Applied Optics

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Module: 3
Lecture: 14

Introduction To Polarization, Linear And Circular Polarization

Hello everyone, welcome again to my class. In last class, we talked about superposition of waves. Now, since with the start of the superposition of wave we also get exposed to the interference, but before starting interference, I feel that we must have the knowledge of polarization. Therefore, today I will introduce polarization.

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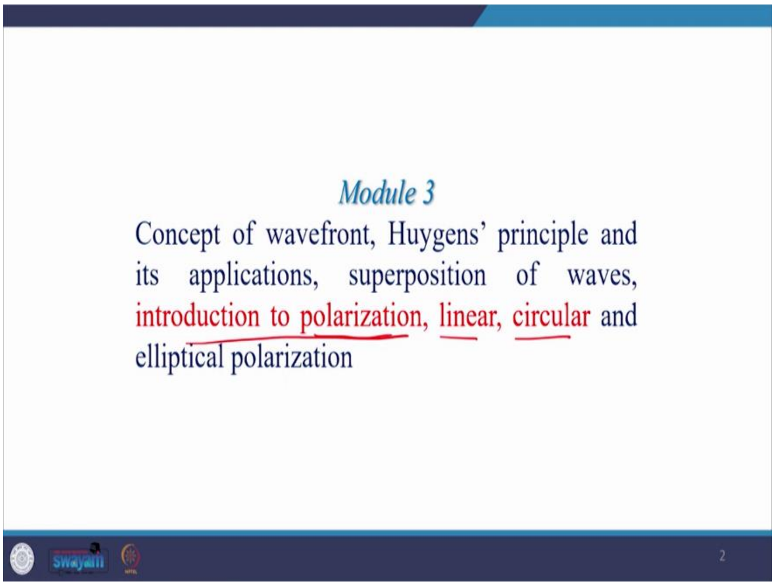

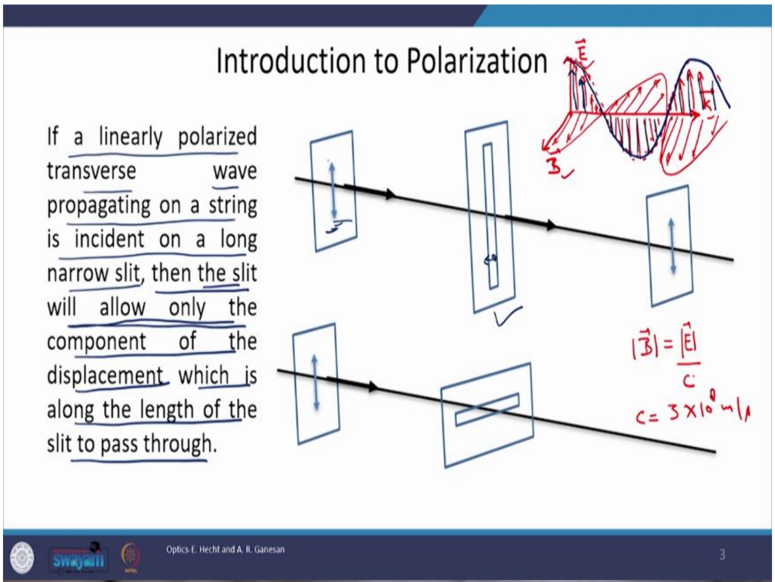
Introduction to Polarization
If a linearly polarized transverse wave propagating on a string is incident on a long narrow slit, then the slit will allow only the component of the displacement which is along the length of the slit to pass through.
Optics E. Hecht and A. R. Ganesan
3



And in polarization we will talk about linear polarization and circular polarization, we will cover elliptical polarization in the next class. Now, suppose we have a wave here we always associate the polarization with transverse wave, but in transverse wave we know that there is a electric component and magnetic component. Transverse wave is made up of electric field and magnetic field and both these fields must be time dependent and they propagate in certain direction.

A wave is set to be transverse if its electric field and magnetic field they both are oriented perpendicular to the direction of propagation as well as these two fields must also be perpendicular to each other. Alternatively, what we can say is that E, B and K (wave vector) all three must be perpendicular to each other.

And polarization is always associated with the direction of vibration of E because we know the electric field is a time dependent field in electromagnetic wave therefore, it will keep varying its magnitude is a function of time, it will slowly reduce down and then it will change its orientation and then it will increase in a reverse direction and then again will go down and that’s how it oscillate, the electric field vector will oscillate slowly.

Similarly, the B field will also oscillate in a plane which will be perpendicular to the E field, B field will oscillate in this plane, the perpendicular and E field is much stronger than the B field and the magnitude of E is related to B through speed of light in vacuum, it means electric field E, the magnitude of E is c times stronger than B and what is the value of c? c is 3×10^8 meter per second, a very big number.

And there is therefore a huge difference between the magnitude of electric field and the magnitude of magnetic field. Therefore, when we shine light on some object then it is electric field which interacts with the object dominantly and the interaction of magnetic field would be much weaker.

Now, since the dominant component is electric field, we associate polarization with the E field. Therefore, whenever we say polarization, it means a quantity which is directed along E the electric field. Now, you see that in this figure the electric field oscillations, let us pick different color.

The electric field oscillation traces a curve and which is in a plane here and this plane is plane of the paper while the magnetic field oscillation traces a curve which is again in a plane, but this plane is perpendicular to the plane of the paper. Now, the plane created by electric field oscillation is in the plane of the paper.

