Introduction

Learning Objectives

On completion of this chapter you will able to understand

1. The significance of Einstein’s coefficients
2. The concept of Population Inversion
3. Laser Action
Significance of Einstein’s coefficients

The Einstein relations are given by the equations

\[ g_1B_{12} = g_2B_{21} \] \hspace{1cm} (1)
\[ A_{21}/B_{21} = 8\pi\hbar\nu^3/c^3 \] \hspace{1cm} (2)

Equations (1) and (2) are referred as Einstein relations.

The rate of spontaneous emission rate to the stimulated emission rate is given by

\[ R = N_2 A_{21}/N_2 \rho(v) B_{21} \]
\[ = A_{21}/\rho(v) B_{21} \]
\[ R = \left[\exp \left(\frac{h\gamma}{kT}\right) - 1\right] \] \hspace{1cm} (3)

In practice, the absorption and emission processes occur simultaneously. Even for sources operating at higher temperature and lower frequencies \( h\gamma \gg kT \) and hence \( R \gg 1 \). This confirms that under condition of thermal equilibrium, spontaneous emission predominates over stimulated emission.

From the equation (3), we understand that to make \( R \) smaller, \( \rho(v) \) the energy density of interacting radiation has to made larger. Let us consider the ratio of stimulated emission rate to stimulated absorption rate.

\[ \text{Stimulated emission rate/ Stimulated absorption rate} = \frac{N_2 \rho(v) B_{21}}{N_1 \rho(v) B_{12}} \]
\[ = \frac{N_2}{N_1} \quad \text{(as} \quad B_{21} = B_{12} \quad \text{ignoring degeneracy)} \]

At thermal equilibrium \( N_2/N_1 < 1 \)

Thus at thermal equilibrium stimulated absorption predominates over stimulated emission. Instead if we create a situation that \( N_2 > N_1 \), stimulated emission will predominate over stimulated absorption. If stimulated emission predominates, the photon density increases and Light Amplification by Stimulated
Emission of Radiation (LASER) occurs. Therefore, in order to achieve more stimulated emission, population of the excited state \( N_2 \) should be made larger than the population of the lower state \( N_1 \) and the condition is called population inversion. Hence if we wish to amplify a beam of light by stimulated emission then we must

1) create population inversion and

2) increase the energy density of interacting radiation

**Population Inversion**

The population inversion condition required for light amplification is non equilibrium distribution of atoms among the various energy levels of atomic system. Boltzman distribution law specifies what fraction of atoms are found in any particular energy state for any given equilibrium temperature. If \( N_0 \) is the number of atoms in the ground state, \( N_i \) is the number of atoms in the excited state of energy \( E_i \) measured relative to the ground state, then (ignoring degeneracy)

\[
\frac{N_i}{N_0} = \exp \left\{ -\frac{E_i}{kT} \right\} \quad ---- \ (4)
\]

Where

\( T \) is the absolute temperature in degree Kelvin and \( k=1.38 \times 10^{-29} \) joule/K (Boltzman constant). Since the right hand side of the above equation is exponential of a negative quantity, maximum possible value is 1. That happen when \( kT > 1 \). Even then at this extreme (impossible) case, \( N_i \) can be equal \( N_0 \) but it will never exceed \( N_0 \). Hence from this it is very obvious that by feeding energy level, higher level can never be made populated than the lower level. i.e. by direct pumping population inversion is not possible.
A population inversion cannot be achieved with just two levels because the probability for absorption and for spontaneous emission is exactly the same, as shown by Einstein and expressed in the Einstein A and B coefficients. The lifetime of a typical excited state is about $10^{-8}$ seconds, so in practical terms, the electrons drop back down by photon emission about as fast as you can pump them up to the upper level.

Most lasers are based on 3 or 4 level energy level systems, which depends on the lasing medium. These systems are shown in figs 3a and 3b. In case of a three-level laser, the material is pumped from level 1 to level 3, which decays rapidly to level 2 through spontaneous emission. Level 2 is a metastable level and promotes stimulated emission from level 2 to level 1.

On the other hand in a four level laser, the material is pumped to level 4, which is a fast decaying level, and the atoms decay rapidly to level 3, which is a metastable level. The stimulated emission takes place from level 3 to level 2 from where the atoms decay back to level 1. Four level lasers is an improvement on a system based on three level systems. In this case, the laser transition takes place between the third and second excited states. Since lower laser level 2 is a fast
decaying level which ensures that it rapidly gets empty and as such always supports the population inversion condition.

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**Basic requirement of a Laser**

1. **Active Medium**

   This basic medium is required to start the laser action. In which, the atomic or molecular transitions takes place to the laser action.

   Solid, liquid, gas, dye or semiconductor may be used as active medium

2. **Pumping System**

   The basic system is required to achieve the pumping action in the active medium

3. **Optical Resonator**

   This system is formed by a pair of reflecting surfaces facing each other, in which one is fully reflecting and the other is partially reflecting. These mirrors are kept on the both sides of active medium during laser action are bounced
back and forth between these two reflecting surfaces. This reflection process
induces more and more stimulated transition leading laser action

Check your Understanding

1. For getting laser radiation, the Einstein’s coefficient should be such that
   (a) $A/B < 1$   (b) $A/B > 1$   (C) $A/B = 1$   (d) $A = b$
2. Population inversion means that
   (a) maintaining more number of atoms in high energy levels
   (b) maintaining more number of atoms in ground level
   (c) maintaining more number of atoms in the metastate than the ground state
   (d) maintaining more number of atoms in the laser transition levels.
3. To amplify the beam of light, we must --------- and -----------

Summary

On the completion of this chapter you have learned that

1. Einstein proposed mathematical expressions for the existence of stimulated emission of light, which is known as Einstein expression. The coefficient of $A_{21}$, $B_{12}$ and $B_{21}$ is known as Einstein’s coefficients.
2. The $A$ and $B$ coefficients received particular attention in the period in which lasers were being developed. The nature of the coefficients is such that you cannot use the radiation in a cavity to elevate electrons preferentially into an upper state, producing the population inversion necessary for laser action.
3. The establishment of situation in which the number of atoms in higher energy state is greater than in lower energy state is called population inversion. i.e., $N_2 >$
\[ N_1, \text{ where } N_1 \text{ and } N_2 \text{ are the number of atoms in the ground state and excited state respectively.} \]

4. A population inversion is required for laser operation

**Suggested Reading**

1. Engineering Physics by Dr. P.K.Palanisamy

**Answers to Check your Understanding**

1. (a)
2. (c)
3. Creating population and increase the energy density of increasing radiation