General Physics I (PHYS 101)

Lecture 20

Laser

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Outline

Introduction

The word LASER stands for the Light Amplification by Stimulated Emission of Radiation. The laser is a device that can produce a very intense monochromatic and coherent beam of light. The laser light emerges out as a narrow beam which can travel over long distances without much loss in its intensity. The characteristics of laser light are

1. it is monochromatic because all the photons have the same energy $E = E_2 - E_1 = h\nu$ and hence the same frequency
2. it is coherent in the sense that all the photons or waves are in the same phase
3. it is very intense because of the same phase photons and
4. a laser beam diverges hardly at all

Emission of radiation

The three kinds of transition involving electromagnetic radiations are possible between two energy levels E_1 and E_2 in an atom. They are: *induced absorption*, *spontaneous emission* and *stimulated emission*.

An atom or molecule can have energy in discrete values but not in a continuous range. These discrete values of energy of the atom are referred to as the energy levels of the atom. The transition of an atom form one energy level to another occurs in jump and is called quantum transition. The quantum transition from a lower energy level to the higher one causes absorption of photons while that of from higher energy level to the lower corresponds to an emission of photons.

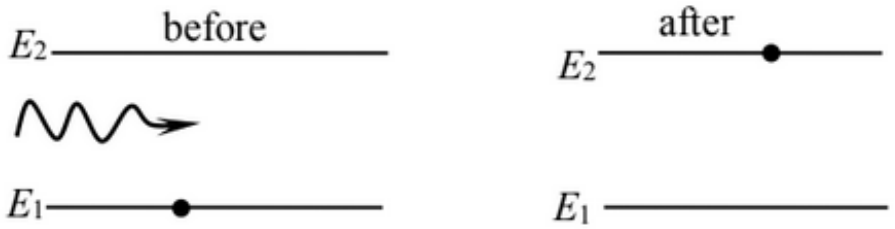

Figure 1: Induced absorption

Consider two levels of an atom with energies E_1 and E_2 as shown in figure 1. Suppose the atom is on the lower state E_1. If a photon of energy $E_{12} = h\nu = E_2 - E_1$ travels nearby the atom, it may absorb this incident photon thereby making a transition to higher energy level E_2.

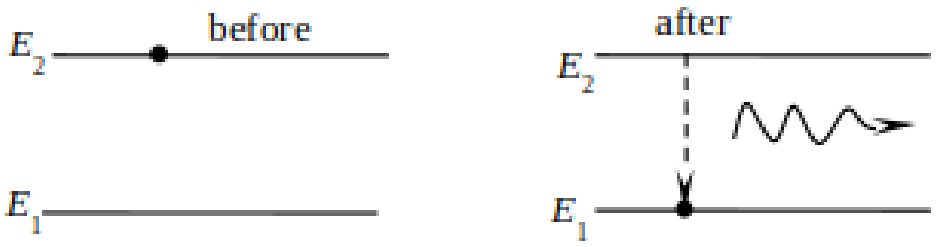

Figure 2: Spontaneous emission

The atom in an excited state or level E_2 has a tendency to decay to the lower level E_1 without any external inducing agent. This emission of photon is referred to as spontaneous emission because it is not caused by any external agent. The emitted photons will have the energy $E_{21} = h\nu = E_2 - E_1$ but its other characteristics such as direction of momentum, polarization and phase may be arbitrary. This is uncontrollable process.

The way to cause a non-random transition is stimulated emission of photon. Suppose an atom is in its excited state E_2. A photon of frequency may become a trigger (stimulate) and induced the transition from E_2 to E_1 resulting with another photon of same frequency ν. Both the inducing and induced photons have not only the same energy $E_{12} = E_2 - E_1 = h\nu$ but also have the identical direction of their momenta, polarization and phase. In other words, secondary photon finds itself in the state as the primary photon.

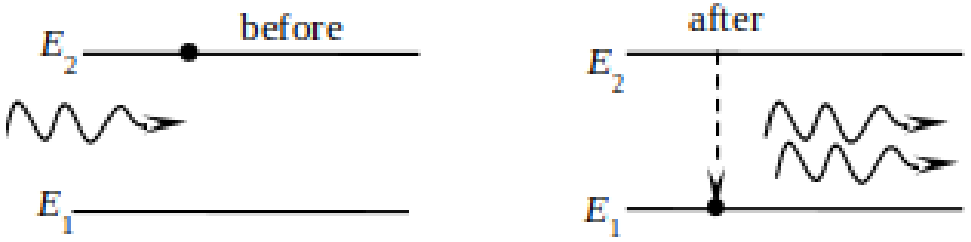

Figure 3: Stimulated emission

The physical behavior of inducing photon plays the same role as the catalysts do in chemical reaction. The two photons again cause similar emissions and the process continues.

