Laser: Fundamentals and Applications

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Lecture – 29
Non Linear Optics

Hello and welcome back. So, in the last class we started talking about the non-linear optics and we stopped where we were discussing about the mediums polarization and it is relation with the input in electric field.

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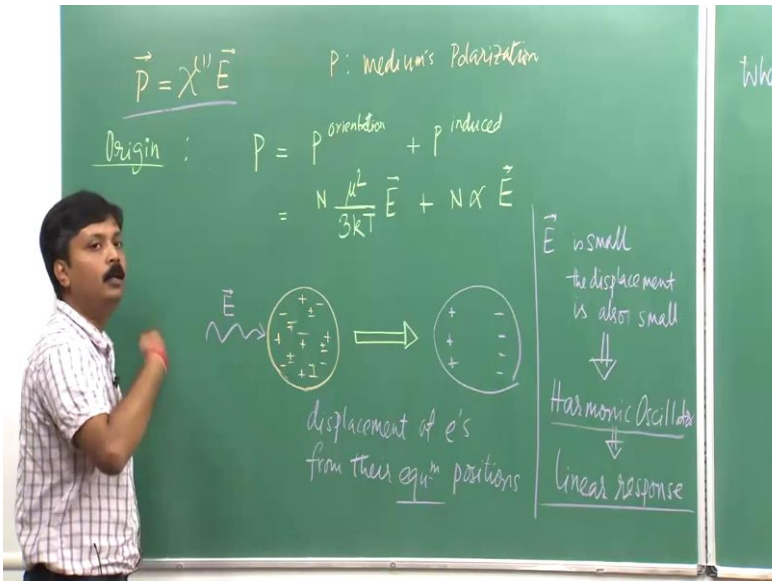

So, we were right here. So, P is given by this equation, where P is the mediums polarization, is the electric field. Now at this point we asked what is the origin of this expression. So, this is the part that we will discuss now. So, this above expression it arises from the fact that this mediums polarization is essentially a sum of 2 different polarizations. One is the orientation polarization, another is the induced polarization.

So, essentially P is sum of P orientation orientational polarization, and P induced or induced polarization. So, this one as we know is given by N mu square by 3 k t multiplied by the E and this one is given by N alpha E right. So, when we taken dielectric and allow the light to interact it is this electric field of light which will interact with the light. And what part of light what part of the material will interact with light is essentially the electrons. So, in an particular medium we can, we can take it like an isotropic distribution of charges that is electrons like this right. So, it is very much isotropic in nature. Now when I have an input light coming associated with an electric field E, the response is the creation of an anisotropic right.

So, what is the meaning of the picture shown here, when the light interacts with this matter in equilibrium. Here of course, one thing is obvious that the electrons in the matter will be displaced from their equilibrium position right. So, in this picture it was isotropic and some electrons are here, now here everything is like moving in this direction all the electrons. So, this essentially nothing but the displacement of electrons from their equilibrium positions, this disturbance created by the light will if the electric field of the light is very small, then this displacement of electrons will be very small. So, when E is small the displacement is also small.

So, the periodic nature of the light oscillation will cause this displacement also to be periodic in nature right. So that means, there will be an oscillation of this electron position with respect to it is equilibrium position. And this behavior will be pretty much similar to an harmonic oscillator. This is quite simple to understand, if the disturbance is small the displacement will be very small and this displacement in both the direction with respect to the equilibrium positions will follow an harmonic oscillator model.

Now, if that is true then of course, my response is also linear and of course, I have seen that when the E is small I have a fairly linear relationship, linear response in terms of the polarization. So, this is essentially clear creation of a polarization. So, everything is well understood when the electric field of light is small.