And if we say that polarization is along E then with propagation this polarization is creating a plane. And therefore, this particular type of polarization is called plane polarization or the wave is said to be linearly polarized wave or plane polarized wave. Now, if a linearly polarized transverse wave propagating on a string is incident on a long narrow slit as is shown here.

This is opening of certain width and a wave who is polarized linearly and it is oscillation, the direction of polarization is along the length of the opening, along the length of the slit then hole of this oscillation will pass through and if there is some rotation of the oscillation or of this narrow slit.

Then it will stop the component of the wave, it means or we can say that the slit will allow only the component of the displacement which is along the length of the slit to pass through and if the slit is allowing this particular oscillation, then we can say that, at that instant the electric field is oscillating along the length of the slit.

And such a slit will convert an un-polarized light to a polarized light or more accurately to a linearly polarized light or to a plane polarized light. Now, what is the difference between un-polarized light and linearly polarized light then?

Now, we know that an electromagnetic wave is a transverse wave and it has a certain direction of propagation and perpendicular to the direction of propagation we have electric and magnetic field orientation. Now, since E electric field and magnetic field are functions of time they will keep changing their amplitudes.

But they may take any orientation while propagating along the medium they may at one instant of time they would be oriented like this while on the other instance they may take this orientation, in the next instance they may take this orientation, the orientation of electric and magnetic field is completely random.

And if this is the case the wave is set to be un-polarized, while a wave which propagates like this are a waves in which the electric field vector, the oscillation of electric field vector, traces a plane with propagation such a wave is called linearly polarized light or linearly polarized wave or plane polarized wave.

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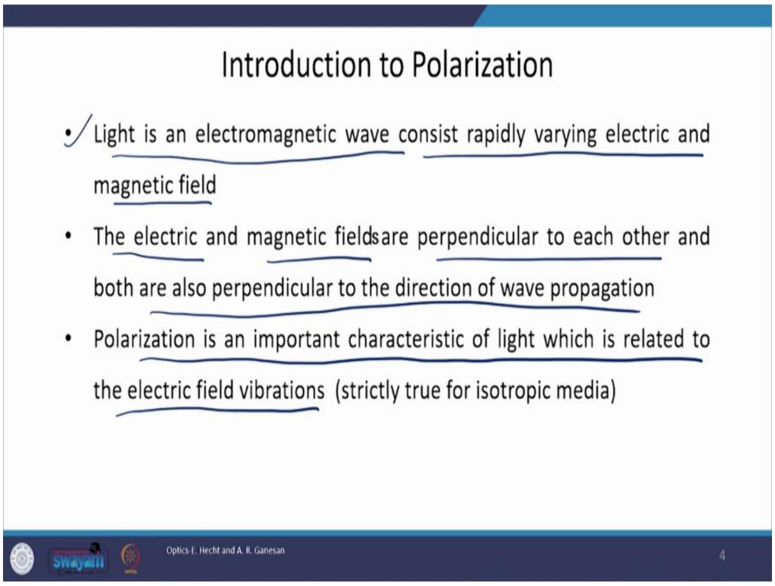

Now, let us go deeper into this concept the first thing which we should understand is that light is an electromagnetic wave and it consists of rapidly varying electric and magnetic field. Since electric and magnetic fields are time dependent therefore, they vary very rapidly. The electric field and magnetic field are perpendicular to each other this we have understood and they both are also perpendicular to the direction of propagation of wave. And polarization is an important characteristic of light which is related to the electric field vibration.

It is always along the E field orientation. But, this statement is strictly true for isotropic media. As discussed earlier isotropic materials are materials in which the properties of the medium are not direction dependent. The isotropic medium will have same property in this direction as well as in this direction as well as in this direction. In all the directions the isotropic material will exhibit the same properties while in anisotropic material, the optical properties of the material become direction dependent and these materials are called anisotropic.

Now for isotropic material this definition holds very good, we will talk about anisotropic material in our later classes. But for now on it is correct to associate polarization with the direction of E field, why, because E field is dominant as compared to the other field, which is our magnetic field.

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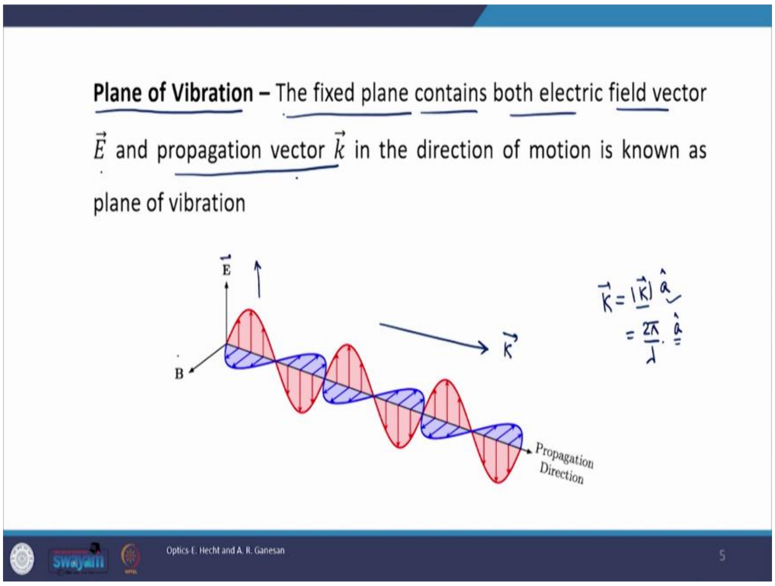

Now, before moving ahead, we must understand what is plane of vibration. The plane of vibration is defined as a fixed plane which consists both electric field vector E and propagation vector k. And from this figure what you can see is that the red curves shows the evolution of tip of electric vector, while the blue curve traces the tip of B fields the magnetic field. Now, this vertical direction is the direction of E and this is the direction of propagation the direction of propagation is represented by propagation vector K and K is this and a unit vector say $\hat{a}$.

