(Foreign language). Knowledge is supreme.

We have seen in the previous class that two level systems cannot give you laser. The laser is light amplification by stimulated emission of radiation. So the idea is, when light goes in to some medium and then the light comes out, number of photons going in, well number of photons coming out, should be more than number of photons going in. That can only happen when there is a net stimulated emission. If you think of steady state, of course, there is absorption, stimulated emission, spontaneous emission, everything going on, but what is the net effect? Is there a loss of photon or is there a gain in number of photons, that is what we are trying to discuss here, okay. If there is a gain in photons, then only you can think of making a laser out of the system. So that happens only when there is population inversion, this is something that we worked out in the previous class by very simple kinetic approach, okay. Population inversion is an e essential requirement for this net gain to happen. And as we have seen is that, you cannot get population inversion, if you have a two level system. So you cannot make a laser out of a two level system.
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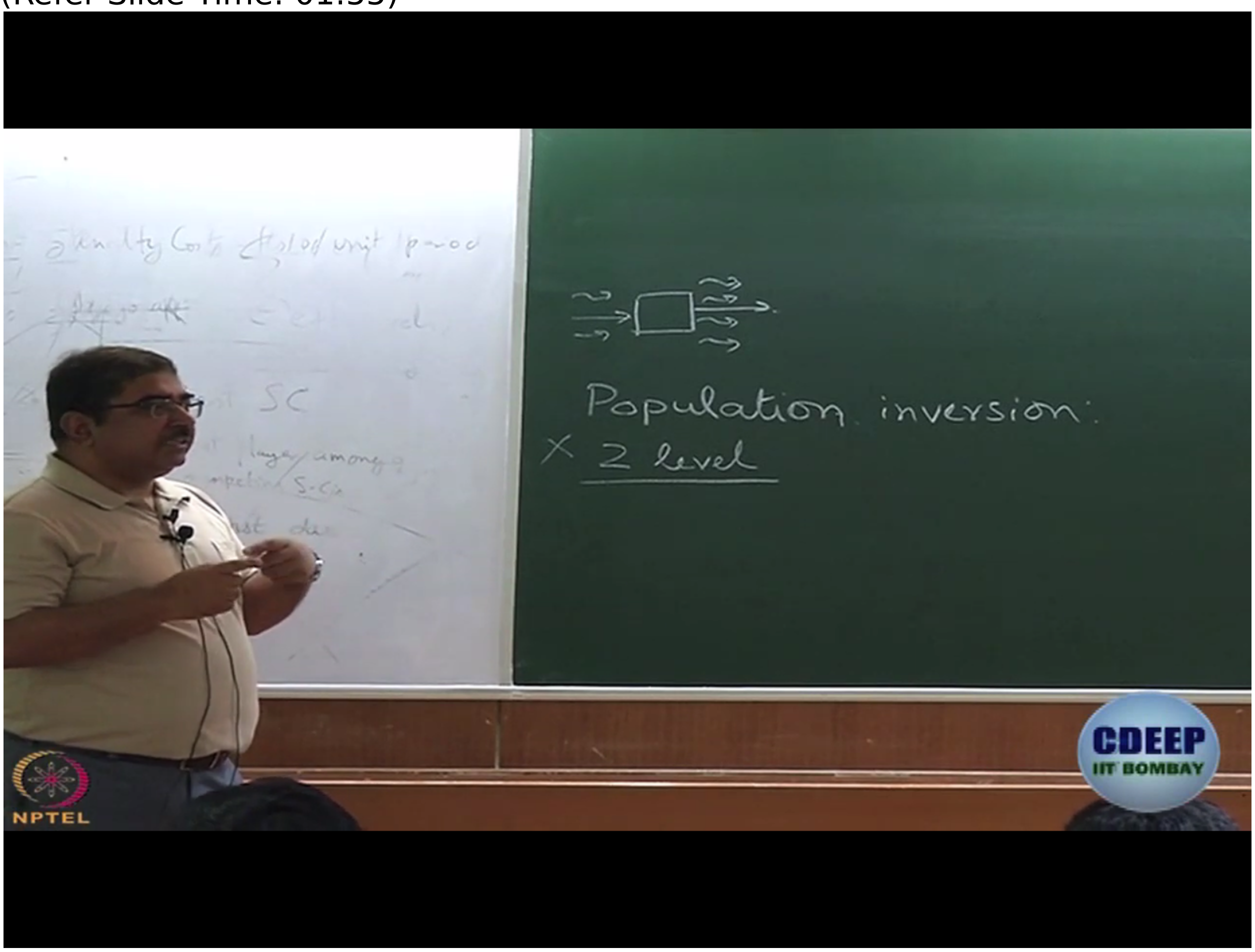

There was a paper in science, I think three years ago or four years ago, where they claimed that they have obtained lasing form a two level system, but then they talked about something very bizarre, they talked about negative absolute temperature and the impression I got from reading that paper is that it is not a true two level system, alright.