Since the incident photon stimulates or causes the emission of another photon of exactly same nature this type of emission of radiation is referred to as a stimulated emission of radiation. Unlike the spontaneous emission, this emission is not random and emitted photon's characteristics may not be arbitrary and it is controllable process.

Population inversion and pumping

Under ordinary conditions of thermal equilibrium, the number of atoms in the higher energy state is considerably smaller than the number in the lower energy state i.e. $N_2 < N_1$. Hence there is very little stimulated emission compared with absorption. Let by some means the atoms are initially excited so that there are more atoms in the higher energy state E_2 than in the lower energy state E_1. We have $N_2 > N_1$, this is known as population inversion. Thus, the population inversion means that the number of active centers (atoms, molecules or ions that can produce lasing action) per unit volume per unit time in upper lasing level is greater than that in lower lasing level. The two types of pumping methods are common. They are *optical pumping* and *electrical pumping*.

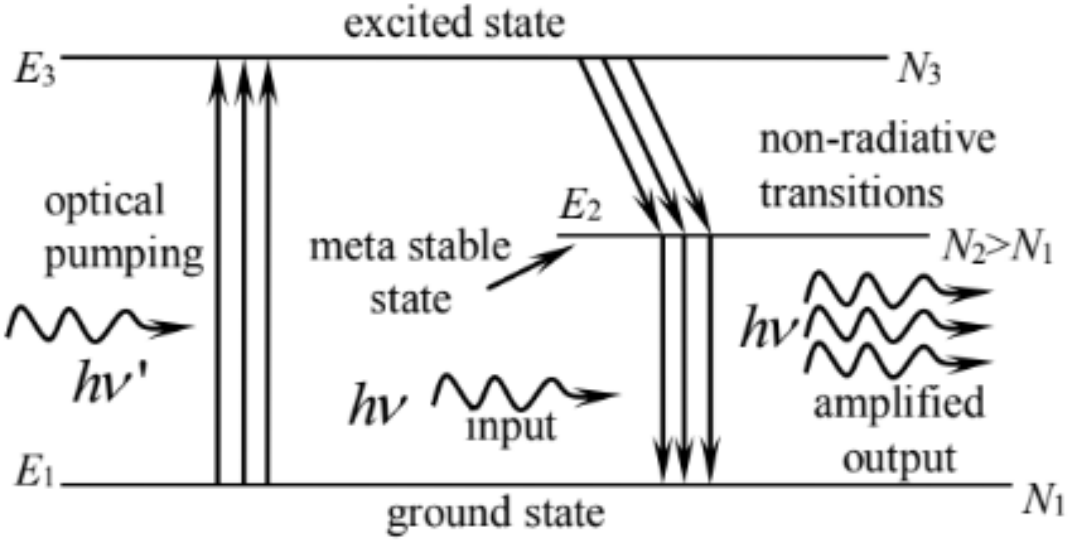

Figure 4: An optical pumping

The pumping done by photons is called optical pumping. Consider a material whose atoms can be reside in three different states as shown in figure. Atoms in ground state are pumped to state E_3 by photons of

energy $h\nu' = E_3 - E_1$. The excited atoms remains nearly $10^{-8}s$ and then undergo non-radiative transitions to the level E_2. They remain in this meta stable energy state for a comparatively long time i.e. until $10^{-3}s$. Thus, there will be more atoms in the higher meta stable energy state E_2 than in the ground state E_1 i.e. we have a population inversion. Atoms in the meta stable state E_2 are now bombarded by photons of energy $h\nu = E_2 - E_1$ resulting in a stimulated emission giving an intense coherent beam in the direction of the incident photons.

It is accomplished by means of a sufficiently intense electrical discharge in the medium and is particularly suitable for gas media at low pressure. The discharge converts gas in to plasma where free electrons collide with active centers inelastically and causes the predominant population in the upper lasing level i.e. due to continuous discharge at low pressure; the active centers get excited to the higher pumping levels.

Application of laser

The laser is used in

- communication in outer space and inside water,
- piercing holes in materials,
- cutting and welding of metals,
- detecting objects at great distance,
- measurement of atmospheric pollution and
- in medical and engineering uses.