A unit vector is a vector quantity which indicates the direction and mod of K is K which we already defined which is equal to $2\pi/\lambda$ and the vector nature is coming from this $\hat{a}$ (a-cap) which is unit vector which is in the direction of propagation. Now, using E and K we can trace a plane and this plane is called plane of vibration.

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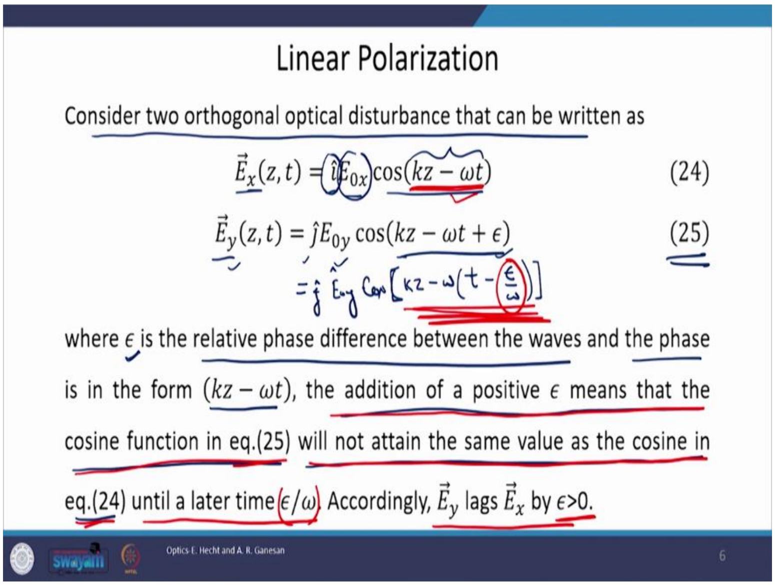

Now, once the plane of vibration is understood let us move further in understanding the concept of polarization or in particular linear polarization mathematically. Now, consider two orthogonal optical disturbances first is $\vec{E}_x$ and second is $\vec{E}_y$, x and y represents the direction of vibration, it means that $\vec{E}_x$ represents a field which is oscillating along x-axis and $\vec{E}_y$ represent, represents of field which is oscillating along y-axis.

And $\vec{E}_x = \hat{\imath}E_{0x}cos(kz - \omega t)$. $kz - \omega t$ is phase, E_{0x} is amplitude and $\hat{\imath}$ is nothing but unit vector along x- axis. Similarly, the expression for $\vec{E}_y = \hat{\jmath}E_{0y}cos(kz - \omega t + \epsilon)$. Here again ĵ is nothing but unit vector along y-axis, E_{0y} is the amplitude and $kz - \omega t + \epsilon$ is phase.

But here ϵ (epsilon) is the relative phase difference between the two waves and the usual phase is in the form of $kz - \omega t$. Now, the addition of a positive phase which is ϵ means that the cosine function in equation number 25 will not attain the same value as the cosine in equation number 24.

Let us understand it in a different way we can write equation number 25 as $\hat{\jmath}E_{0y}coskz$, let us take ω out of the bracket and then we will have $t - \epsilon/\omega$ this is the modified expression. Now, if you compare equation number 24 with this modified expression then what you see is that, what you see is that in question 24 the phase part is $kz - \omega t$ while in this modified equation 25 the phase part is $kz - \omega(t - \epsilon/\omega)$. This ϵ/ω factor is being subtracted from time, it means in equation number 25 the overall phase is running slower, it is a behind and this is what is, what exactly is being said in the line here.

The addition of a positive ϵ means that the cosine function in equation number 25 here will not attain the same value as the cosine in equation 24 until a later time ϵ/ω, equation number 24 has this phase it evolves in time and the same phase would be achieved by equation number 25 only after an additional time and this additional time is ϵ/ω which clearly says that equation number 25 is lagging behind equation number 24. Or in other words $\vec{E}_y$ is lagging behind $\vec{E}_x$ provided ϵ is larger than 0. $\vec{E}_y$ lags $\vec{E}_x$ by ϵ. Now, if ϵ is negative quantity then $\vec{E}_x$ will lag $\vec{E}_y$.

