Introduction to Quantum Mechanics
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Lecture - 07
Brief description of a LASER

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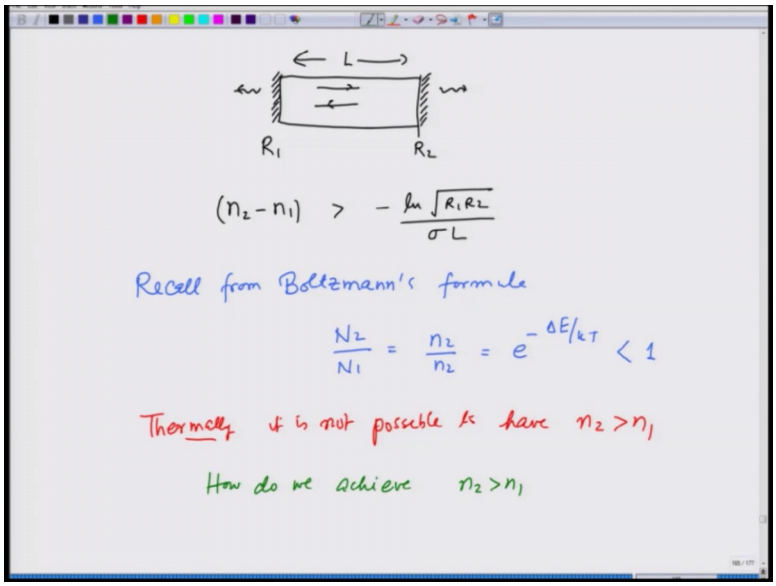

The previous lecture we considered case where I have a cavity with mirrors on two sides with reflectivity R 1 and R 2 and light going back and forth. And what we showed is that if n 2 minus n 1 that is the difference in density of atoms in the upper level and the lower level is greater than minus log of square root of R 1 R 2 over sigma L, where L is the length of this cavity. Then the light gets amplified light which comes out of here or here would be amplified. How do we achieve this, because number one remember recall from Boltzmann's formula that the number of atoms in the upper level and number of atoms in the lower level which will be same as their density also is e raise to minus delta E over k T which is also less than 1. So, thermally it is not possible to have n 2 greater than n 1.

So, let us conclude thermally that means, if you raise the temperature right it as not possible to have n 2 greater than n 1, so something else as to be done and that is what is done in a laser. And what happens then is the light which comes out through stimulated emission has exactly the same properties that makes it come out. So, photon that is

coming in has exactly the same properties that is the photon that makes it come out, and therefore, this light has special property which I will discuss at the end of this lecture.

Right now, let us consider how do we achieve n 2 greater than n 1. So, this is a brief introduction to the laser action and the related technology right for more details you may going to read you know advanced books.

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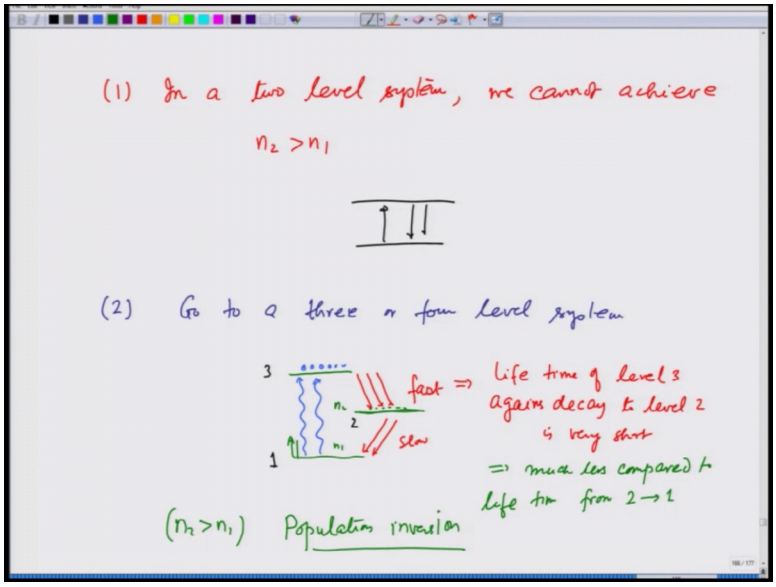

So, now number one in a two level system, we cannot achieve n 2 greater than n 1 why suppose there is a two level system. More I pump to upper level, more the more atoms come down. So, I can never achieve a situation where you know n 2 greater than n 1. So, in two level system I cannot do that. So, one goes beyond to the two level systems. So, go to a three or four level system. So, in designing a laser, I have to choose material properly, so that there are these levels and now I going to show you what kind of property is these should have.

So, suppose I have a three level system one level, second level and third level. What I can do is pump shine light of these frequencies between the first in the third level. So, that lot of atoms comes here. And choose these levels in such a way that as soon as the atoms reach the upper level, they come down very fast. What that means is lifetime of level 3, I am going to name them now level 1, level 2, level 3 against decay to level 2 is very short. And when I say very short that means, this is slow, 2 to 3 is slow; that means much less compare to life time from 2 to 1.