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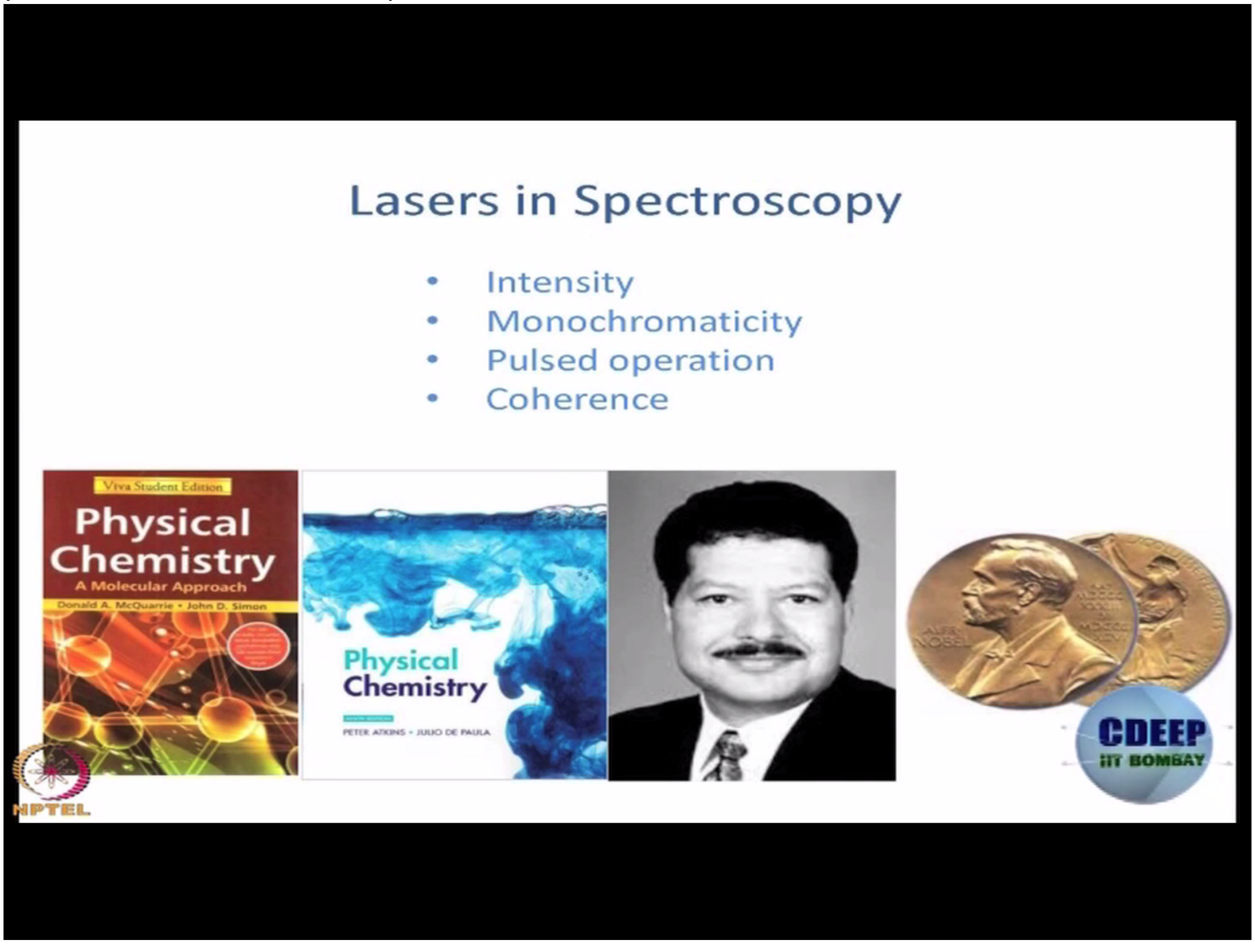

So until something very drastically different happens, two level system does not give you a laser. What about three level system? What about four level system. Is it possible to generate a population inversion, if you have say a three level system. Now three levels… in fact three level systems also can be of two kinds. Let us see at this level one, now instead of going into detail of singlet, triplet and all that, I will just write level 1, level 2, level 3, level 4, what they are depends on the system. Let us say this is level 2, you cannot have population inversion between them. Suppose there is a metastable level between these two, then what happens. Okay a very simple example that perhaps most of us will understand is that, think of an organic molecule. For organic molecules with all paired electrons and round, stated as singlet, right? Then this state is also a singlet excited state and in which you have a triplet state, do you all know this? this energy order, singlet, excited singlet, triplet. So as you know, if this is a singlet state and this is a triplet state then transitions between singlet and triplet are not allowed, we are going to deal with it in more detail, when we talk about electronic spectroscopy. For now, if you don’t know this, let us take it extrametrical. So what happens is, and suppose these are electronic levels, what is the meaning of electronic levels, when you start the experiment, all the population is here, right, the energy gap is too much, so you start with this, excite the molecule to state 2, and then by some non-radiative process, if this is singlet and this is triplet, then what is that non-radiative process called? ISC, and what is ISC, other than Indian School Certificate, intersystem crossing, right. So here we mean intersystem crossing. So this state sits here. Now see to start with before this, so this process is actually called pumping. Populate the excited state, it is actually called pumping. At time 0, when pumping begins, is there any population in the excited state, so question of population inversion doesn’t arise. Now see, initially let us say there are 1 2 3 4 5 6 7 8 9 10 multiplied by 10 to the power, what is Avogadro number? 10 to the power, yeah so 10 multiplied by 10 to the power 23 number of molecules, okay each is 10 to the power 23. Suppose you start pumping, and you manage to send two of these here. Have we achieved population inversion? No. But then you know that this transition between three and one Is not allowed, so that is an essential condition, okay, in a system like this, this transition has to be disallowed. If that is the case, then what will happen, this life time of state 3 is going to be long, it is going to be long enough for you to have a chance of keeping on populating it until you have population inversion. Do you understand, what we are saying? Let us say it has a lifetime of several milliseconds. Do triplet states, can triplet states have lifetime of