WAVE OPTICS

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

Lecture - 52: Polarization of light (Basic concept)

Hello, student, welcome to the wave optics course. Today we are going to start a new topic which is polarization of light and we are going to discuss the basic concept of polarization in this lecture. So we have lecture number 52 today. And we start a new topic: polarization of light. So by definition polarization of light is nothing but the direction of the electric field vector E and if I draw that. Suppose I am drawing an electric field sinusoidally varying electric field and that is normally the way we draw. So in this plane, suppose the electric field is vibrating and this is the direction of the vibration of the electric field. So if I write this direction as x direction and this direction as z direction. So, the E electric field E, in the vector which is a vector quantity I can write as some amplitude E naught with a unit vector and then cos of say kz minus omega t, that is a propagating wave and this is the way we represent it. When we represent that then this is the direction of the polarization of the electric field. So E is associated with a plane monochromatic electromagnetic wave as I mentioned which is perpendicular to the direction of the energy that is carried which is Z. So here the direction of the E and the propagation direction which is defined by K is perpendicular to each other. In the electromagnetic field E and B they are mutually perpendicular. So if I draw, suppose the magnetic field associated is vibrating along this direction. So, E cross B is a direction along which the energy is flowing. So, E and B if they are polarized along this direction then the energy will always be flowing in this direction. So, generally the polarization can be divided into a few categories, linearly polarized, circularly polarized, elliptically polarized, etcetera.

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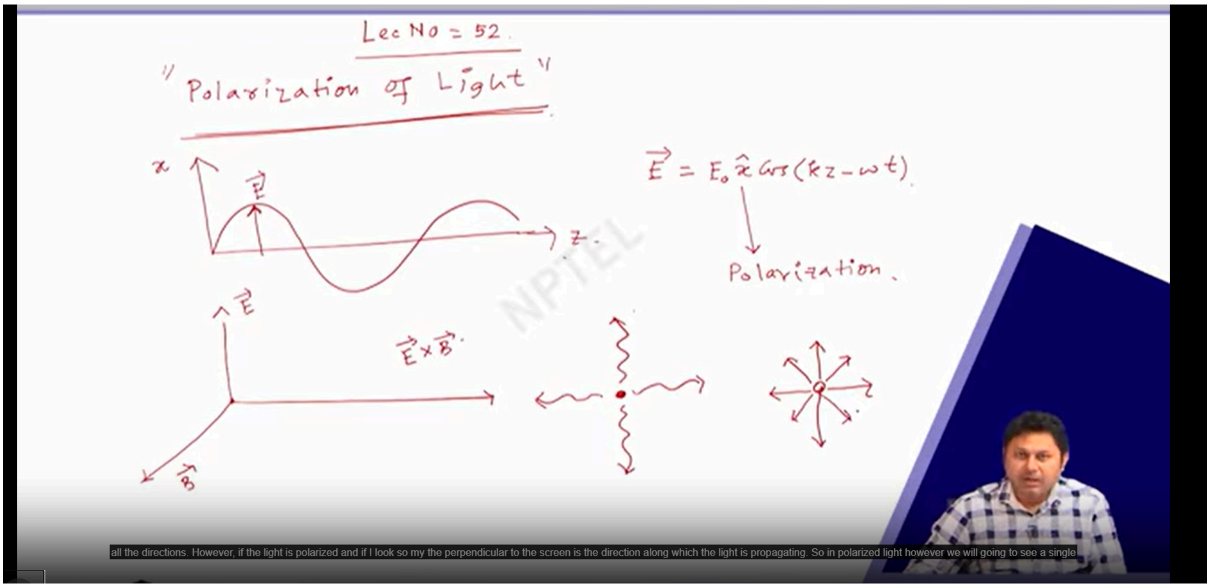