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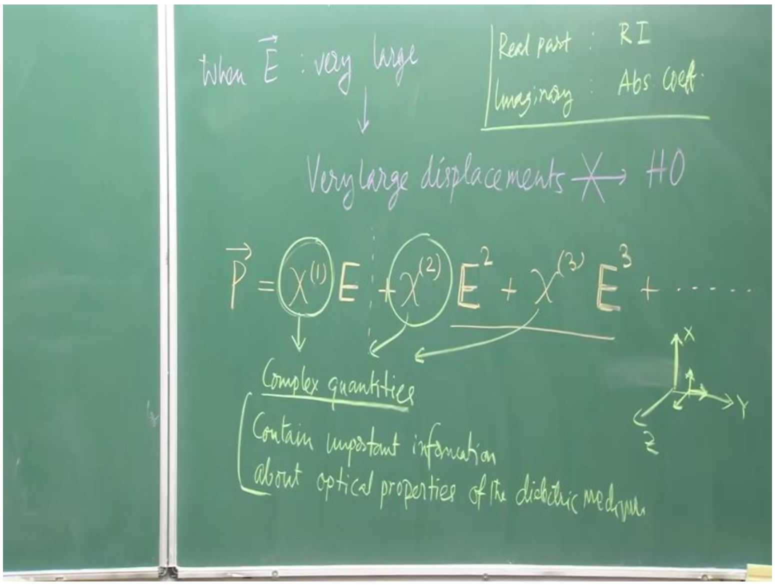

What will happen if I increase the electric field of light to a very large value? So, so when E is very large as large as that comes from a pulse laser, then what will happen? Then electric field is very large. So, this will be just opposite to this effect where small E creates a small displacement. So, very large electric field will cause very large displacementRight.

So, if the electrons move very far with respect to their equilibrium position then what will happen? Then I do not have the same condition as I was having earlier that is I will not have the condition of an harmonic oscillator. So, instead I will have an harmonic oscillator model acting there, when I have very large amount of this electric field. And so, this harmonic oscillator approximation is no longer valid. In that case I cannot express my polarization by this simple linear equation anymore. Because I have an harmonicity in my electronic oscillation right. In that case I have to redefine my polarization as following.

So, if there is there is an harmonicity in my electron oscillation created by large electric field of light then this polarization I can expand by using a power series on the electric field and I can write it keeping my usual linear term. So, I am writing a bold and so on. So, you can clearly see that beyond this limit the response of the medium in terms of it is polarization is nonlinearly dependent on the electric field. So, either square cube and high terms. This is the region of non-linear optics. Let us try to be even more specific in this regard. So, before we go further let me tell you one thing about this susceptibility chi these are very very important quantities in optics. Because these chi which are normally complex quantities and they contain several important information, particularly about the optical properties of any material mostly deal with dielectric material. So, they contain important information about optical properties of say the dielectric medium. One more important aspect of this chi is, so is that they are tensors.

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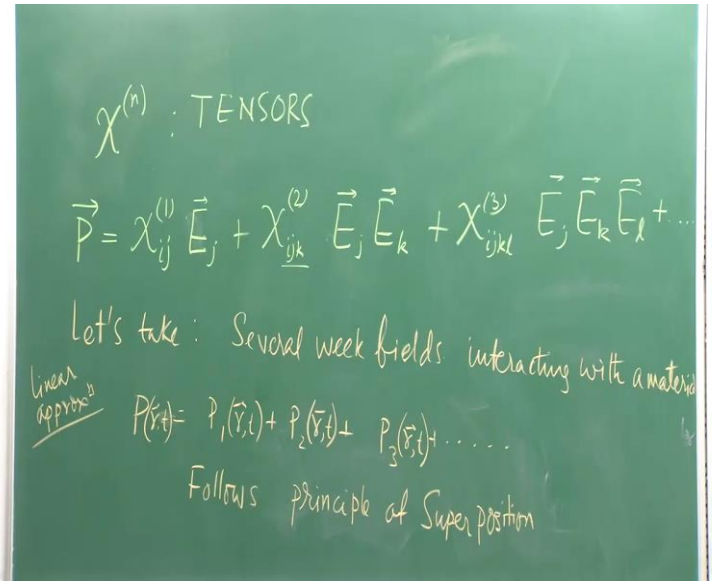

So, they are tensors, why? Why am I calling them tensor? Think about the situation I bring in an electric field oscillating in a particular direction. So, I have a linearly polarized light. So, my field is along the direction of this polarization correct. So, suppose I have an electric field in x direction it is not all not necessary that it will induce oscillation of electrons only along x direction. It can also induce oscillation of electrons along a y or along z fine.

So, that is why this chi which dictates the polarization is a tensor. So, if we want to elaborate this one, then you know whatever we discussed it resolves from the fact that when I have this electric field causing the oscillation of the electrons. That not only feels and recoil or restoring force in that particular direction that is x if I say the incident electric field is polarized along x direction. So, so suppose this is my x this is my y and this is my z direction. So, if a incident field is along x direction I said that not necessary the electric or you know electrons also will oscillate in this direction they can oscillate along this direction they can also allow you know oscillate along this direction.

