depends upon

(i) The number of atoms in the excited state and

(ii) The energy density of the incident photon $\rho(\nu)$

To achieve a higher probability of stimulated emission we make use of the phenomenon of Population inversion.

Population inversion :-

In a material, in normal distribution of atoms, the number of atoms in the higher energy state is less than the number of atoms in the lower energy state. In other words, the population of atoms in higher energy levels is less than that in the lower energy levels.

When radiation of matching frequency $\nu = \frac{E_2 - E_1}{h}$ is incident on such a collection, the atoms are excited due to Stimulated absorption. The excited atoms return to the normal state either Spontaneous emission or Stimulated emission.

In order to achieve higher probability of stimulated emission, two conditions must be satisfied:

(i) The higher energy state should have a longer mean life i.e it should be a metastable state.

(ii) The number of atom in the higher energy state E_2 must be greater than that in E_1.

"The establishment of situation in which the number of atoms in the higher energy level is greater than that in the lower energy level is called Population inversion".

Requirements for Population inversion and LASER action :-

For the purpose of population inversion and to produce laser action we require (i) an active ~~material~~ medium and (ii) a pumping arrangement. → have an metastable region.

(i) **Active ~~material~~ medium :-** An active medium or material is a medium, the atom of which have a metastable energy state. Such atoms produce more stimulated emission than spontaneous emission and when excited soon reach the state of population inversion leading to laser action.

(ii) **Pumping :-** The procedure adopted to achieve population inversion is called pumping. For achieving and maintaining the condition of population inversion, we have to raise continuously the atoms from the lower energy level to higher energy level. This requires energy to be supplied to the system.

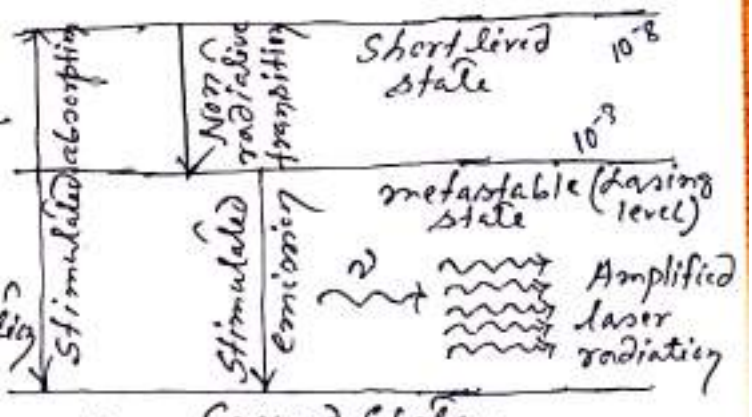
There are a number of technique for producing population inversion eg optical pumping, electrical discharge, direct conversion etc. optical pumping is very important and convinient method.

Optical pumping :-

The Procedure adopted to achieve population inversion is called pumping. In optical pumping, the active material is illuminated with light of frequency $\nu = \frac{E_2 - E_1}{h}$. As a result, an atom in the lower energy state E_1 absorbs the incident photon of energy $h\nu$ and is raised to higher energy level E_2. As the excited atoms lose their energy by spontaneous emission and drop to the lower energy level in a very short time, the process fails to produce necessary population inversion.

Therefore, population inversion is brought about by (i) a three level scheme or (ii) a four level scheme.

(i) Three level Scheme :- Let us consider an atom with energy level E_1, E_2 and E_3 with increasing values of energy, E_1 is the ground state, E_3 is the short lived state and E_2 is an intermediate meta stable state. The transition from E_3 to E_1 is forbidden * Hence the atoms are excited with an exciting radiation but E_3 to E_2 is allowed.



Vibrational Kinetic Energy

M.S 1. Time

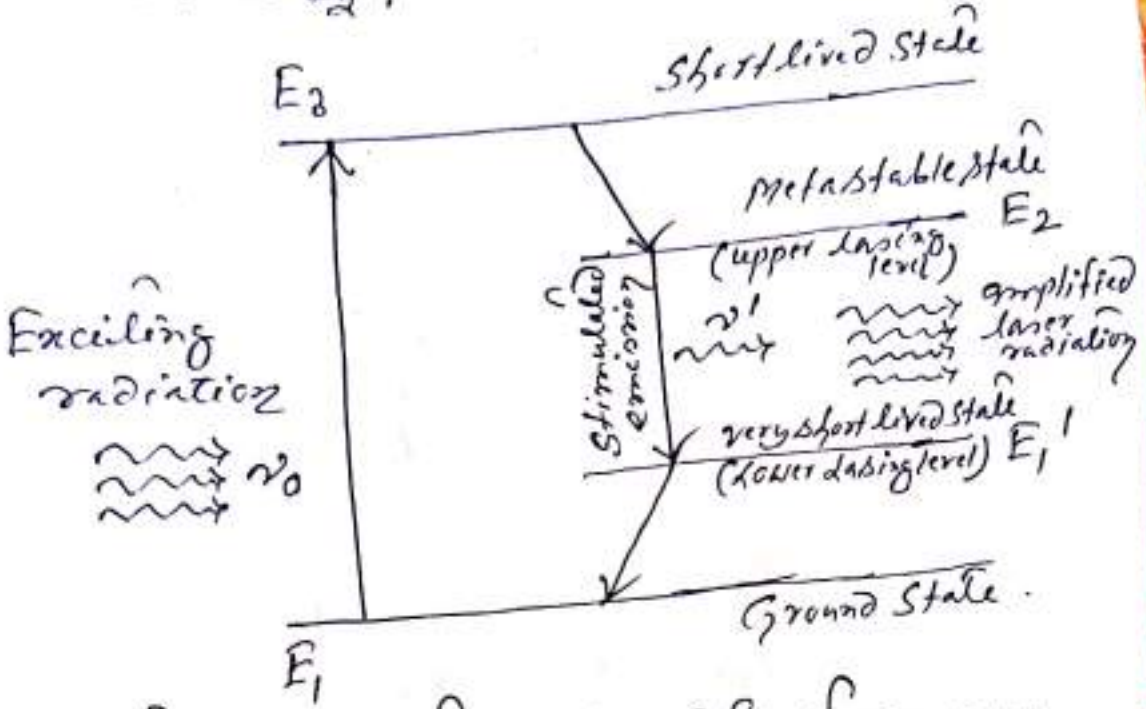
4 → Ext.