But before going to that critical problem, we need to know that polarization normally occurs when the source is emitting light, suppose this is a normal source, say sunlight, it is emitting light in all directions. So, the electric field that is coming through this light is randomly polarized. So, the direction of the polarisation is not unique, it is changing randomly over the descent, that is in general the case. So, whatever the light in real life we observe, they are heavily unpolarized because their polarization direction is not uniquely defined in a particular direction. Rather, it is changing all over the space. If I look at a random polarized light, it will be polarized in all possible directions and pictorially if I show it will be like this. So the electric field that is vibrating is showing all the directions. However, if the light is polarized and if I look so my the perpendicular to the screen is the direction along which the light is propagating. So in polarized light however we are going to see a single line and this is a typical polarization, linearly polarized light that is the way the electric field is moving. However, there are other categories also that are polarized but this electric field no longer will be, they will be rotated in either direction and that is what we are going to discuss in today's class. So first let us start with the simple thing and that is linearly polarized light. So, linearly polarized light, how are we going to define it? Let me first draw the coordinate system because polarization is all about the direction. So, we have to be very careful about drawing this electric field. So, x, y and suppose this is z. So, the electric field suppose it is in x y plane. So, my electric field this which is lying in a x-y plane. If that is the case I can write E as two component E x which is varying with respect to time and z, so I can write this is a function of z and t and unit vector x plus e y which is function of z and t y unit vector where e x, x component of E is varying with respect to z and t as I mentioned. So, it can be represented as some amplitude 0x cos of kz minus omega t. So, this is the way it is varying, E y on the other hand I write a different amplitude for the time being 0 y E 0 x not necessarily equal to E 0 y in general they are different, but in special case they are same and then we have cos kz minus omega t and I add a phase over that plus phi that is very important because the component E and the X component of the E and Y component of the E they may not travel with a same phase. There may be a phase lag and depending on the phase lag actually it depends whether they will be forming a linear or circular polarization.

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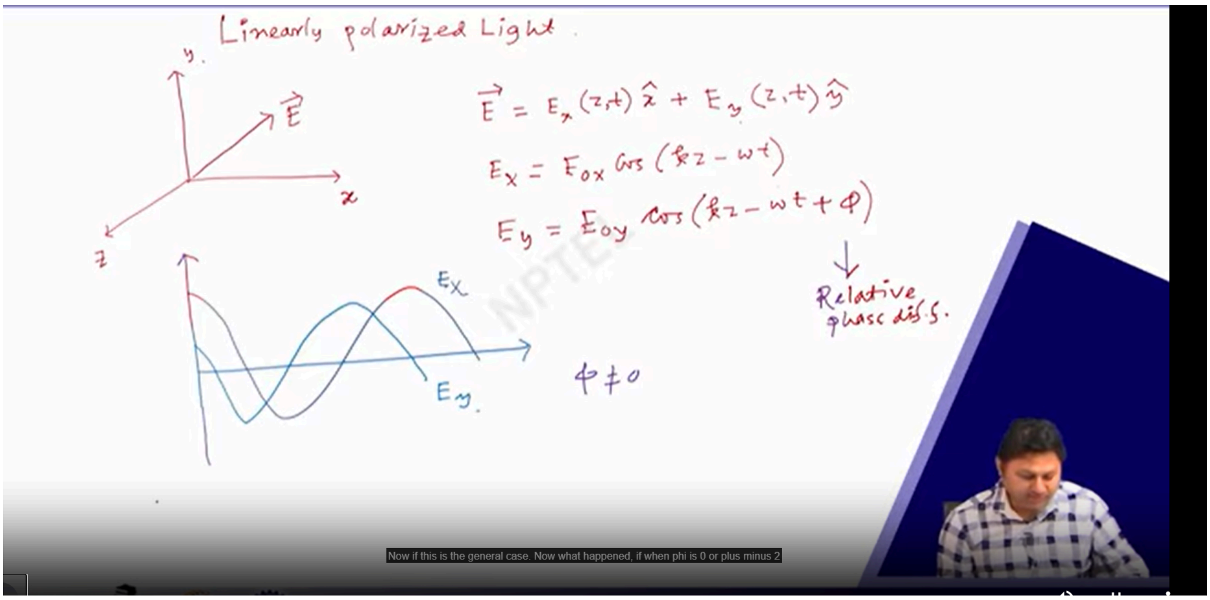