milliseconds, can triplet states have lifetimes of seconds, minutes, hours? Triplet states can actually have lifetimes of hours, okay, right, so you have something like this, long enough. So if this lifetime of state number 3 is long enough, then what you can do is, you can keep increasing the population of it gradually by pumping continually until you achieve population inversion, right. Do you understand what I am saying? Rate of pumping has to be fast and lifetime of state 3 has to be long. In that case, the moment now if we reach the situation, we have 6 in state 3, we have 4 in state 1, now population inversion is achieved, right. Now you can have stimulated emission, strong stimulated emission, which takes all these 6 x 10 to the power 10 molecules, down to the ground state all of a sudden. Alright, so what we see that for a three level system, I will call this three level system of type A, we can having lasing. But have you noticed what kind of lasing it is? Does this laser remain long, sorry remain on all the time, no, right. Initially until population inversion is achieved, there is no lasing. Okay, so what kind of a laser is it called? It's called a pulse laser. So if you look at the output, for the time that is required, so this is time, for the time that is required to build population inversion, there is no intensity. The moment population inversion is achieved, you get a huge burst of light, then again there is nothing, then again when the population inversion is achieve, you get a huge burst of light, and so on and so forth, a good example of this class of laser is a Ruby laser, that gives you the so called giant pulses. Okay, so first thing that we learned is that you can have lasers that are pulsed. And we also learned that for three level systems like this you can have... you can make lasers. Now let us think of three level systems of type B and this is the system that is discussed in your McQuarrie and Simon's book. With a little bit of modification. Let us say this is one, level one, level 2, and level 3. Now let us say that this transition is allowed, but this transition is not allowed, okay. Now what will happen? You start with the same situation 1 2 3 4 5 6 7 8 9 10 x 10 to the power whatever, is there, okay. Populate level 2, let us say, I have sent even one of these here. Do I have population inversion between level 2 and level 1, no, but what is the population of level three 0, so do I have population inversion between level 2 and level 3, we do. So what will happen is that the moment even one molecule goes there, you already have population inversion between level 2 and level 3 and level 3 population is never built up, because let us that there is a non-radiative, efficient non-radiative relaxation happening between level three and level one, okay. So this efficient non-radiative relaxation keeps on depleting the population of level three. The moment level three gets populated, it gets repopulated non-radiatively. In this situation what you have is, you have, let us draw a laser like this. You can have