Optical Spectroscopy and Microscopy : Fundamentals of Optical Measurements and Instrumentation

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Lecture - 29

Hello and welcome to the lecture series on Optical Spectroscopy and Microscopy. Until now what we have seen is different kinds of laser mediums that we can possibly use and the restrictions that they that or the conditions that they need to meet in order for them to act as a lasing medium if we have to use them in through optical pumping, right.

The input light source its energy source itself is a light another light. And if you were to use it like that, then there are that provides that has a restriction on the kind of lasing medium that we use. We went through 2 level 3 level and 4 level systems and then we said 3 and 4, it is possible to have though the fourth level laser or lasers are based on the efficient.

So I and also I told you about the threshold phenomena that concise because of the losses existing in the cavity and then how, what it means in terms of the population inversion. Today, what I am going to start with is to give you a real world example of some of these lasers specifically two lasers and tell you how exactly these things operate. And then I will we will revisit this topic, topic of different kinds of lasers as and when it is required during the course, okay.

So it is not very meaningful or fruitful if I just club all the laser’s descriptions all the different laser example descriptions and then put together in one place. But, so for that reason what I am going do is I am going to describe to you just two of them. One because of historical reasons and being the first laser and so on. And second is a perfect example of what I mean 4 level laser system could be.

Later on we will see more examples of 4 level laser systems as we go along in the course. Okay. So the first laser system that we are going to see or we going to talk about is the first laser to be discovered. It is the Ruby laser and it turns out the Ruby laser is a 3 level system. Now what do I mean by that and how is practically that the laser system is achieved.

So if you take a inside view of the laser, then what we would have, as we all know is a lasing medium, alright?

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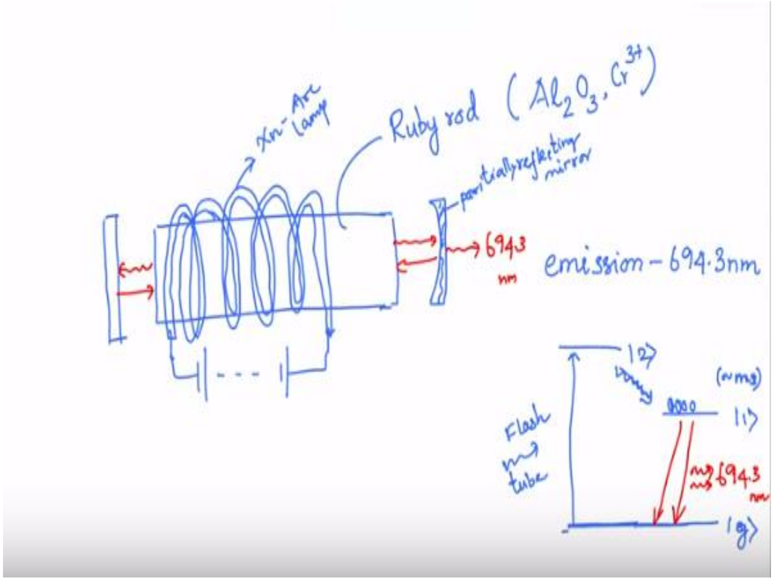

Lasing medium. Now this lasing medium here is it is a solid Ruby rod, okay which as many of you might know is aluminum oxide, Al 2 O 3. Just aluminum oxide may not be of much use. What happens is that here in Ruby the color is because of the aluminum oxide getting doped with chromium ions, okay. It is actually Cr 3+ ions.

So this chromium ions when they are present in the Ruby, I mean present in the alumina gives you this characteristic red color, deep red color. And you take one of those crystals and what happens is that when we look at the structure, the electronic structure, you end up having three different levels, ground state, I mean many levels.

But then the specific thing that we are interested in is the transitions happening or transition that is giving rise to lasing or emission at okay emission at three, I mean 694 nanometers 94.3 nanometers, okay. Now so and the one of the reasons even this was possible is that if you remember, in our three level atom, one thing we demanded is that so this is our ground 1 and 2.