When these atoms are irradiated with an exciting radiation of right frequency $\nu_0 = \frac{E_3 - E_1}{h}$, the atoms are excited to the E_3 state by the process of stimulated absorption. Some excited ~~atom~~ atoms quickly drop to the intermediate level E_2 by spontaneous emission or by a non-radiative process, there by converting their excess energy into vibrational kinetic energy of the atoms forming the substance.

As E_2 is a metastable state, the atoms remain in this state for a comparatively longer time of 10^{-3} sec as compared to 10^{-8} second for short lived state E_3 and for this time, the population of the state E_2 is more than that of state E_1, thus resulting the population of the collection of atoms.

If an atom in the state E_2 decays by spontaneous emission or stimulated emission; it emits a radiation of frequency $\nu = \frac{E_2 - E_1}{h}$. The photon may produced stimulated emission from another atom, there by giving ~~in~~ two coherent photons, moving in the same direction. These two photons produce two more photons and so on, producing an amplified beam of photons.

(ii) Four level Scheme :- In four level scheme there is an additional very short lived energy state E_1' between the ground state E_1 and metastable state E_2.



Very exciting radiation of right frequency $\nu_0 = \frac{E_3 - E_1}{h}$ $\left(\frac{E_3 - E_1}{h}\right)$ is incident on the lasing medium, the atoms in the ground state E_1 are excited to the level E_3 by the process of stimulated absorption. The atoms stay at the E_3 level for a very short time of about 10^{-8} second and quickly drop down to the metastable state E_2. Spontaneous transition from the metastable state E_2 to the level E_1' is forbidden and therefore cannot take place. As a result, the atoms accumulate at the level E_2 and the population at this level rapidly increases.

Again the level E_1' is well above the ground level E_1, so that $(E_1' - E_1) \gg KT$. Therefore

(NB: YAG laser four level scheme)

at normal temperature atoms cannot jump to the level E_1' from the ground level E_1 because of thermal energy. As a result, the level E_1' is almost virtually empty. The population inversion is thus maintained between the levels E_2 and E_1'.

Further, when the atom in the state E_2 decays by spontaneous emission or stimulated emission to state E_1', it emits a photon of frequency $\nu' = \frac{E_2 - E_1'}{h}$. This photon further produces stimulated emission from another atom and thus starts the laser action.

Comparision of four level pumping scheme with three level pumping scheme :-

1) In three level pumping scheme the atoms finally return to the ground state directly from the mete stable state. Therefore, inorder to achieve population inversion pumping has to go on until more than half of the ground state atoms reach the metastable state E_2, which is the actual lasing level. As number of atoms in the ground state is very large so a very high pumping power is required for the purpose.

But in case of four level scheme the terminal level is almost virtually empty so that the condition of population inversion is readily established even if a small number of atoms arrive at the metastable

state. Consequently only a small pumping power is required to establish population inversion in four level scheme.

2) In three level pumping scheme, as soon as stimulated emission starts, the population inversion condition returns to normal population condition and lasing stop as soon as the excited atoms drop to ground level. Again lasing action begins only when the condition of population inversion is re-established. The laser light giving out is, therefore, in the form of pulses of short duration. But in the case of four level scheme, the population inversion continues without interruption and laser light is continuously obtained. The LASER, therefore, operates in continuous wave mode.

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Metastable state :-

An atom in the ground state can be excited to a higher state by supplying energy to it. Normally, an atom in the excited state comes back to the original or ground state in a very short time of about 10^{-8} to 10^{-9} second by emission of a photon through spontaneous emission.

The average time for which an atom remains in an excited state is known as its mean life

The mean life of an atom is characteristic

of energy state. Some energy states have comparatively a longer mean life.

Energy states having mean life of more than 10^{-3} second are known as metastable states.

// Importance :- The atoms in the excited state can not stay for long time since life time is very small. Immediately it drops to the ground state by spontaneous emission. Thus large number of atoms do not accumulate there and population inversion is not possible.

For population inversion to take place excited state should have a long life time. i.e it should be a metastable state. It is not possible to create population inversion with out the presence of a metastabe state and hence ~~the~~ laser acting.

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Example of two level, three level and four level laser :

1) Two level laser : PN-Junction - Semiconductor laser
2) Three level laser : Ruby (Al_2O_3 crystal) laser.
3) Four level Laser :- Nd YAG laser.

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