Laser: Fundamentals and Applications

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Lecture – 03
Interaction of Light with matter

Hello and welcome to the day 3 of a first week of this course. In the last 2 classes we have looked into a various different applications that are possible with laser and also we looked into the brief history of laser development. So, with this a brief a background we can now go on to learn about the basics of laser the laser action.

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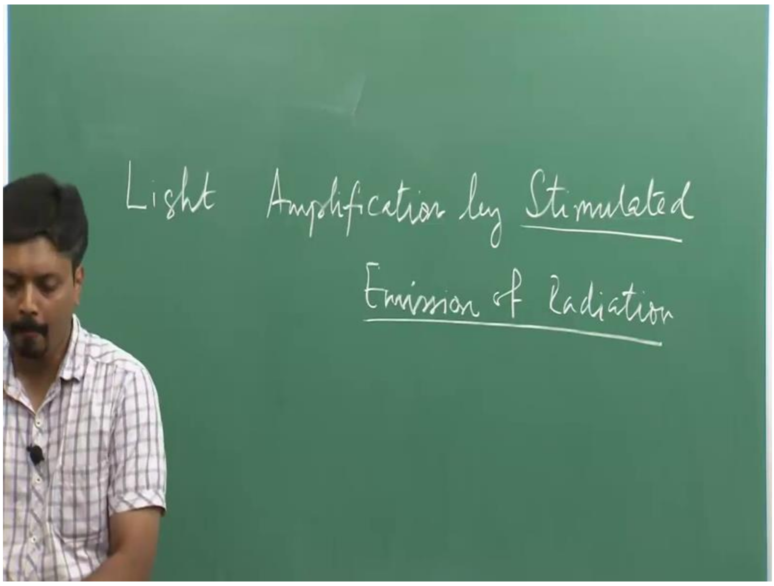

So, in the previous class I mentioned the full form of laser that is Light Amplification by Stimulated Emission of Radiation is the full form of laser and we said that there are few things and that we need to know in order to understand the laser how laser works what is the basic principle of laser and one of the most important thing to learn will be the stimulated emission of radiation.

Now, before we can start talking about stimulated emission of radiation. We should know what are the different processes that can take place when light interact with matter. As we know that light can absorb or emit. How exactly this absorption or emission process is? So, in a word what are the optical transitions that are possible within a system which can be an atom or an iron or molecule or large material?

We will start with a simple description of optical transition in an atom. There are you know some benefit of using an atom to describe this process means this is very simple. We do not have to consider any rotation or vibration of an atom, but we can deal with the simple energy level of an atom. We will start with a you know a very energy and a simple energy level diagram which is known as a 2 state model or 2-level System

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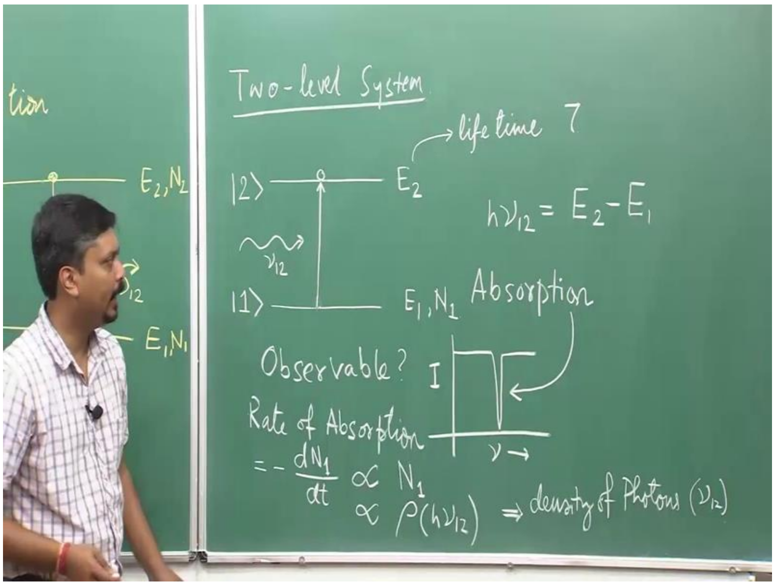

So, we will consider 2-level System. What is a 2 level system; a 2 level system consists of a ground state and an excited state. We can write the ground state and excited state by giving them the names state one and state 2.

So, you know the electrons in an atom can reside in ground state. Now what happens when we shine light into the system consisting of 2 states and also one more thing I need to specify here that the energies of the 2 states are given by E 1 and E 2.