One thing we demanded is that we need to be able to populate these level, right populate this level because the lasing is going to come from here 694.3 nanometer light. Now we need to populate this level right? So the way if we have to populate this level, one thing we want to make sure is that this in flow rate needs to be larger than the outflow rate.

Both by the stimulated emission and by the I mean outflow rate from this level which is, on other words, we want to have a longer fluorescence lifetime from the for the state, and that is guaranteed in this Ruby crystal. Typically, the lifetime of this chromium ions in the state, for the state is of the order of milliseconds. It is a long, really long lifetime, allowing you to be able to really construct this laser.

And what you do is that you actually take this Ruby rod and then the light source that actually takes the molecules the chromium ions from the ground state all the way to the electronic excited state two is your flash tube typically as they are known are clamper. So the as the known at clamp, it is basically a gas tube filled with Xenon okay and we have a discharge tube that has been set up alright.

So this flash lamp it is an arc lamp. It is a it is very intense in white light and this excites the chromium ions present on the Ruby crystal to the excited state and then when the chromium ions then relax back to the state one or the lower electronic state and then due to fluorescence due to spontaneous emission, if there is a fluorescence that gets emitted and then one of the floors and I mean then we put this Ruby rod inside cavity defined by two mirrors.

Then what you have is okay, this is a partially reflecting mirror so that the fluorescent photons that comes out from here ends up traversing between these two mirrors trapped in the cavity, and then a small fraction of that comes out as 694.3 nanometer light. So as we have seen this is very inefficient, I mean it is a beautiful red that comes out. And first it was the first laser. So it is a worth looking into the I mean this details.

However, it is practically of I mean not much use in the present day scenario given the advent of the semiconductor lasers and so on and so forth. Because it is very inefficient it takes in a lot of energy threshold to actually generate light out. It has some interesting properties from a fundamental laser science point of view. We will revisit this laser. Not specifically the design but the laser itself Ruby laser light emission itself in a different context little later in the course.

Now another real world example of lasers and it is of very good use is that of helium neon laser, okay.

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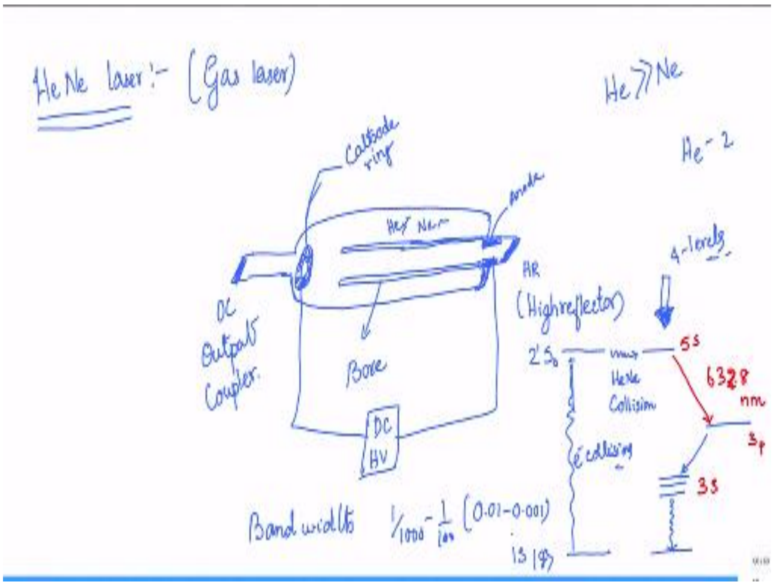

And He Ne laser. This is of interest for quite a few reasons. The one that we have seen before was of solid state laser and that is a three level laser system. Now this helium neon laser is a gas laser. That is to say the lasing medium, it is gas. The laser itself is generated through a mechanism pretty much like that of a discharge tube except inside this discharge tube, you have a special kind of anode and the cathode, okay.