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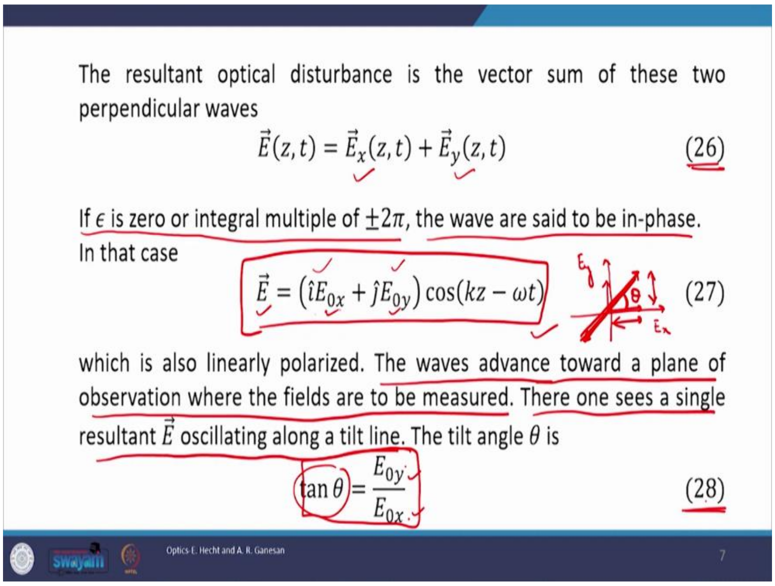
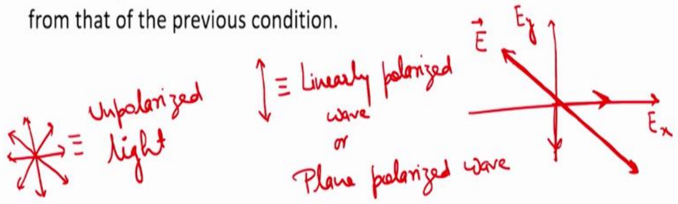
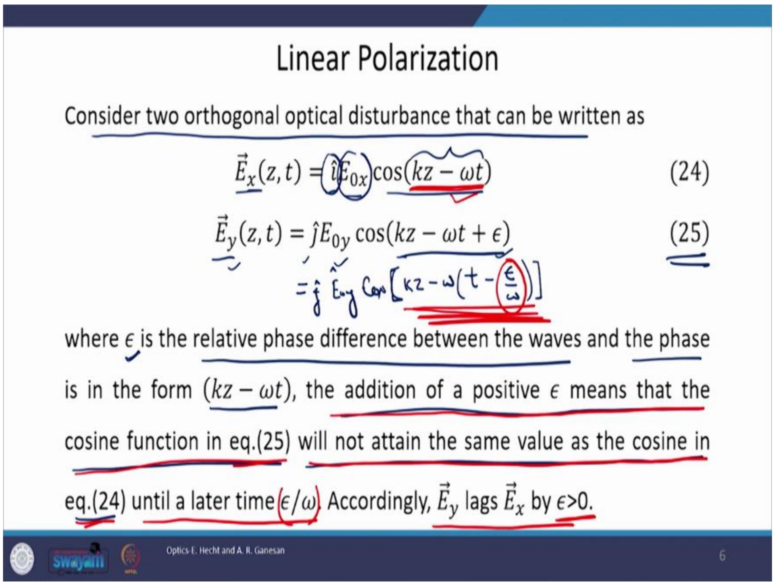


If ϵ is an odd integral multiple of $\pm\pi$. The two wave are 180° out of phase and

$$\vec{E} = \left(\hat{\imath}E_{0x} - \hat{\jmath}E_{0y}\right)\cos(kz - \omega t) \tag{29}$$

which is again linearly polarized but the plane of vibration has been rotated from that of the previous condition.





Now, let us calculate the resultant, how to calculate the resultant? We will again resolve to superposition principle, we will add these two waves now as in the previous slide we assume that these waves are orthogonal and these are the fields which are a vector quantity and therefore, we will have to take into account this vector nature and this addition would be vector addition.

Now, here in equation number 26, we are adding $\vec{E}_x$ and $\vec{E}_y$ vectorally. Because these are two perpendicular components $\vec{E}_x$ is perpendicular to $\vec{E}_y$. Now, if ϵ is 0 or integral multiple of 2π, the waves are said to be in-phase. We know it, we understood it in our last lecture. Now, in the case when ϵ is either 0, ϵ is our initial phase, if ϵ is either 0 or multiple of $\pm 2\pi$, integral multiple of $\pm 2\,\pi$.

Then the resultant will have this expression which is given by equation number 27 and the resultant $E = (\hat{\imath}E_{0x} + \hat{\jmath}E_{0y})cos(kz - \omega t)$. Now, what is the state of polarization of this resultant wave, how to know about this? Now, you see that it is a vector addition, we are adding $\vec{E}_x$ and $\vec{E}_y$ then let us plot it, if you plot it if let us put $\vec{E}_x$ on x-axis and $\vec{E}_y$ on y- axis.

Now, the magnitude here is E_{0x} along x-axis and E_{0y} along y-axis, there would be some magnitude here in x direction and some magnitude here in the y direction and the resultant would definitely be pointing here and the resultant will oscillate in first and third quadrant here, this would be the oscillation direction of the resultant.

That would again be a linearly polarized wave because the resultant oscillation is again linear it is confined to a certain plane and with propagation this linear oscillation will generate a plane therefore, this wave is plane polarized or linearly polarized. The waves advance towards a plane of observation where fields are to be measured.

There one sees a single resultant E oscillating along a tilt line. You see that the resultant is oscillating here, but it is tilted by an angle θ. How to know θ? Very easy, this is how we can calculate θ. How it is done? We have two part $E_{0x}cos(kz - \omega t)$ and in $E_{0y}cos(kz - \omega t)$, y/x will give us the angle.

If we want to calculate θ, how to calculate? Take y component and divide it with x component. The y/x value will give you tanθ this is what is done here, $E_{0y}cos(kz - \omega t)$ is kept in numerator and $E_{0x}cos(kz - \omega t)$ is kept in the denominator and cos cos will go away and then tanθ would be equal to E_{0y}/E_{0x} which are nothing but amplitudes of $\vec{E}_y$ and $\vec{E}_x$ respectively.