lasing between level 2 and level 3, alright. Now let me ask you something, in this case, if I try to draw a similar output, if I want to draw the similar graph of laser output versus time, what kind of plot should I get, here I got pulse operation, will I get pulse operation in case B as well, yeah, no right? Because the moment you pump, the moment even one molecule is here, you already have population inversion between level 2 and level 3. So you are going to have, let's say this Y axis is intensity or output or whatever, you want to cal it, this is going to be hopefully constant. So now for this one I have pulsed operation and pulsed laser. For this kind of a three level system, I have what is called a continuous wave, in laser technology, it is very common to call it as CW laser. And of course what you could do is for these systems, what is the rate of excitation. Rate of excitation is B12 Rho Mu12 x population of level one. What is the rate of depopulation of this, this is K NR multiplied by population of level 2. What is the rate of depopulation of this? If you consider only stimulated emission, it would be B31 Rho31 Mu N3. The point to note is that Rho 12 and Rho 31 are not going to be the same, okay. Yes, and also you might have A, well you are going to have A always. If B21 is there then A21 also has to be there, as we know, so you have to consider that as well. Alright, what we are saying is this B21 is going to be very small, we are saying the transition is not allowed, in that case, why do we have lasing at all. When I say not allowed, I don’t mean exactly 0, it is small, but the issue is that can be overcome if NC is sufficiently high. Rate constant is small, but if you can have a large enough population, then you can still get it, okay then the rates can become equal. So similarly you can write those stamps here and you can work out the equation. Next let us add one more level. So 1 2 3 4. In this case, what we ar saying is that, there is an efficient non-radiative channel between 4 and 1, there is an efficient non-radiative channel between 2 and 3, understood. Now what will happen, take the system to level 2, the efficient non-radiative channel takes it to level 3. Now we are saying this is allowed. So what is… the moment anything comes to level 4, it gets repopulated once again by your efficient non-radiative pathway between 4 and 1, so population of 4 is tactically maintained at 0 all the time. So what will happen now, even if one molecule comes, we have population inversion between 3 and 4, so this is where your laser might be possible, this is a four level system. A very common example of four level system is the so called Nd: YAG laser… yttrium-aluminum garnet… yttrium aluminum garnet is just a matrix, what matters is, it has levels like this and it gives you… it gives you laser. Now what will be the output, is it going to be continuously or is it going to be pulse. Four level laser, this one will be CW, right. This is also something that gives the CW laser. Alright, so these are the different kinds of lasers.