As a result what would happened these atoms that go to the upper level immediately come down here. So, they are getting depleted form here lots of levels are being pumped up and they will be a n 2 and n 1 would be such that I can achieve a condition where n 2 is greater than n 1. So, n 2 greater than n 1 is called population inversion, you have inverted the population from what normally happens in thermal case.

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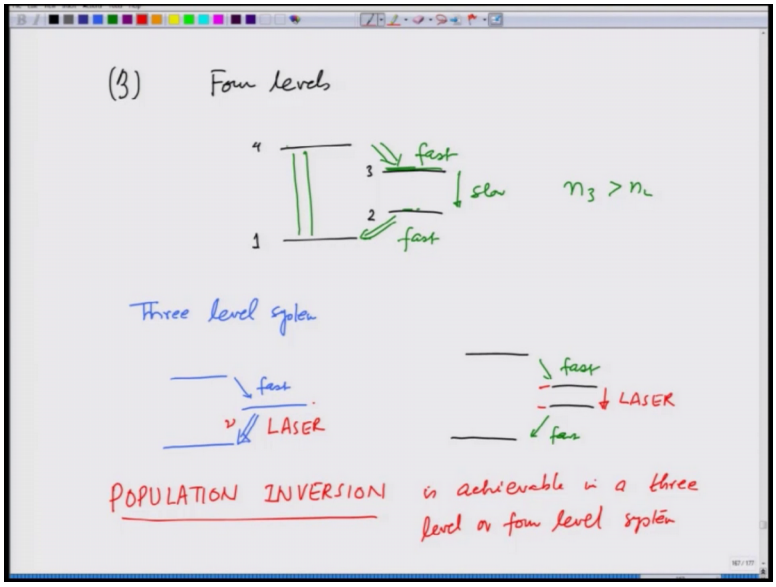

Other possibility is four levels, you have 1, 2, 3, 4. And what you do here is label them 1 2, 3, 4 pump atoms here and make this fast transition make lower transition fast and this is slow. So, what is going to happen is as soon as the atoms reach level 4, they going to come now the level 3. As slowly they come down as soon as they come down to level one and therefore, there is a possibility that number n 3 would become greater than n 2. So, wherever this slow action taken place that is those are going to be the levels for which I can use to amplify the lights. So, in a three level system this is fast and this is going to be laser action. So, laser is going to be of the frequency corresponding to level 2 and level 4.

In a four level system, this is fast. So, is this and level in the middle onward will be laser. So, laser frequencies is going to be the corresponding to the frequency between the these two levels. So, this is how population inversion is achieve. So, population inversion which is a new word now you are learning is achievable in a three level or four level

system, but not in a system that as only two levels their no matter what you do you cannot achieve that.

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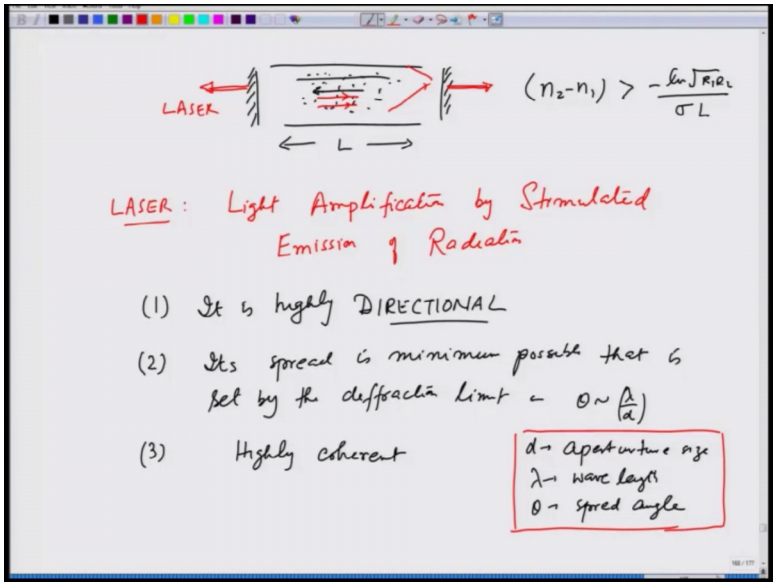

And once you do that, so I have this cavity in which I am doing this population inversion of atoms and suppose I have achieve this population inversion that means, I have achieved n 2 minus n 1 greater than minus log of root R 1 R 2 over sigma L, where L is the length. Then as light goes back and forth it is going to amplified and the light which comes out is going to be that amplified light and these have special properties.