Now, why is it so? This is because when I apply this electric field here this electrons not only feel that in this stirring force in this x direction alone because of the excitation field, but also it feels the effect of the neighboring molecules or atoms. So, those neighboring molecules and their molecular field will also dictate that how much polarization is created you know how much electron oscillation will take place in this direction or in this direction which are definitely not the same direction as that of the incident field.

And those information is contained in this quantities chi’s and that is why they are known as tensors. They are they relate 2 vectorial quantities electric field and the polarization and they dictate in which direction the electron oscillation will take place. So, if I consider this fact then I can no longer write the expression in this simple manner, because I have already understood that this is not a simple quantity, but this is this is a tensor quantity. So, I need to rewrite this one.

So, before I rewrite one more thing I will mention that I say that they contain this important information about the optical properties of material. So, what kind of information? So, they contain information about the refractive index of the system, they contain information about absorption coefficient of the medium. So, as I said this is a complex quantity. So, chi of any order, so here within the bracket these numbers they refer to the order of the process. So, this one means it is a first order process which is a linear phenomenon and second order third order process no processes and these are known as the susceptibilities of certain order in. So, this is second order susceptibility third order susceptibility and so on. So, these are complex quantities it is they have a real value as well as imaginary part. So, the real part of this chi. so, if I can use this space. So, the real part of chi it will give us information about the refractive index of the medium. While the imaginary part it will give me the information about absorption coefficients. We will not talk too much detail about those things, but we should know at least that part.

So, with this knowledge and knowing that this chi’s or susceptibilities are tensor quantity let us rewrite this expression in the correct way. So now, I have polarization is equal to chi a first order sorry E plus chi of second order j k chi of third order and so on. Why did we write like this? Because chi is a tenser and tenser will define the directionality of the electron oscillations. And I must specify the cartesian components of the particular susceptibility tensors. So, this is how we write the expression for polarization in general way.

Now if we have a situation where we have, so let us take a condition where we have several weak fields interacting with the matter, with a material what will happen? It will create polarization. So, each individual wave will create it is own polarization and in the linear approximation I can write the total polarization P as P 1 plus P 2 plus P 3 So on. So, this is under linear approximation right. So, I can be very specific here by putting this as r is a vector and also we have time. So, when I can write this expression this means that the interaction of this weak fields with this material it follows the super position principle. So, the case of many weak fields interacting with material follows principle of super position super position right.

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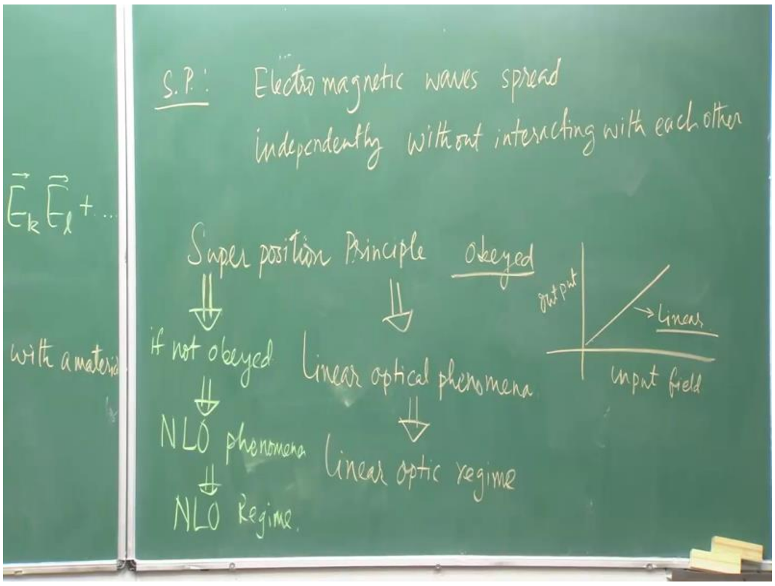

So, what is this principle of super position? So, super position principle it says that electromagnetic waves spread independent without interacting with each other. So, what does it mean? It means if I put light through the material and if I put several such slides having several different electric fields having low field strength. In that case it will follow the super position principle and super position principle says that all these waves will interact with the material independent of each other and each wave will not talk to another wave.