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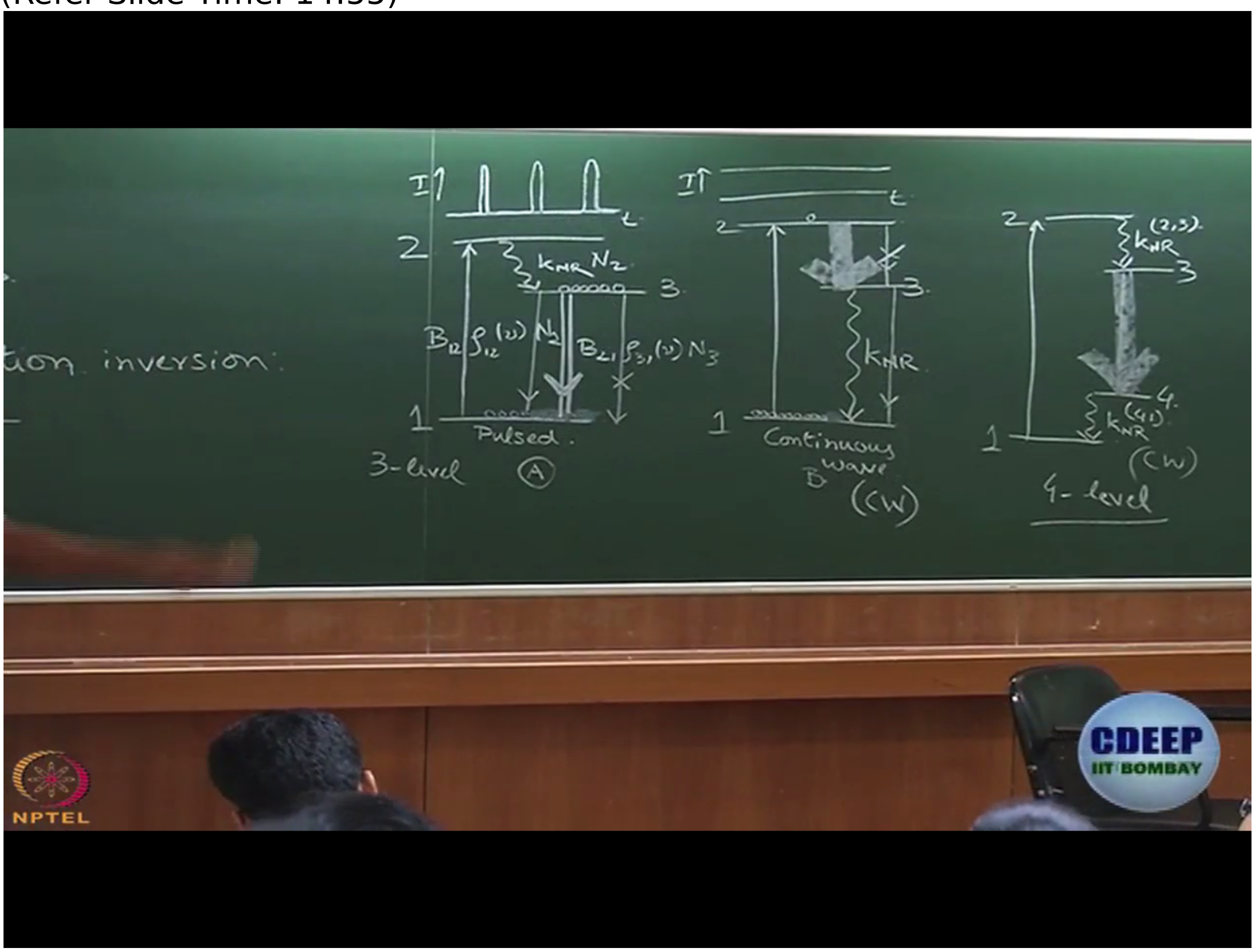

Quickly what are we discussing now? We are discussing say laser basics. Now, so very quickly let me just tell you, what is there is inside a laser. First of all you have a, what is called a gain medium. Gain medium means your molecule or iron whatever, it is that actually gives you the stimulated emission, okay. It can be solid, it can be liquid and it can be gas. Very common example of gas laser is CO_2 laser, well nitrogen laser is also there, but I am not taking its name for some reason. Very common example of solid state laser is what I just told you, well two examples we have discussed, one is ruby laser and the other is Nd: YAG neodymium-yttrium-aluminum-garnet laser. And then in liquid phase, many times what you want to do is, you want to take a dye, an dye, dissolve it in some solvent and use that as the medium that is going to give you the light, but dye lasers are becoming less and less and less popular. One reason why dye lasers have been popular traditionally is that they are actually tunable, it can… they can give you many different colors at your will, but they have problems as well. So dye lasers dissolve, well dye molecule dissolve in organic solvent you can understand, smelly, your container can least, dyes are carcinogenic, your hand gets, it has happened many times to me while doing experiments, hand gets stained for days, so they are not very nice things to work with, so they are by and large being replaced in most of applications by solid state lasers. So you have this gain medium. Next what you need is, you need a pump, okay. Pump means something that is going to populate the excited state. So you can do it either by using electricity or by using a light source, right. You can have some other light source or you can have an electrical source also. So you have some pump source, okay. And then when light comes out, what you do is you want to catch the stimulated emission in a particular direction and then you want to, if you want to amplify, suppose one photon goes in and two photons come out, that is not too much of amplification, right. If you can make those two photons come back and go through gain medium once again, then you will get four photons, is it right? Make those four photons come back and go through the gain medium once again, then you get how many eight photons. So the number of photons can impressible get double in every… it can get four times in every round trip, right. So the way we do it is, you put one mirror her and you put one mirror here, they are always curved mirrors, because what you want is, you also want to focus your light at the center of the gain medium, that gives you best result, but just for the sake of simplicity, I will draw one line, okay, so