Now if I shine light such that the frequency of that light let me call it as 1 2 nu 1 2. Such that h nu 1 2 where h is the planck constant is equal to the energy gap in this system that is E 2 minus E 1. So, I am bringing a light with a frequency nu 1 2 such that the h nu 1 2 matches the gap between the energy levels 1 and 2. So, what will happen this atom will be now excited? This from the ground state it will make a transition to displace now, this process is known as Absorption of light or in short we call it Absorption.

When we you know let this process happen what do I observe, in other word what is the Observable? If I come with a light I can detect the light in absence and in presence of this system this 2 level system. The intensity of the light in absence and presence of this 2 level system if I look at then what will I see. If I see or measure the intensity of light then when this process happens I will see a sudden drop in the intensity and this drop is due to the process Absorption.

I can come with different frequency of light whenever the frequency matches with this gap I can see this. If I plot it against nu I see a plot like that, this is my Observable. So, many of you are probably aware of this fact. Once I take the system from ground state to the excited state, the molecule will be there now for how long, will it be there forever or it will be there for a certain period of time. The answer is that this state of the system that is when the molecule has made a transition from here and is residing on this state to it will not be there eternally.

It has a finite time for staying in that particular state 2 which is known as the lifetime and. So, this state is associated with lifetime which is normally denoted by this tau. This tau amount of time is the maximum amount of time for which the molecule can all atom can stay here at level 2. After this time tau the molecule is going to jump back to the ground state that is state 1. What will happen if I can show here or say I will use the same diagram.

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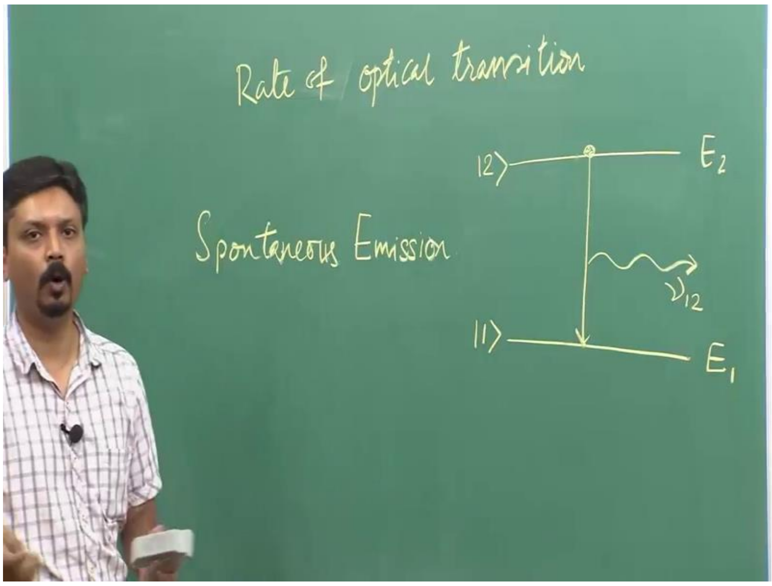

After some time when or maybe I can go for separate one. So, that it is easy for you to understand. All the description remains as it is only thing is that now molecule is here and I am not doing anything I am not perturbing anything perturbing the system with any external force.

On it is own it will make a jump from this state to this state after a time period tau which is the lifetime of the state. And when it jumps from state 2 to state 1 what will happen the energy equal to the gap E 2 minus E 1 will be emitted. So, accompanied by this jump there will be a release of photon and that photon frequency will be such that it matches this gap. Again the photon frequency will be nu 1 2 you may call this as nu 2 1, but you can understand for this given 2 level system it does not matter whether I write nu 1 2 or nu 2 1 because both are same. So, we will all the time use this nu 1 2.

The first process was Absorption and this process is known as of course Emission because a photon is being emitted, now what kind of Emission we are not perturbing the system externally. It is happening spontaneously and therefore, this is known as Spontaneous Emission. These are the 2 processes that people knew for long time that this is what happens.

If we 1 2 understand the you know this transitions in a detailed way and for that matter if we want to really understand the how laser works, we need to understand this processes in terms of their rate. We need to know the Rates of this optical transition any given optical transition we need to know at which rate this transition is happening. Then we will be able to understand this processes bit more and also we will be in a condition where we can you know manipulate this transition. So, that we can you know get something useful something like a laser we will learn that in a bit.