From here we can get the orientation of the resultant $\vec{E}_y$. Now, this angle as you can see from equation number 28, it depends upon the amplitudes. Now, depending upon the relative amplitude of the two wave the resultant will change its tilt, the θ value will vary and this variation would be directly proportional to the relative amplitude of the two waves.

Now, let us consider another case. Till now, we were considering that ϵ is either 0 or integral multiple of 2π. What if ϵ is an odd integral multiple of $\pm\pi$. Under this case, the two waves will be out of phase by 180 degree or π radian and the resultant now will be expressed differently and this is expressed here by equation number 29.

And the difference between the previous resultant disturbance which is given by equation number 27 and this new resultant is that there is a minus sign instead of plus sign. Here in equation number 27 you see that there is a plus sign while in equation number 29 you see there is a minus sign, how would it introduce a difference?

Now, let us again plot $\vec{E}_x$ and $\vec{E}_y$, $\vec{E}_x$ here and y component here what will happen here? The plane of vibration now the resultant here you see it will now be along this line this would be a resultant.

Why? because the y is minus here, y component is in opposite direction x is pointing here at particular instant, y is here, the resultant therefore would again be although linearly polarized, but plane of vibration has now been rotated from that of the previous condition, resultant is again a linearly polarized light but there is a rotation of plane of vibration.

Now you see that whenever we represent a plane polarized wave, the resultant always looks like a double headed arrow, what does this represent, a linearly polarized wave or a plane polarized wave. Now, if this is the representation of a linearly polarized wave what will be the representation of an un-polarized wave.

Now, since in an un-polarized wave the electric field vibration can take any orientation therefore, usually the convention to represent an un-polarized light is this, this is used for un-polarized light. Single double headed arrow stands for a linearly polarized light and multiple double headed arrow which forms star like structure it is used for un-polarized light.

Now, after this analysis, what we can see is the following: In an un-polarized light if you know the orientation of electric field at a particular instant of time suppose $T = T_0$ then you cannot predict or you cannot forecast the orientation of electric field at a later time, while in a linearly polarized light if you know the orientation of electric field at some time $T = T_0$ then at a later time you can predict its orientation, you know that it will always be in the same orientation, it means that we can say that once a wave is polarized the predictability comes in our hand if you can predict the orientation of the electric field once you know the orientation, once you know the earlier orientation then the wave would be polarized.

I repeat it again in an un-polarized wave if you know the orientation of field at some earlier time, then you cannot predict its orientation in later time while in a polarized wave if the orientation of electric field at some earlier point in time, then you can predict its orientation in some later point in time. This power of predictability comes in our hand once the wave is polarized, having understood this let us discuss the second type of polarization. What is the second type of polarization?

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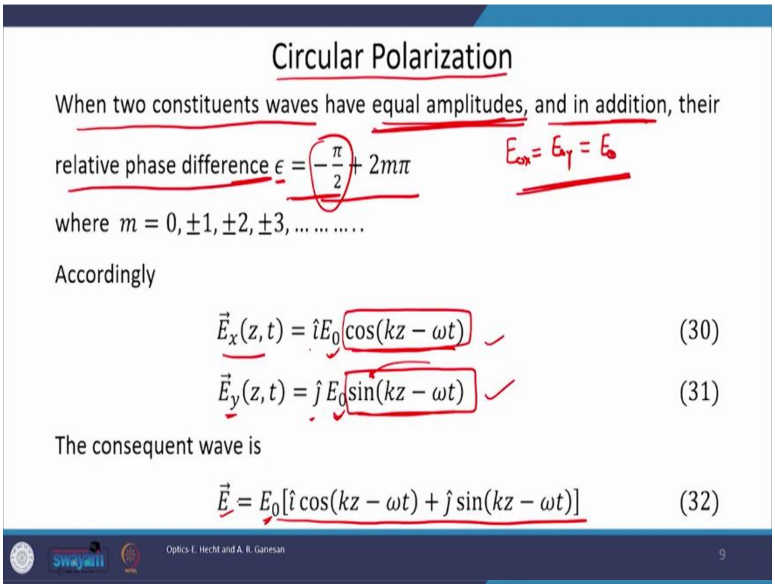

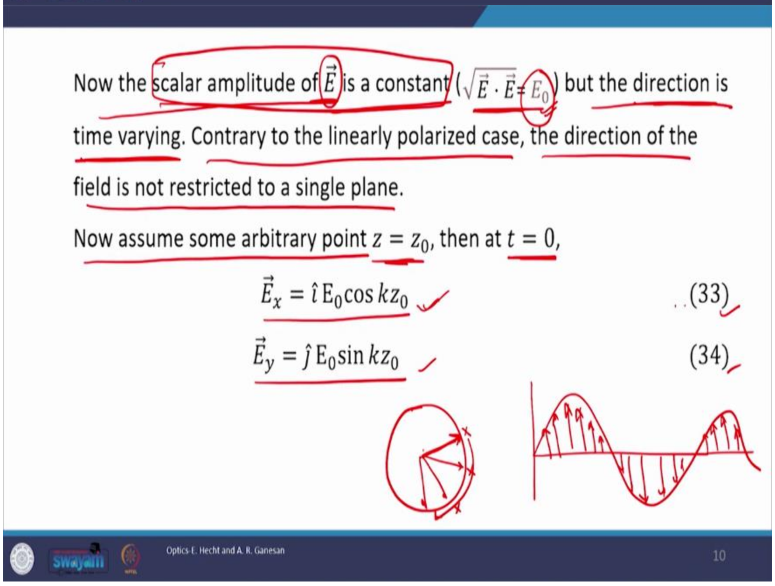

Circular polarization, till now, we were considering two waves which were orthogonal that is they were oriented in two directions which are 90 degree to each other and they were having different amplitudes. Now, here we will consider waves which have equal amplitudes $E_{0x} = E_{0y}$ now.