this is what happens. Let us say, you get one photon coming out of here, it goes, it spins, and comes back, that gives rise to tow photons. These two photons in this mirror come back, gives rise to four photons, when they come back they give rise to eight photons and so on and so forth. This is how you get a very quick build up of light intensity of number of photons, whatever you are more comfortable with, okay. So this is called the gain medium and this entire thing containing this pump, gain medium, and these tow mirrors is called the laser cavity. Now length of cavity has an important role to play here, because you understand, we are saying photons, but we cannot neglect that wave nature of light also, right. And as you understand you have this wave going back and forth, essentially what you want to do is you want to be in the standing wave, right. What is the condition of having a standing wave, yeah. Yes so what is the condition of that? Let us say the cavity length is L, that should be equal to lambda multiplied by something, N by 2, right. You should have integral multiple of half wave lengths, is it right? So this is the condition that has to be fulfilled. So what light you are dealing with, actually determines what kind of cavity length you should have, okay, it's a different matter, what actually this N is, generally this N is not one or two, N is a large number, but we don't have to go into so much of detail in this course. So this is your laser cavity, alright. Now what I have shown you here is that, suppose these two mirrors are perfectly reflecting mirrors, then you are going to have build-up of energy within the cavity, right, but then it's a closed loop, understand what I am saying? We have the gain medium, we have these two mirrors. Let us say these two mirrors are perfectly reflecting, then it is true, the number of photons will keep increasing within the cavity. How do you get it out? I have to get it out, right. There are two ways of doing it, the simplest way of doing it is to use a high reflect… highly reflecting mirror on one end and what is called an output coupler in the other end. Output coupler is commonly referred to as OC. The only difference is that here reflectance is 100%, here reflectance is let us say 95 or 97%, 97% reflectance, that means what 3% of light will go out, right, this gives you a way of getting the light also. The simplest way of doing it, there are more complex ways of doing it, somebody mentioned energy field, that is right. So there are things like… things called pockel cells that you can use here and you can switch the light out without having to use an output coupler, but let us not get into that much of detail now. If you understand this, you are good enough. Are we clear so far, any questions. If not, this is the end of the first module.