Now alright, so this the ends of the discharged tubes contain special mirrors high reflecting mirrors, okay. Now typically they are kept at a Brewster angle, so let us do that. And then there is a high reflector and the one that is kept with I am sorry. Now the light path will be different, I mean will be slanted to because it is coming at an angle. But so encapturing that we can have we will draw the high reflector something like this.

And this end we call it as OC or output coupler. But the discharge itself I mean the pump or the initial source of energy comes from the discharge that is high voltage discharge that has been set up. However, unlike a regular discharge tube, these are special cathodes, which have which is actually a cathode ring, which is like a doughnut shaped an electrode that is kept and then you also have anode.

Now anode is again, a hollow I mean a cylinder that has been kept. So cathode ring. And in order to ensure that we have a we are able to trap the discharge or increase the capturing of energy in a particular in a directed manner what we do is we also have small physical restriction for and this is also called as the bore. For confining the gas, the helium neon gas that have been ionized helium neon gas to a spatial location.

So you have a lot of helium and neon gas that is present here. And what is happening is that when you energize the cathode and the anode, okay, so and you connect it to your DC high voltage supply. So then what you end up doing is that you end up generating the discharge and ionizing the discharge lamp or the discharge arc and ionizing the gases present.

In response to that quite a few interesting things start to happen giving rise to our laser system. So we can actually write down the laser system or the electronic structure or that corresponds to this in the following manner. So this is basically through the discharge, what you do is that you excite the helium ions that are the helium you ionize the helium and as a result, what you do is that you generate an excited state helium and neon.

So I am going to take a little time to draw this electronic structure so that we can later edit it out. So this is, alright. So we have the if you look at the electronic structure of this helium and neon gas mixture. So we have helium atoms electronic structure that is in the left hand side. Now we know that helium has atomic number of 2. So the ground state to start with is basically the 1s state.

And when you send it through a gas discharge tube what is happening is that you are actually exciting this atoms from the ground state some of them through to the excited state. And the excited state is actually 2s state of the helium. Now this excited state atom, helium atom then collides with neon, okay. Now when it collides with neon, the energy of the neon corresponding to 5s level is corresponds to 5s level.

It is almost similar to that of this. And as a result, what you are I mean with I mean with as a result, what you have, what you end up having is an excited state of the neon that is been generated. And this excited state neon atoms then some of them radiate to 3p state giving out radiation of 632.8 nanometers the energy gap corresponds to that.

Before the 3p atom then collapses to 3s and then finally to the ground state itself, okay. Now the point here is that because of the presence of the helium atom, what you are doing is you are effectively decoupling the pumping in the, so basically what you are doing is that you are not optically exciting this but you are actually exciting this through collision of the electrons with the helium atom.

So you can call it as, okay. Now this causes the helium atoms, see some of them, so because of the discharge you have generated the charged particles the electrons with a very high kinetic energy and so forth. They actually effectively excite the helium ions, helium atom sorry.

Those helium atom actually go into that excited state which then collides with the neon to transfer its energy to the neon resulting in this beautiful laser system which is equivalent of a 4 level system. The level being for first and I mean these two corresponding to the pumping levels of the helium, while the lasing action happening between the neon's higher excited state and then the lower state before it coming back to the ground state.

So now in this gas the neon, the levels that we are dealing with are four numbers so we tend to call that as 4 level though it is not in true sense an optically pumped laser because what you are doing is you are not using a light to take the molecule from the ground state to the excited state but actually you are using the you are generating a discharge and then through the discharge you are transferring the energy from to the helium which then transfers to the neon. So those are the 4 levels.

So in order for this to be effective, you typically have helium, the helium proportion is much larger than the neon in terms of the composition of this gas mixture. But the beautiful part is that you can actually generate this wavelength of light 632.8 to and then if you ask what the bandwidth of such lasers, you can easily get 1 in 1000 I mean 1 in 100 to 1 in 1000 range. That is anywhere between 0.01 to 0.001 nanometer.

