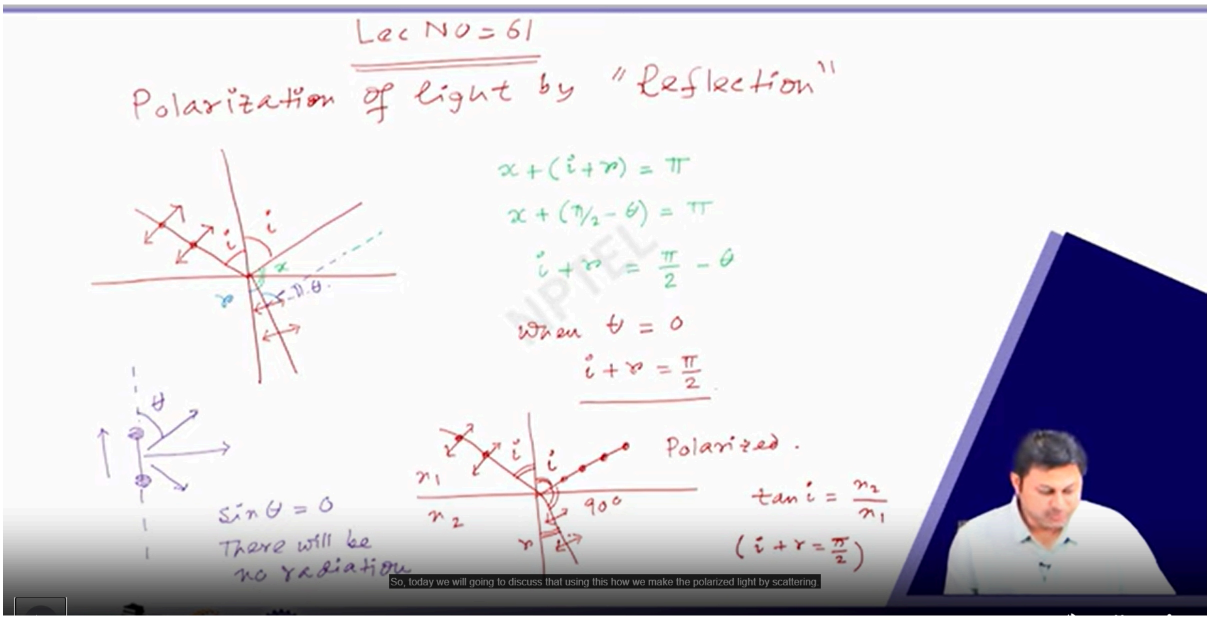
WAVE OPTICS

Prof. Samudra Roy
Department of Physics
Indian Institute of Technology Kharagpur

Lecture - 61: Production of polarized light (cont.)

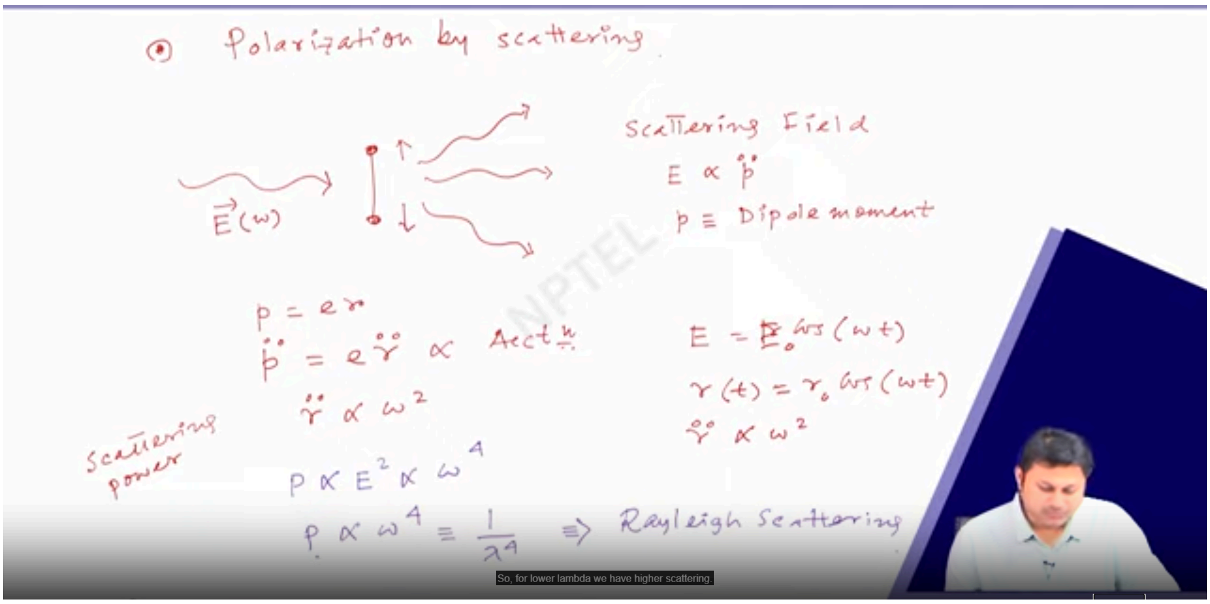
Hello, student, welcome to the wave optics course. Today we have lecture number 61 and we're going to continue with the way we polarize the light. So today we have lecture number 61. So, in the last class we discussed how we can polarize the light by reflection. So let me do it once again because that will be useful to understand how we can polarize the light by scattering. So polarization of light by reflection. We have already discussed this. Let me do it once again. So, when we calculated the Brewster law. So that was the incident light having polarized light like this and that was the transmitted light, where the electric field vibration was this. So, when the electric field vibrates in this direction then it will vibrate the molecule in this direction and it is going to radiate this, so, these are the dipoles basically and suppose it is vibrating in this direction. So if it is vibrating in this direction it will radiate along this direction, along this direction, along this direction but the amplitude of this thing will depend on the theta. If it is along this direction then what happened? So if I write this as a theta then when sine theta is equal to 0 that means along this axis of dipole there will be no radiation. So, here the dipole is vibrating this direction and if I write this is my theta then it is radiating along this direction. So I am going to get a component in this direction which is perpendicular to which is like this. Now if I try to understand what is this theta in terms of initial angle. Suppose this is my i, so this angle will be i, then say this is my r and this total angle is 90 degree because this line. So the total angle from here to here is 90 degrees. So what is this angle? So let me define this angle, yellow line if I write it as x for example, so, x plus, i plus, r that has to be angle pi and this angle x and this is theta and it is 90 degree.