If we look at the rate for this process then what I can say that before doing that we need to define some more things that is the population. The population of atoms in state 1 and state 2; if I say in 1 is the population of ground state 1 and in 2 is the population of state 2 now the rate. So, Rate of Absorption let us consider that first what is the Rate of Absorption. I can understand the Rate of Absorption by noticing the rate at which the number of you know atoms resulting in state a deplete with time. Rate of Absorption is equal to the decay of number of atoms at 1. So, it is minus dN 1 dt this is my Rate of Absorption.

How can I find the Rate of Absorption? Then if we need to find that out then what we have to do we have to understand on which on what thing this Rate of Absorption actually depend or the decay of population in the ground state one you know decays. This Rate of Absorption is proportional to the number of atoms itself in that particular state. In our case Rate of Absorption is proportional to N1 more the number of atoms in that level more will be the optical transition that the rate will be more.

And what will be the second thing that it can depend on if you think about it will depend on the density of photons with energy nu 1 2 that is available. So, more number of photons that are available to make this transition the rate of transition will be more. So, minus dN 1 dt is proportional to the density of photons having frequency nu 1 2 and let me call this as h nu 1 2. So, rho is the density of photons having frequency nu 1 2 and we write it in this fashion row of h nu 1 2.

If I put together, this one let me write down this is density of photons having frequency nu 1 2. If I have to find out the you know what is the value of minus dN1 dt then we have to go from this proportionality to an equality condition. If I can write that up here let me take the liberty to erase this part, from here I can write this Rate of

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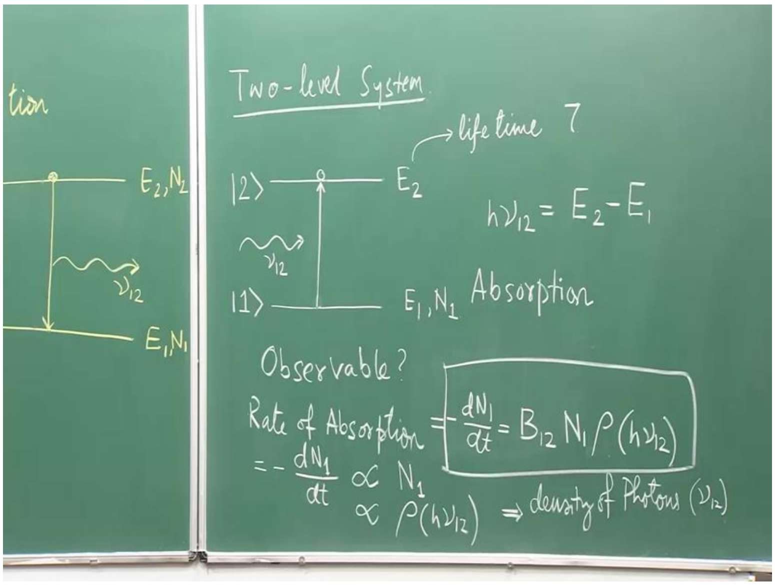

Absorption equals to again minus dN 1 dt equal to some constant let me call that constant as B 1 2 and multiplied by N 1 and rho h nu 1 2. So, this is my Rate of Absorption fine we got what is the Rate of Absorption.

Now, let us find out what is the rate of Spontaneous Emission, here we have the picture for Spontaneous Emission.

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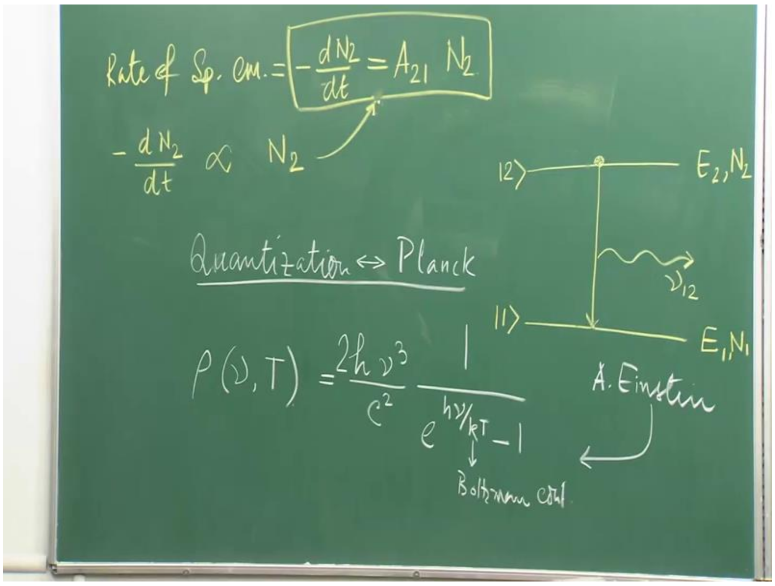