Such a high bandwidth, I mean such a low bandwidth such a high frequency specificity together with the power of the I mean the photon density gives the power of the power of I mean gives the power to the laser light or makes the laser light very special. Now it brings to the very next topic of what is so special about the laser light. If you actually look at it, we are investing a lot of energy in generating this light.

And if you have to I mean why is that that we need to invest so much of energy and generate this light and what use is it going to give us and how it is unique is the question that you would like to ask, right. So if you list out some of the characteristics that makes the laser emission very useful then they would be one of the foremost thing that comes to you in your mind is that coherence, okay.

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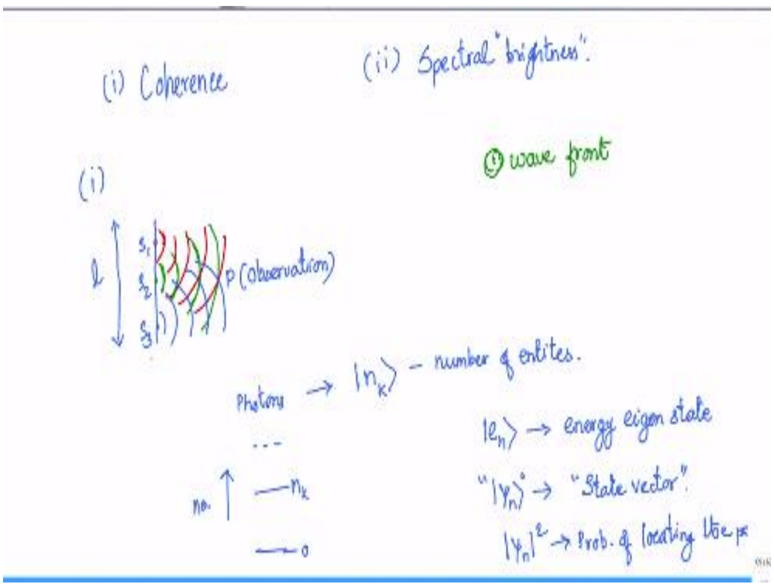

And then what is called as a spectral brightness, okay. Rest every property is basically a derivative of one of these characteristics in my mind. So if you I mean, for example monochromaticity or use say power, when typically we say it is very intense and stuff like that. They are of consequence of one of these property.

And in fact, it is slightly misleading and slightly loosely spoken when you see in terms of if you talk in terms of monochromaticity or high in intensity because a laser light that is coming out from He Ne for example is in the order of milliwatts. But then the incandescent lamp that we have in our, light that we generate from the incandescent lamp or tube light or any other light can mean like a floodlight can be of extremely high intensities.

They run into about watts of hundreds of watts of lights that energy consumption and the light generation that you can think of. So it is not just the intensity per se, but it is a special kind of intensity that makes it really unique and that special kind what is it. And in order to define that more precisely we are going to look at these two different properties property of coherence and property of spectral brightness.

The coherence per se is defined, so let us look at start with coherence. Coherence per se is defined as if you take in the following manner, so let us take an extended source of light. So what do you mean extended source of light? A source of light like a filament or for that matter something in I mean something has a finite extent. Okay? So it is called, it is not an infinite decimal point source.

But it is something has some finite length, let us call that as length l or extent. So now what we are going to do is, let us now this finite source can be thought of having many source points, okay? Now each of them what do we mean by a source point? So I am going to represent each of them with slightly different color, though technically what you are actually talking about is the same color. Same, everything being same.

So just for our understanding or our representation, I am going to use three different colors. So they so now what does this source mean? So these are essentially point sources. So if what you are doing is you are taking a point source and then placing them separated in space by some length dl in space. When you do that, and then we are going to ask how does the light emanate from each of these source points.

So now we can actually represent that propagation or that light the travel of the light in the following manner where I show you as a different emergence of concentric circles with different radii, okay. What does this lines mean? These are the place so we know that if we talk in terms of light source now these lines represent a particular these lines represent a particular property.