And we will assume that $E_{0x} = E_{0y} = E_{0x} = E_0$. And in addition to this their relative phase difference which is $\epsilon = -\pi/2 + 2m\pi$. Now, let us consider the simplest case where m=0 then in that case the relative phase difference between the two orthogonal waves.

The two overlapping orthogonal waves is $-\pi/2$. The simplest case is $\epsilon = -\pi/2$. With this let us rewrite the expression for wave. Two assumptions here are equal amplitudes and relative phase difference is $-\pi/2$, with this $\vec{E}_x = \hat{\imath} E_{0x} cos(kz - \omega t)$ and $\vec{E}_y = \hat{\jmath} E_{0y} sin(kz - \omega t)$, no

ϵ right now, where is ϵ? It is eaten up by this function, you see in the first expression there is cosine term while in the later second expression it is a sin term, $\pi/2$ is now absorbed here in sin function and the amplitudes are the same as per our assumption. Now let us calculate the expression for the resultant disturbance, how to calculate, add them vectorially. If we add them, we will get this expression the resultant one.

Now, it has E_0 came out of the bracket, why? Because it is a common. Now, the scalar amplitude of $\vec{E},$ how to calculate the amplitude of $\vec{E}$? amplitude of $\vec{E}$ is calculated using this formula, $\vec{E}$ is a vector quantity take dot product with itself and then square root it this will give you the scalar amplitude of vector $\vec{E}$. It is a constant, this resultant vector $\vec{E}$ has amplitude which is a constant but the direction is time varying, the direction of $\vec{E}$ is now time varying.

Now, contrary to the linear polarization case, the direction of the field is not restricted to a single plane here I repeat for clear understanding the resultant field E you see has a constant amplitude, the amplitude is not varying with propagation or with time but the direction of E field is now varying.

Till now, we were in the habit of seeing this kind of wave whose amplitude is function of time you see the magnitude of these arrows are reducing here and then they are changing directions and this is how we trace a sinusoidal wave. The amplitude was function of time whenever we say a field is function of time then it is amplitude which was varying with time or varying with z, propagation space.

But here in case of circularly polarized light what we saw is that the amplitude is constant, it is not varying, where does the time dependence comes in? the time dependence comes in from the time dependent direction. In linearly polarized light, the electric field was vibrating in a particular plane, its direction of vibration was not changing with the propagation, it was neither function of time nor function of space.

But in case of circularly polarized light, the direction of E field is now changing with propagation it is a function of time and space. However, its magnitude neither depends on a space nor on time, it is a constant quantity. Now, with this in mind, let us now assume some arbitrary point in space in direction of propagation and that point is $z = z_0$.

We are assuming that wave is propagating in z direction and at a particular point $z = z_0$ and at this point when the wave reaches at point $z = z_0$ assume that the time counting starts from there that is time is equal to 0 there at $z = z_0$, under these two conditions, we can rewrite equation number 30 and 31.

And new expression for $\vec{E}_x$ and $\vec{E}_y$ are given by equation number 33 and 34, these are the two waves which will overlap. Now, if you square 33 and 34 and add them up when you see that they trace a circle, it means the resultant would be a circularly polarized light because when you trace a circle out of the tip of the electric field vector.

Then the radius of the circle irrespective of where you are on the circumference the radius is constant, it does not vary and this is what is being said here also the scalar amplitude is constant. Now, what is varying the electric field vector will keep changing its direction at some point of time it would be here next here next here it would keep changing its direction.

But, this change in direction would not be random, why, if this would be random, then we would lose the power of predictability and we have already discussed that if orientation of E field is predictable then only we can say that the wave is polarized, that much information must be in our hand. Let us see further what happens with equation number 33 and 34.

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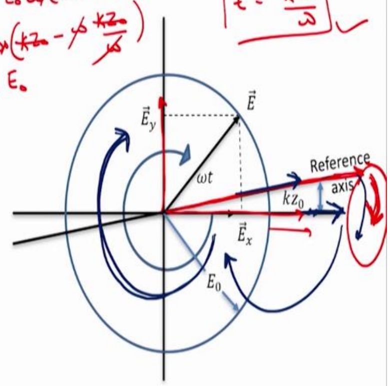
At later time $t = kz_0/\omega$,

$$\vec{E}_x = \hat{\imath}E_0,$$

$$\vec{E}_y = 0$$

and $\vec{E}$ is along the x- axis

The resultant electric field vector $\vec{E}$ is rotating clockwise at an angular frequency ω, as seen by an observer towards whom the wave is moving. Such a wave is right-circularly polarized (RCP).



Circular Polarization

When two constituents waves have equal amplitudes, and in addition, their relative phase difference $\epsilon = -\frac{\pi}{2} + 2m\pi$

where $m = 0, \pm1, \pm2, \pm3, \ldots\ldots\ldots$

Accordingly

$$\vec{E}_x(z,t) = \hat{\imath}E_0\cos(kz - \omega t) \quad (30)$$

$$\vec{E}_y(z,t) = \hat{\jmath}\,E_0\sin(kz - \omega t) \quad (31)$$

The consequent wave is

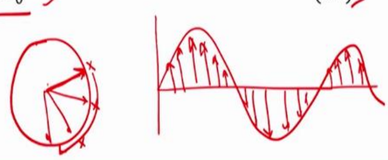
$$\vec{E} = E_0[\hat{\imath}\cos(kz - \omega t) + \hat{\jmath}\sin(kz - \omega t)] \quad (32)$$

Now the scalar amplitude of $\vec{E}$ is a constant ($\sqrt{\vec{E}\cdot\vec{E}} = E_0$) but the direction is time varying. Contrary to the linearly polarized case, the direction of the field is not restricted to a single plane.