So this is the relative phase difference between the waves. So this is the relative phase difference we are having. Now if I plot how these things are working. Let us plot it, so and say this is the way ex is changing and I draw another this is the way ey is changing. But you can see that there is a constant phase difference between them and that arises when phi is not equal to 0. If phi is 0 they will superimpose to each other and that figure I will show and if this is not they will not superimpose to each other there will be a phase delay. Now if this is the general case. Now what happened, if when phi is 0 or plus minus 2 2 pi n then these two waves are in phase. So I can write my electric field in this way, e is equal to e 0 x, x unit vector plus e 0 y, y unit vector and since the phase is 0 or 2 pi n, I can write it as cos of a common term cos of kz minus omega t. Okay, so how the figure will look like here because they are now having the same phase. So the electric field, this is my y-axis and this is my x-axis and this is the z-axis. So the x-axis is a cos-axis it will be vibrating like this and in the y-axis it will be vibrating like this and this will be E y and this will be e x and the resultant will be the total electric field E. Now if I imagine what is the resultant, we can see that, let me draw here based on this figure, this is my y axis and this is my x axis. In figure 1, both are 0. So, I am going to get a tip here where the electric field is 0 at this point. Now gradually the elliptic field is increasing both for ex and ey. So i'm going to get a small increment here and this is figure 245 degree angle then in another case what happened that it increases more in figure 3, then it increases to a maximum that is precisely this point, where we have Emax and the resultant E will be along this direction this is the resultant E. Here in this point the electric field will be like this and this and the resultant electric field will be along this direction. So let me go back to this. Now what happened? So this is case four. In case five what happens is that this will go to 0, again will be going down actually, it will go up and then it goes to 0 and then from the next half it will go in this direction and go to a maximum. So from z direction we can see there is a vibration along 45 degrees in this way. Along 45 degrees or not it depends on what is the amplitude of E x and E y but it will vibrate in this direction.

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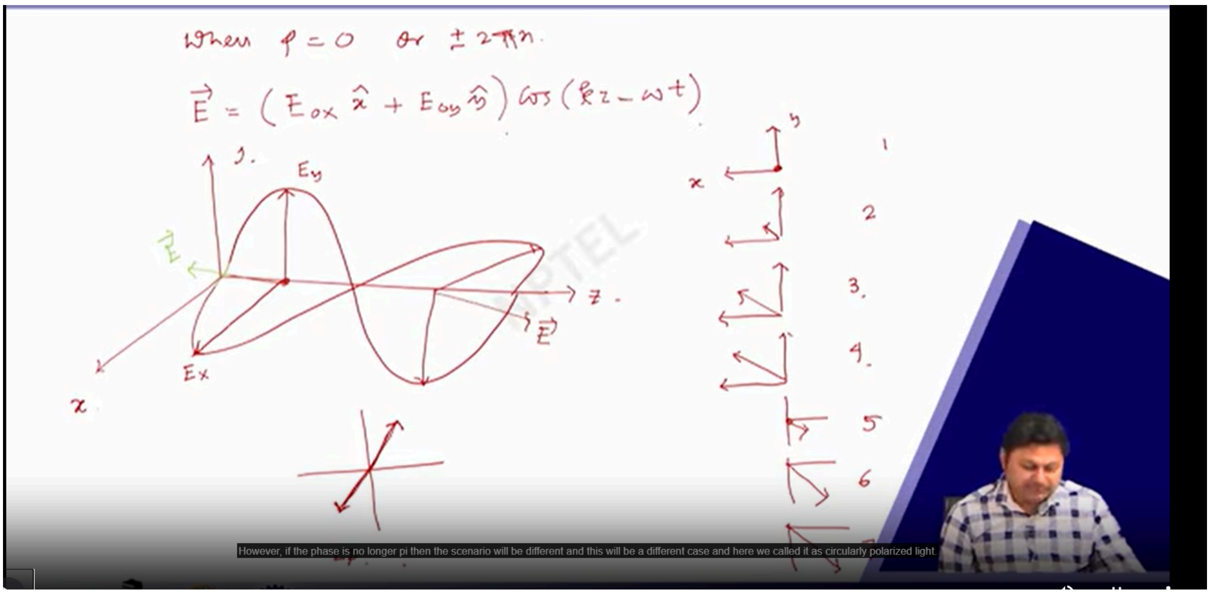