The property here we are going to talk about is called as the wave front okay. But what it is, we would see in a minute. But the point is you can think of that the light is emanating from that point and as the distance increases we, distance increases from the source are we can have some finite probability of locating a photon that is originated from this point which is green in color, the green I mean which we are represented in green color.

Similarly, this is we have seen that light source when it is a symmetric right emission, if you are talking in terms of when there is no anisotropic emission and it is tend to be spherically symmetric. It is an all four pi solid angle direction. So red the wave fronts originating from red points can be thought of I mean kind of represented as following, okay. Okay and similarly the blue point alright.

So now this point let this point P be our point of observation. What we see is that three different light sources, the photon could come in principle from any of these three different light sources and as a result if we have to do describe the probability of locating a photon at that point P, we need to be able to describe the probability of the photon distribution from the light source let us say s 1, s 2, and s 3.

At this point, I would like to draw your attention to the fact that we have been treating light so far that is originating from any place through photons right. I mean we are, we have talked about how we can actually give a description of the light in terms of photons and when it comes to understanding the light matter interaction. And then, which eventually led to the idea of generating the photons themselves.

And we saw what we saw was that we can use what are called as Fock states, which are basically number states right. Basically they represent they are related to the number of entities present. Now this tells you that there are I mean a state of n k tells you that there are this represents in a space of number of entities we have a state, which corresponds to like say 0, 1 and so we have n k, alright and so on.

This is n k+1, n k-1 and so on. We also have talked about, I mean this can be photons, it can also be particles where the particles with energy state k and so on and so forth. We have also in parallel talked about energy Eigen states or in general some other states right. So which are like e n's sorry. When we have e n, what it tells you is that this we can think of that as an energy Eigen state.

Or in general, we can think of that as psi n being something called as a State vector describing SS the quantum mechanical system that we are trying to investigate. Now when we try to give a physical interpretation of this states, what we said was that they represent a probability amplitude, and we can think of this probability amplitude varying in space and time. Why do we say that?

It comes directly from bonds of interpretation. And then wherein we said the modulus square represents the, or gives us the probability of locating or the particle or the system, locating the system or the particle in state psi in a given place at any given time. So one way to actually think about the relationship between these two is that when we are actually talking about the number states.

And then this is talking about the, how the total entities themselves are changing or how the total entities themselves are evolving. And we pick one of these entities, and these entities themselves can be associated with a state vector, something like a chi n right psi n. So now when you do that, the psi n itself takes a functional form of a different nature and that is dictated by the potential and the kinetic energy description of that particular system.

So now when you do that, and then you arrive at a state function, that function practically tells you actual that function describes to you a wave of probability amplitude, when you whose intensity corresponds to probability itself of locating the system. So now when we talk about photon here, then we can actually talk about such kind of probability amplitude functions.

And it turns out they are our typical wave descriptions. They correspond to our wave descriptions of the light, electromagnetic light radiation itself or in other words in short, if you want to go I mean if you the connecting link between the photonic description and that of the wave description that we seem to have used it for a long time.

And understood a lot of different properties not I mean is the fact that equating the amplitude of this wave to the square of the amplitude rather to the probability of locating that photon in space and time. So having said that now what we can do is that we can actually start writing and when particularly the intensity, the number density of the photons really become large then we can start writing the description of these systems in terms of the wave functions or the waves themselves, okay.

Now in that spirit, then when we are looking at P here the point of observation, then what we are actually talking about is we finding the intensity at point P or the probability of you locating the photons at point P is proportional to linear sum of all these probabilities or in other words, linear sum of the amplitude functions of the waves that are originating from s1, s2, and s3.

So now what we will do in the next class is that we actually would break this down or we actually will write the corresponding probability function in terms of the amplitude functions, add them up and then arrive at a fruitful and a practical way of defining what we call it as coherence and then see how this is unique. I mean this is in what way the lasers are unique compared to the normal light that we talk about.