So, there is no interaction between these waves no mixing of this wave. So, note this term I am saying that there is no mixing of waves are allowed. And the superposition principle where I can write the total polarization in terms of just a sum of individual polarization created by each of this waves. As long as the light metal interaction obeys super position principle the phenomena the related phenomena or optical phenomena is known as linear optical phenomena and we are in the regime of linear optics.

So, if the super position principle is obeyed. So, super position principle obeyed I have linear optical phenomena. Like we have linear absorption scattering reflection refraction. And a direct implication will be obtained in your observable where if you have the input field strength and if you measure the output, what you will see you will see a behavior like this and this is linear. So, the response will be totally linear when the light metal interaction for low's super position principle we obtain all this linear optical phenomena and we say that we are in the regime of linear optics, linear optic regime. So, by now you must have understood that when this light metal interaction do not obey superposition principle. So, I have said that this is obeyed when it does not obey I have optical phenomenon known as non-linear optical phenomena. So, if this one if not obeyed what I have is non-linear optical phenomena and we are in the non-linear optic regime.

We can have several different types of non-linear optical phenomena. Now what I will do I will first give you couple of example before going in to the detail of different non-linear optical phenomena for example, like second order third order non-linear optical phenomena and so on. So, we will give you just 2 brief examples. So, by the way when I said that this you know when it is not obeyed then I have I am in the non-linear optical regime. So, we can easily understand just by comparing with my earlier discussion in the linear optics that in this case when it does not you know obey super position principle that; obviously, mean then now different waves can interact. So, they can be mixed together and that is exactly the basis of non-linear optics, we will see in a while. So now, coming back to the context that is we are going to see a couple of examples of this non-linear optical phenomena.

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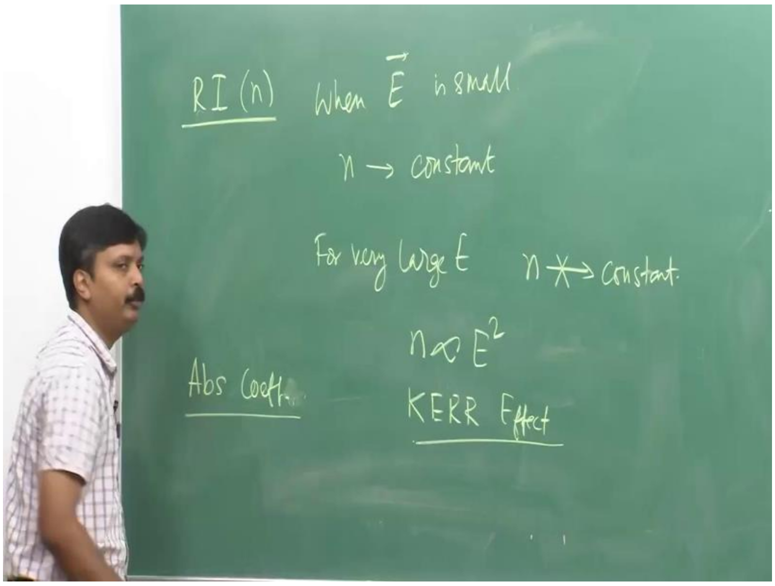

So, the first example is like refractive index of the medium. So, the refractive index as long as the electric field is. So, refractive index we write it by N right. So, when electric field strength is small N is fairly constant, when E is large, for very large E N is no longer a constant. So, in that case what happens N varies with the square of the electric field you are familiar with this term because in one of the last lectures we mentioned about this one and we say we said that this is known as kerr effect when we are discussing about pockel cells that time we mentioned about this particular thing.

So, this is called kerr effect and this is a non-linear optical phenomena. So, refractive index as long as the E is small is a constant the moment that I increase the intensity like a bring in laser it starts varying as the square of the electric field amplitude of the light. So, this is one case another incident is the absorption coefficient, as long as absorption coefficient. So, as long as the intensity is very small I have absorption coefficient we can measure it from lambert P s law. When I increase the intensity no longer the lambert P s law is valid and we incorporate non-linearity in to the system. We will come back with you know much detail about different orders of nonlinearity and how these you know optical nonlinearities are applied in the following lectures.

Thank you very much.