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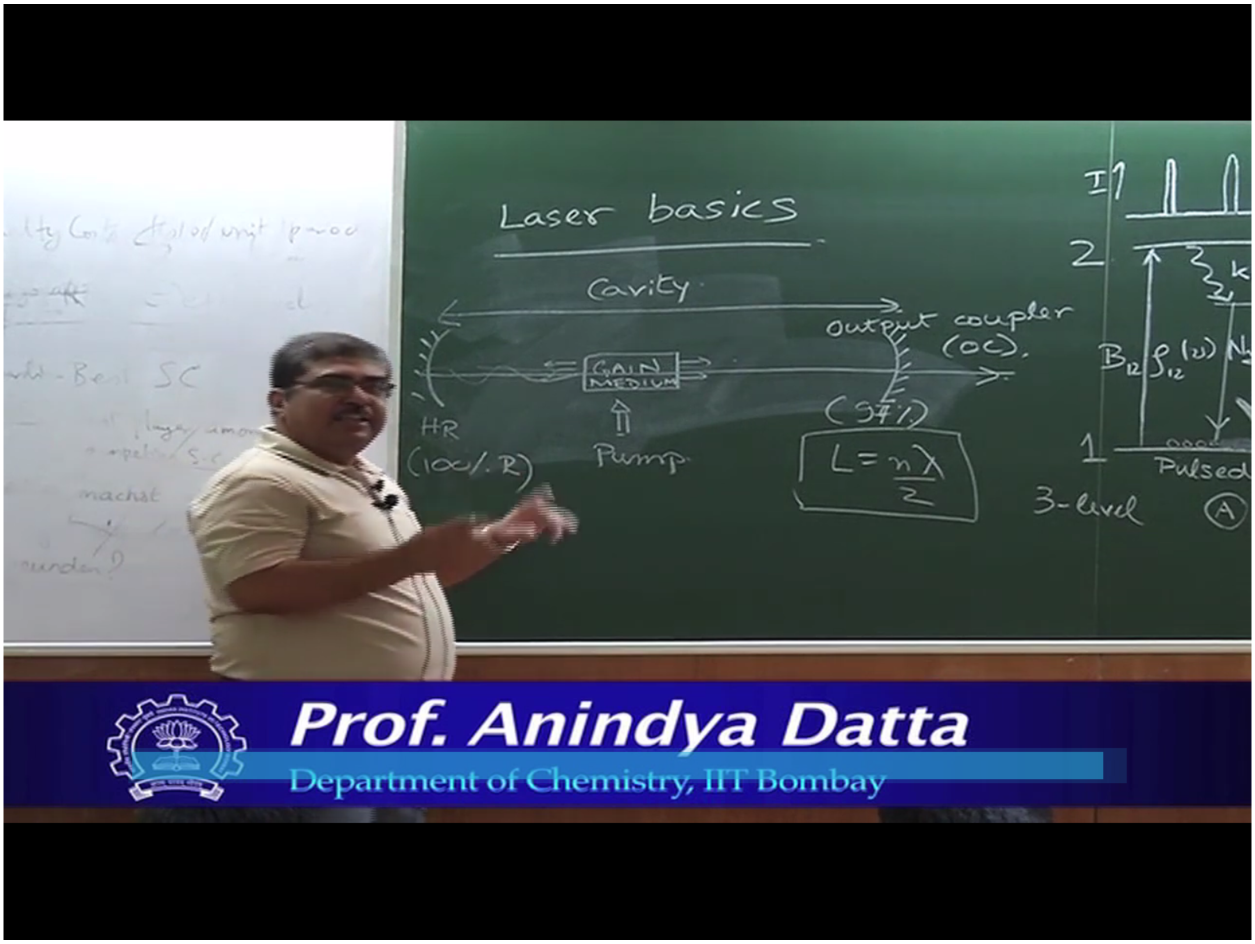
Laser basics
Cavity
output coupler
(OC)
GAIN MEDIUM
HR
(100% R)
Pump
(97%)
L = nλ/2
2
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3-level