Now assume some arbitrary point $z = z_0$, then at $t = 0$,

$$\vec{E}_x = \hat{\imath}\,E_0\cos kz_0 \quad (33)$$

$$\vec{E}_y = \hat{\jmath}\,E_0\sin kz_0 \quad (34)$$



Equation number 33 and 34 is written at $z = z_0$ and time $t = t_0$. Now, this particular point is given by this reference, say this is the reference on this horizontal axis we express vector $\vec{E}$, on this vertical axis it is vector $\vec{E}_y$, on horizontal axis it is vector $\vec{E}_x$, on vertical axis it is vector $\vec{E}_y$ and at certain point in space which is z is equal to z_0 and time t is equal to 0. Suppose, this is the direction of the resultant field which we call reference axis.

Now, since this is the reference axis we will start the calculation from this reference axis. Since, we are assuming time is equal to 0 here at this reference axis. As soon as we start from here time will increase in positive direction here. Now, time slowly will increase. Now, suppose at a later time which is given by kz_0/ω where did we get this expression from? We know that $\vec{E} = E_0$ suppose a vector quantity is here.

And then $cos(\omega t - kz_0)$. Now, how did we choose later time from this expression, when will this expression will become 0. This expression will become 0, at a time point which is given by kz_0/ω this we choose as our later time this is given here. At this point what will happen, the $\vec{E}_x$ component, what is the expression of $\vec{E}_x$ component, it is given by equation number 13, if you replace $t = kz_0/\omega$ here then you will get 0 here.

Now, let me write it here for more clarity $\vec{E}_x = \hat{\imath}E_0 cos(kz - \omega t) = \hat{\imath}E_0 cos(kz_0 - \omega \times kz_0/\omega)$. Now t has this value kz_0/ω, the ω ω will go away and kz_0 will go with kz_0.

Therefore, we would be left with this value and this is what is written here. Similarly, we can calculate $\vec{E}_y$, if the phase is 0 then sin which is sitting here, the sin of 0 would be equal to 0 and therefore, $\vec{E}_y$ would be equal to 0 and therefore, the wave was initially along the reference axis direction and at a later time the x component has some finite positive value.

And the y component has 0 value, x component has some finite value and y component has 0 value, it means from the reference axis direction wave rotated, wave came here in this the electric field resultant electric field rotated in this direction as shown by this arrow here. Initially it was in along references axis direction now the resultant is along $\vec{E}_x$ vector direction and therefore, the resultant is along x-axis.

Therefore, we can say that the resultant electric field vector E is rotating clockwise direction at an angular frequency ω as seen by an observer towards whom the wave is moving, a very important concept. Initially the wave was along this reference axis direction now, the wave is on x-axis and the resultant $\vec{E}$ is pointing along x-axis, the whole rotation is clockwise fashion, this is how the wave is rotating, the rotation is like this, which is clockwise rotation.

And we are standing in the front and we are looking into the source the light is coming towards us and as an observer, we are looking into the source. Under this case, if we see the resultant electric field vectored tip rotates along clockwise direction then such a wave is called right circularly polarized wave.

I repeat if we are looking into the source and seeing the resultant electric field is rotating clockwise direction or more accurately the tip of resultant electric field vector is tracing a circle in a clockwise direction then this kind of polarization or this kind of wave is called right circularly polarized wave.

And this is also very much clear in this figure the tip of the electric field vector is rotating in a clockwise fashion. In the case when we are looking into the source the light is coming towards us and this wave is called right circularly polarized. This is very important concept that we must look into the source and light must be coming towards us therefore, the referencing is very important, we must look into the source, light must be coming towards us and under this condition if the tip is rotating in a clockwise fashion. Then the wave is called right circularly then the wave is right circularly polarized wave. The acronyms for right circularly polarized wave is RCP right circularly polarized.

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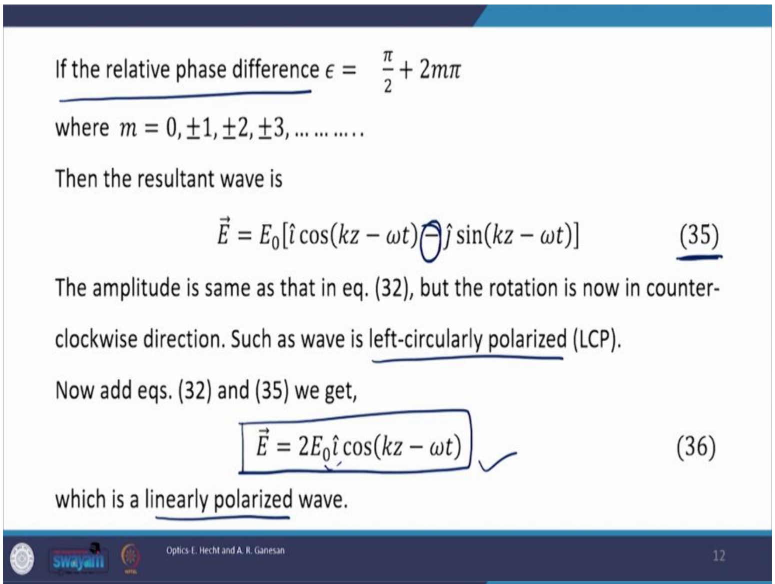