(Refer slide time: 08:50)



So x plus, because this dotted line and this red line and this dotted line, this dotted line and this line they are parallel to each other. So x plus this angle which is pi by 2 minus theta should be pi as well. So what I have is i plus r, from these two i plus r will be equal to pi by 2 minus theta that I get. Now, what happens if theta equal to 0 that means, that is the direction. So, when theta is 0 then the dipole that is vibrating along this will not be going to radiate any radiation along this side. So, that is the condition one can achieve when I plus R is pi by 2. That is a very special condition. And that special condition we derived in the last class. So, let me draw it. So here I have this radiation, this polarization and when it enters it has this vibration but here because this angle is 90 degree whatever the radiation it generates because of the vibration of the dipole. So, this component will not be there. So, whatever the radiation will have in the reflected ray will be only this component and that is polarized. Now if this is n 1 and n 2 we calculated that this incident angle should be such that tan of i will be n 2 minus n 1 in order to have i plus r equal to pi by 2 this condition needs to be there. So, this is r and this is i. So, that condition we achieve only to make theta equal to 0 such that no radiation is there. So, that we discussed in the earlier class. So, today we will discuss how we make polarized light by scattering. So, similar concepts will be there. So, today we are going to discuss polarization by scattering. So, what happened in the scattering let me draw it once again. When the electric is coming which has a frequency say omega and it falls on a system where we have dipoles and these dipoles will start vibrating, so there is a vibration of the dipole and we know that when the dipole vibrates it start radiate, so radiation will come out from this dipole vibration and this is scattering field, this scattering field E will be proportional to P double dot that we need to know and what is P? P is a dipole moment. Now P is charge e multiplied by the distance r during the electric field, when there is a dipole then there is a separation of the charge. So this separation is r. So if I write p double dot, it should be essentially er double dot that means it is proportional to acceleration. Now r double dot is proportional to the omega square how I get because of the electric field. If I define this as r cos omega t, sorry, e naught cos omega t then r which is a function of time will be also represented in this Lorentz model.

(Refer slide time: 13:47)