Since it is vibrating in one direction, we call this linear polarization or in short form it is called LP. However, if the phase is no longer pi then the scenario will be different and this will be a different case and here we call it as circularly polarized light. So again go back to

our original expression e, the electric field is defined as ex, x unit vector plus e y, y unit vector assuming the electric field is in the x y plane. Now e x, this x component I write e 0 x cos of kz minus omega t you can write a sign of kz minus omega t also and ey will be e 0 y cos of kz minus omega t and then a phase phi that we need to add. So this is the most general expression of the electric field by dividing it into x and y components. And x and y components are also a function of z and t because this is a sinusoidally varying propagating field and we write this as sinusoidally varying. Now I have two conditions. One condition is here that E0x is equal to E0y to some value E0, that is condition 1. I put a very special condition that these two are the same. And the second condition I put is that phi is 2 m pi minus pi by 2 where m will be 0 plus minus 1, plus minus 2 etcetera. If that is the case, then my e x and e y, I can write as e x is simply e 0 cos of k z minus omega t and e y will be e naught sine of kz minus omega t. Now instead of cos it becomes sine and also e and e 0 x and e 0 y they are the same that is the condition we put. Now the total electric field if I write E that will be simply E naught and then x cos kz minus omega t plus y sin kz minus omega t. So that is the total electric field. Now we need to understand what kind of electric field the amplitude is for e x and y components but their variation is different, one is cos and another is sine. So that means there is a pi by 2 phase difference they are having. So if I draw this thing together then for E y it starts from sine. So I am going to get a sine function like this. But for cos it will be like it comes from the maxima and it will be 0 here. It is going to maxima here. This point goes to 0 here, so this is a cos function, so this is e x and this is a sine function, it will be e y and there is a phase difference pi by 2 we are having. So it is moving in this direction. So if I take k common then it should be z minus ct, where c is a velocity omega by k. Now if I look, try to find what happened in a three-dimensional view then ey. So let me first draw this x y. So the x component is a cos function. So it goes like this and along y direction it is a sine function, so it goes like this. So here when we have a minimum for x function, for y function that is a maximum. So this is the way. Now it is important to find what is resultant. So let me first this is e of y and this is e of x and along this direction it is moving.
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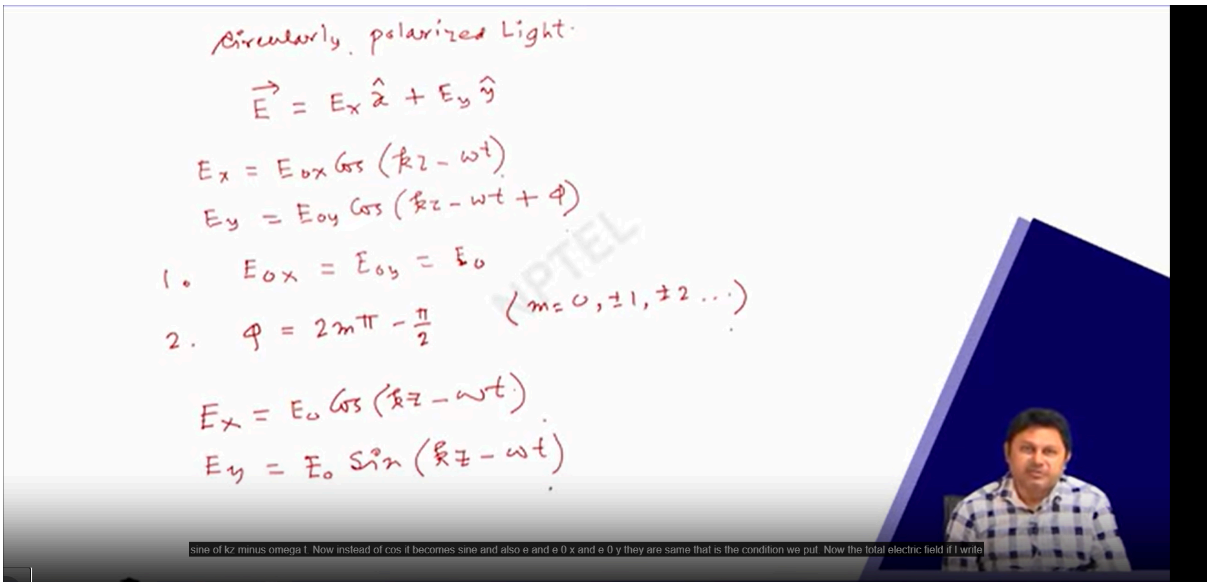