We have to find out the rate of Spontaneous Emission let me put it in this way. This one I can write in a differential form as minus dN 2 dt in a very similar way as we have done it for absorption. In absorption we dealt with the ground state change of population of the ground state and here for spontaneous emission we are dealing with the change of population of the excited state that is state 2. The number of atoms in state 2 is in 2, the changes in 2 with time is my rate of spontaneous emission and remember here there is no light, there is no spectral field or radiation field present when I am considering a spontaneous emission.

Here what are the things that this minus dN 2 dt will depend on. It will depend on only one thing that is the number of atoms present in state 2. Since, we do not have any radiation field here for spontaneous emission. This is the only thing that it can depend on unlike the case of absorption where it depends also on the radiation field. So, I can go from this proportionality do the equality by putting some constant and let us call it A 2 1 multiply by N 2.

If you see the notations that we are using all the time it denotes from which state to which state. If you are looking at A 21 you would be able to tell that it is a process involving a transition from state 2 to state 1 and you will have the corresponding in 2 which is the population at state 2. On the other hand if you look at for the absorption process you will see this is from 1 to 2 and it is also associated with the number of molecular atoms in the state 1, it is very easy to figure out. I have got my rate of Spontaneous Emission.

At this point let us talk about a bit of work done by Max Planck. In the first second class we talked about the history of laser development and there we mentioned that it would not be possible you know to go ahead and develop laser until and less you know there were a tremendous theoretical work done by 2 scientists Max Planck and Albert Einstein.

Let us start with what did Max Planck do. There was an existing problem of blackbody radiation. So, most of you have you know learnt about blackbody radiation in your high school physics or at least in the undergrad days. So, blackbody it emits light now there are certain issues regarding the spectrum of a blackbody a perfect blackbody. People are trying to explain the spectral behavior of blackbody and there were a lot of difficulties you know even if you can explain it to to most extent, but when you go toward the uv region of the spectrum one could not explain and Max Planck was trying to do that in order to do.

What he did he proposed he proved any propped at the optical transition that we see which results in having a spectrum is not discrete, is not continuous I am sorry rather it is discrete. He proposed this discretization of optical transition and he said propose the transition to be quantized. Quantization of optical transition came from Planck’s were Max Planck’s were and in this work done around 1900 he ultimately got a relation which is known as Planck’s law where he gave us the expression for spectral density.

So, is the you know radiation density which is a function of frequency and also a Temperature. So, why is it, because when you know work with blackbody you take it to be in thermal equilibrium at a particular temperature T and then you deal with it is spectral property? So, at a given temperature the spectral density that is you know coming out of a black body and for a given frequency that you are looking at this is the spectral density and this is given by h. So, Planck get this formulation where rho is equals to 2 h nu cube into C by C squared multiplied by this quantity.

What are these terms h is Planck constant nu is the frequency of the light that you are considering C is the speed of light. So, and k is the Boltzmann constant. So, this is and capital T is the temperature. So, you pretty much know what are the you know different quantities on the right side of this. So, he did it and this could explain the blackbody radiation to quite good extinct at that point of time.

Now let us come back to our earlier discussion of this optical transition we will need to use this in a very after a while. So, after Planck did this work Einstein was trying to explain also the blackbody radiation problem by treating the blackbody to be a unit which is consisted of several number of such oscillators. This 2 level system we can call it as an oscillator. So, the you know atoms can go here to here to here and absorb or emit photon. This kind of simple 2 level oscillators Einstein took it as a unit that form the overall blackbody radiation.

So, there are your n numbers of such oscillators constitute the whole blackbody radiation. So, what he was trying to do ultimately that treating blackbody in this way he should come to the same expression that Planck has got right. Albert Einstein he was trying to come to the expression of Planck for this spectral density. He was not successful in doing, so there were certain problems associated this one.

So, what we will do we will stop here today and in the next class we will start looking at how actually Einstein you know solve this problem and you know go to the same form of Planck's expression Planck's law by treating the blackbody as you know an ensemble of this kind of 2 level oscillators.

So, see you tomorrow again.

Thank you very much.