So, r double dot will be simply omega square is proportional to omega square from here we can get. So, scattering power big P is proportional to the electric field square and that should be proportional to omega to the power 4. So scattering power is essentially proportional to omega to the power 4 or 1 by lambda to the power 4 and that is our well-known Rayleigh scattering. So, what happens is that this power, whatever the power we have scattering power, will be proportional to 1 by lambda square. So, if lambda is small then the scattering power will be high. So, for lower lambda we have higher scattering. So what happens when the light is falling to some system and this is an unpolarized light. Suppose it is falling and it will be this polarization will allow the molecule to vibrate along this direction and this direction, so this is unpolarized light. So what happened? If I look from a certain direction which is perpendicular to that, then we can see only one polarization that will come from this vibrating molecule. Why are we going to explain? We have already explained that in the previous calculation. So this will be polarized or partially polarized. One can quickly understand this by considering that this is a Sun emitting radiation and here we have our earth surrounded by an atmosphere like this and this is our earth. So the radiation that is coming from the Sun actually comes here and it is unpolarized, so both the components will be there and let me draw this component like this. So, when it interacts with the atmosphere what happened that suppose we have a molecule here and this molecule will vibrate either this direction it will vibrate, this is one way it can vibrate this is the molecule that is vibrating maybe I can put a different color to make these things, so this is molecule it will vibrating in this way or it can vibrate in this way I mean perpendicular to this. So let me erase this, it will vibrate this direction. So this is the direction I am talking about in this way perpendicular to the page of the paper. So when the molecule is vibrating this way it will not be radiating anything here. If I draw quickly that if this is a dipole if it vibrates on this side no radiation will be there, the maximum radiation will be perpendicular to this radiation, so no radiation will be here. On the other hand when it is vibrating perpendicular to this, then there is no problem, we can have radiation for this vibration. So from here what we see is the light that is scattered from this and comes to earth will no longer have this component, only this component will be there. Same thing happens in the opposite direction when the light falls in the opposite direction and when I look at the thing from here we will see that only these components will be there even though there is unpolarized light that is coming from the sun but only these light are partially polarized. So this is the way when we have scattering then there is a possibility that we get a polarized light. This is one way to polarize the light. This is the sun and this is the earth. So now let us go forward and see what happened for other cases. I mean what is the other way. So another way to polarize the light is by birefringence. I listed that in the earlier class. So polarization happens for optical anisotropic crystals. The optical properties are not the same in this kind of crystal. So optically anisotropic crystals are such that anisotropic crystals are such optical systems or optical material for which the optical properties are not same. in all direction that is I can draw a schematic figure that I have a electron cloud and I have a spring mass system like this considering that electron are vibrating at the presence of electric field but the vibration of the electron is different in different directions. Suppose this is one direction, this is another direction and this is another direction; suppose this is my x direction this is y direction and this is z direction. So, schematically we represent the binding force of the electron cloud in a different direction and like a spring with different spring constant the vibration of this electron cloud is no longer the same in all directions when in the subject to the application of an electric field. So that system can lead to anisotropy because the property is not the same in all directions. So that basically leads to the optical anisotropy. In very simple way I just try to explain without going to a detail analysis of how its works and all these things which is not required at this stage because that is not our topic I just try to make you understand that how this optical anisotropy arises in optical system and simply if this anisotropy arises because of the different optical property in different directions that is the way. So, a simple example of this system because of this. So the direct consequence is that. So because the binding force is different, the refractive index is different in different directions. So whatever the value we have for suppose we have a crystal here like this and if I assume the axis like this x, y and z. So if I move along x direction, if I move along y direction and move along z direction the refractive index may not be same and that is the main feature of an anisotropic crystal and this kind of crystal is essentially called the birefringent type of crystal or in general this property is called the birefringence. T So, in case of birefringence what happens if I draw the refractive index profile. So, this refractive index profile for x and y will be different. For example, if I draw a refractive index profile with respect to omega and then this is the way the refractive index is plotted it goes up and then there is absorption and it goes down. So the point where it goes down is called the absorption band. So suppose this is the absorption band and this is ny, the refractive index along y direction if I plot the same thing for a birefringent crystal, one can see that maybe this value is different and one can get a refractive index profile where the absorption pin shifted some place. So the point is with respect to omega if I plot nx and ny they no longer coincide. For isotropic systems they coincide but for anisotropic systems they no longer coincide. So, for this kind of system what happens is that in two directions we have two kinds of refractive index we get a property that if I launch a light. So, in one case the refractive index will have the electric field see one refractive index and in another direction the refractive index will see another refractive index. So, the propagation of the two components of the light will no longer be the same because the refractive index is different in two different directions. We do not have much time to discuss more about how this birefringence should work. In the next class, however, what we do that we will discuss this more to assuming a specific crystal which exhibit this kind of birefringence and try to analyze how the electric field when the electric field is propagating this system, how the different component of the electric field will experience different refractive index or different velocity and we know that when the two different component, two perpendicular component rather experience two different velocity, so there will be a phase lag between these two components and when there is a phase lag so whatever the light you launch and whatever the light you receive, they may not be in the same polarized mode. So that means utilizing this crystal, we change the polarization. Maybe from linear polarisation we get circularly polarized or different kinds of polarization. So that means we produce some specific polarized light by exploiting this kind of material where by using the refractive index we basically use the phase relation, we differ the phase relationship between x and y components and get the result. So with that note I would like to conclude here thank you very much and see you in the next class.