Now if I calculate the resultant then what happened, let us quickly see. So e x is equal to e naught cos of e naught cos of kz minus omega t and if we have EY minus of E naught sine of kz minus omega t, this minus sign will come depending on what phi value we are getting. Suppose the phi value is such that we are getting this minus sign then at z equal to 0, at z equal to 0 and at z equal to 0 plane over the time if I want to find, so at z equal to 0 plane we are looking. So this is when t is equal to 0. So, t equal to 0 at z equal to 0 plane for this condition what we get? We get that E x is maximum, that is E naught but E y is 0. So, the resultant will be along this direction. This is the resultant electric field if the electric field distribution x y distribution is like that. Now what happens if I gradually increase the time and when we increase the time then E and when z equal to 0 plane, if I increase the time, then it should be sine of minus of omega. This is minus will come out and it will be plus. And then what happened that for increasing t, ex will decrease and ey going to increase. So that means I will get a result somewhere here. This is at some point say pi by 6 omega. Then I increase the t more and I put it equal to pi by 3 omega. And when I put 3 pi t equal to pi by 3 omega, I can find what is the value. And if you do that, you will find the resultant amplitude will be somewhere here. And finally, we put t equal to pi by 2 omega, that is omega t is pi by 2, when omega t is pi by 2 then the sine function will maxima and cos function will 0. So, I will get the result somewhere here. This will be my result. So, here you can see the tip of this arrow is moving in the left side. So let me write down what the e x value here is. So at t equal to 0 e x was e naught and e y was 0 this case e x was e naught root over of 3 by 2 and e y was e naught half in this case e x was e 0 by 2 and e y was E0 root power of 3 by 2. In this case, Ex was 0 and Ey was E naught. Note, in all the cases, the magnitude was E0. The magnitude is always E0. This is the x-axis and this is the y-axis in all the cases. So, this is for this kind of electric field distribution when E is equal to E naught x unit vector cos of, let us put at z equal to 0 okay. Let me write for the general one then I'll do that kz minus omega t and then minus y sine of kz minus omega t. So, this is called left circularly polarized light. T And we can readily have with z equal to 0, the picture I had here, then E will be E naught x cos of omega t plus y sine of omega t because there was a negative sign that's why this will become positive and it will move.

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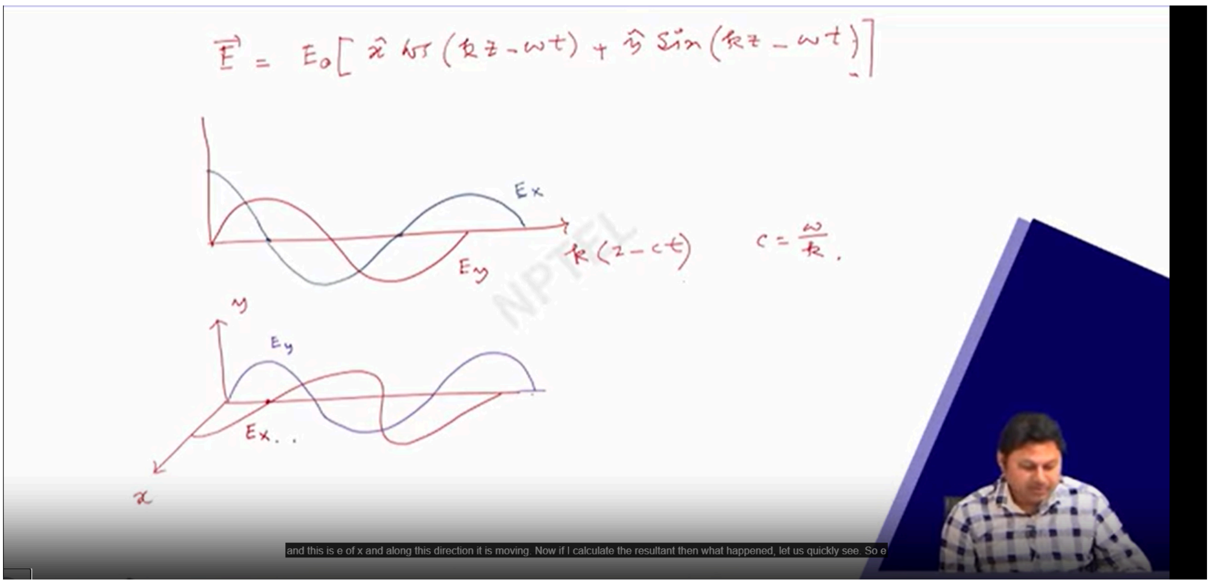