Pulsed
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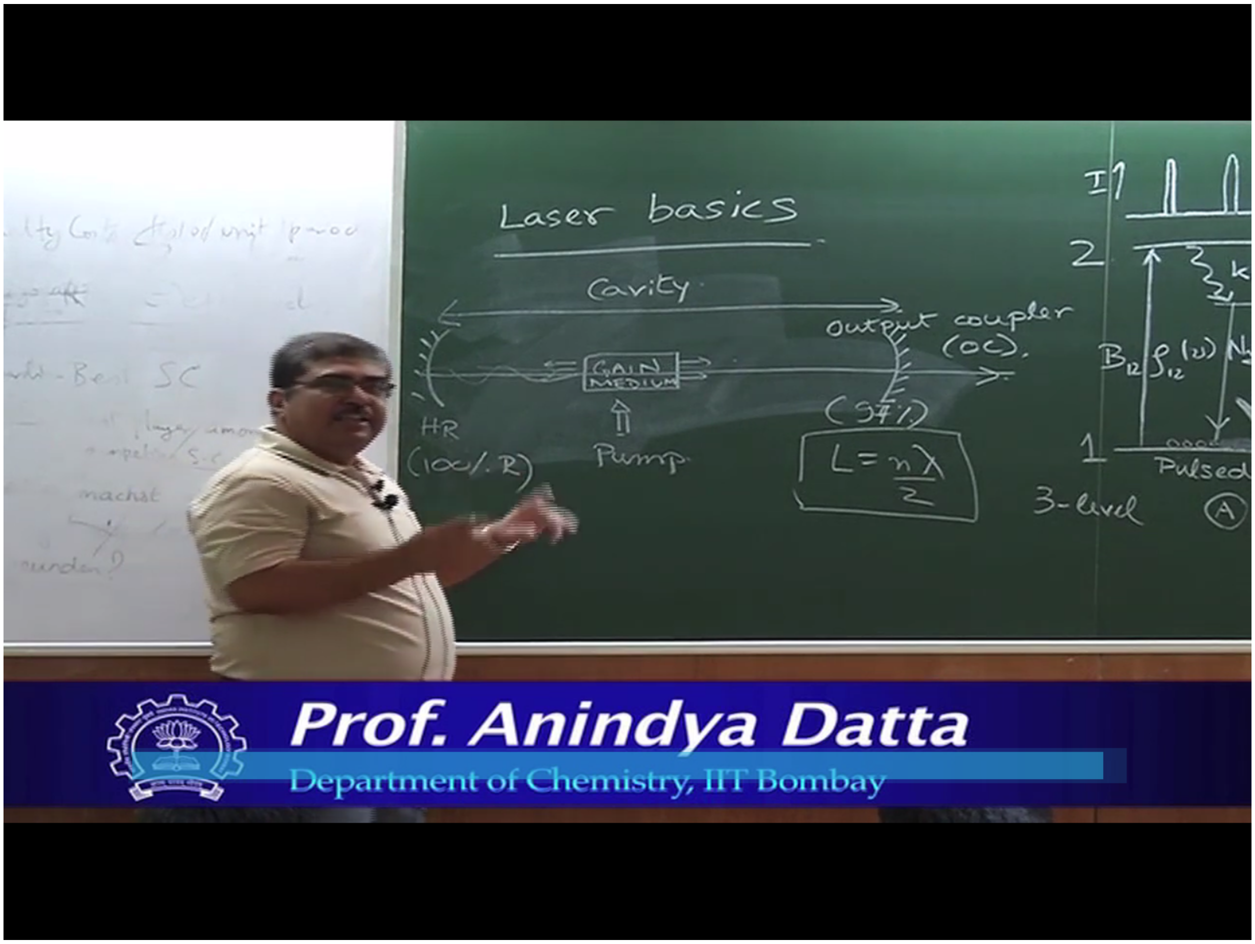
Prof. Anindya Datta
Department of Chemistry, IIT Bombay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