What are the properties, notice number one. Since the mirrors are parallel to each other whatever light comes out is going to be highly directional, any light that goes like this is going to be lost. So, property number 1 and this light which is coming out this laser. Laser means light amplification by stimulated emission of radiation. So, one property is going to have is it is highly directional. Why because you are amplifying the light going in one particular direction, so it is going to be highly directional and also it is so because its spread is minimum possible that is set by the diffraction limit. So, does not spread like a torch light, it is spread very little.

And three and that also happens because this highly coherent; that means, the relationship between phase on different points on the wave front which is known as this special coherence and temporary coherence that is the relationship between phase at one time and the other time. They are very, very stable. And all these three properties make it

a very special light. Let me just mention what is this diffraction limit this is given by theta equals lambda over d, this is a minimum limit where d is the aperture size, lambda is the wavelength and theta is the spread angle. So, this is the minimum spread that is set by the diffraction.

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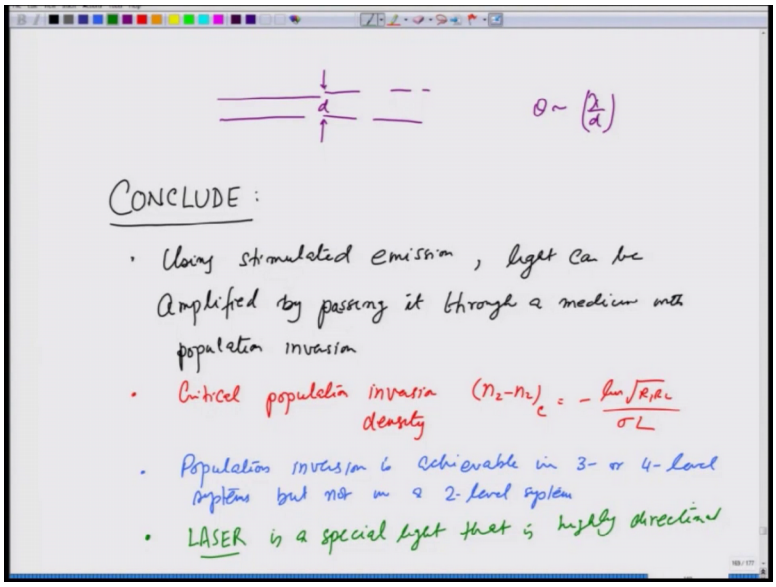

And laser follows this that means if I take a laser beam which is of diameter d, it will spread by angle theta which is of the order of lambda by d, all other lights spread much more because they are not coherent. So, these are special properties of lasers. So, just to conclude this lecture using stimulated emission light can be amplified by passing it through a medium with population inversion to critical population inversion density is given by minus log square root of R 1 R 2 over sigma L, where L is the length of the cavity. Three - inversion is achievable in three or four level systems, but not in a two level system. And four - laser which comes out this amplification is special light that is highly directional.

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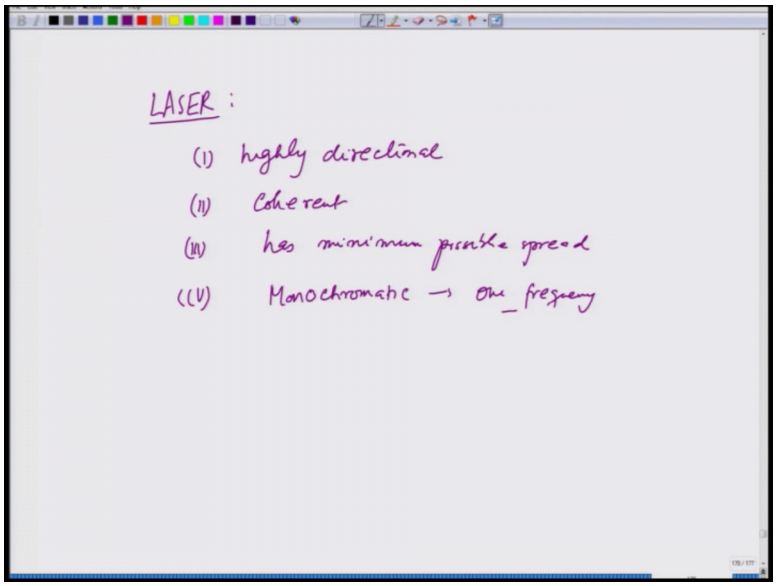

laser is a light, which is highly directional, coherent, has minimum possible spread said by the diffraction limit. And also one they have forgot to mention is highly mono chromatic that means, one frequency. It has on frequency that corresponds to that transition frequency although there is going to be some is spread, but is highly monochromatic compared to all other lights, so that is the special properties of lasers.

So, with this I conclude this a technological application of lasers. Keep in mind that the idea was proposed way back in around mid nineteen a tends. So, 1915, 1914, but the first laser major and laser it was made in 1960s. So, technological advancement had to wait above 50 years after the idea came.

Next, we are going to start the next week the build up to quantum mechanics, and I am going to start with correspondence principal in the first lecture next week.