So if I draw a circle here, then this is the way the electric field is going to move. At this point it will be when t is equal to pi by 4 omega. At this point it will be pi by 2 omega. In a similar way here we have, so over the time here it is t equal to 0. Starting from t equal to 0, the electric field will rotate along this left direction. So this will be 3 pi by 4 omega this will be at pi omega, electric field tip here will come at 5 pi by 4 omega. Here it will be 3 pi by 2 omega. At this point it will be 7 pi by 4 omega and again we will come back to this point when we have 8 pi by 4 omega or 2 pi by omega. So in this way today we understood how, so the electric field for circularly polarized light changes its direction and in this case we find that it is moving in the left direction that is why I call the left circularly polarized light. Today I don't have any time to discuss more about the circularly polarized light. In the next class, however, we are going to discuss how the left circularly polarized light is the way the left circularly polarized light appears, how the right circularly polarized light can change by changing the sign, that is the phase. If I change the phase from positive to negative, then we are going to get the right circularly polarized light. So, with that note, I would like to conclude today's class. Thank you very much for your attention and see you in the next class.

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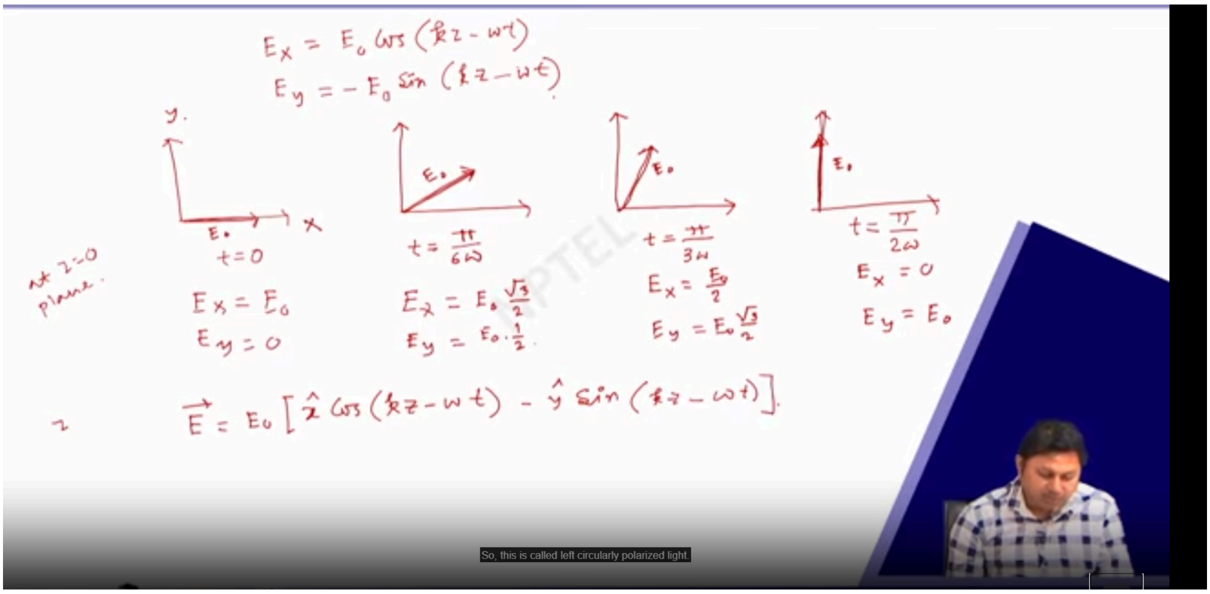

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