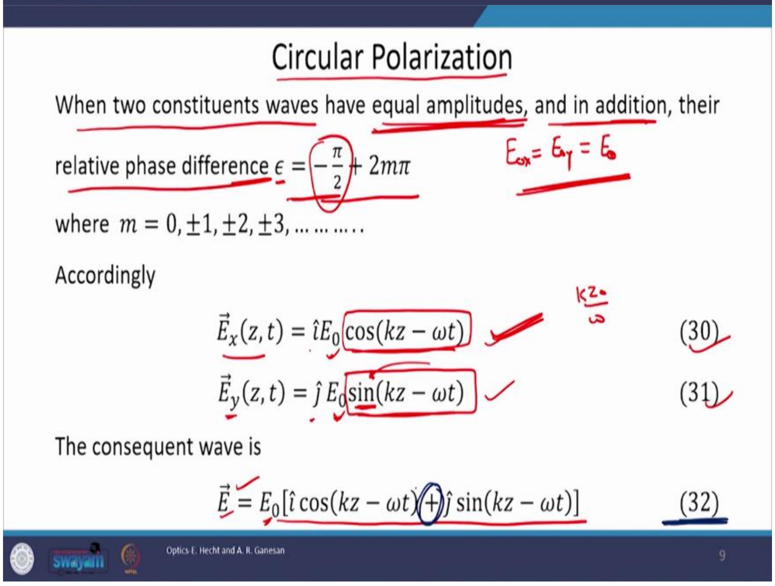

Similarly, if the relative phase difference is $\pi/2$ and then integral multiple of π then what will happen is that, there would be a minus sign here instead of plus sign the resultant will have minus sign here. And if this is the case, then the resultant will trace, the tip of the resultant field will trace a circle in an anti clockwise fashion and such a wave is called left circularly polarized or LCP. Earlier it was RCP now it is LCP. Now this is equation number 35 represent an LCP while equation number 32 which is given here, this represents an RCP.

Now let us add these two equations, here the only difference here is in sign. Now, if we add them up, this is the resultant. If you add LCP and RCP then you get equation number 36 which clearly is pointing along x-axis and which is a linearly polarized light, which means out of left circularly and right circularly polarized light, we can again generate a linearly polarized light, a more generalized statement is using two orthogonally polarized light we can generate any type of polarization or alternatively, any type of polarization can be expressed in the form of orthogonally polarized light, x polarized and y polarized light are orthogonal, left circularly polarized and right circularly polarized light are orthogonal so using these two pairs, we can generate any kind of polarization.

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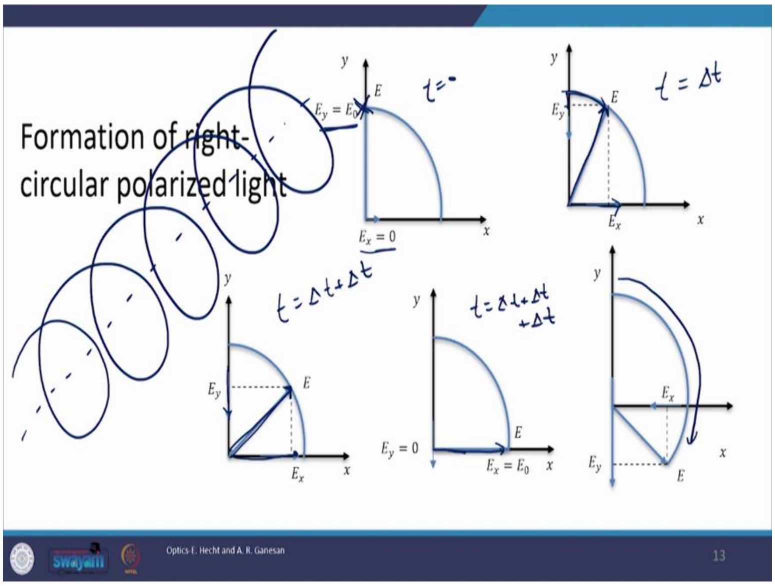

Now, you can see here the formation of circle in a circularly polarized light, you see at some instant where suppose t is equal to 0, you see that $\vec{E}_x$ is equal to 0 and $\vec{E}_y$ has some finite value equal to E_0 therefore, the resultant would be here at some later time, suppose t is equal to Δt, $\vec{E}_x$ has gained some value and E_0 is reducing therefore the resultant is not now pointing towards y axis, it has this orientation now, it has rotated clockwise fashion.

Now, again if you move further $\Delta t + \Delta t$, resultant $\vec{E}$ came here, now $\vec{E}_y$ is reducing down and the resultant in slow is in the next interval of time $\Delta t + \Delta t + \Delta t$.Suppose, now $\vec{E}$ is along the x-axis and slowly you are seeing that it is tracing a circle with propagation.

And this particular light is doing clockwise rotation and therefore, it is called right circularly polarized light, but if you see it in space then this circularly polarized light will form a helix. Initially it would be at some time and then slowly it will create this type of helical structure, the tip of electric field vector will trace a helix in space.

And if you see now, there would be an axis of symmetry of this helical structure and if you point your eyes along this axis of symmetry then you will see a circle. But if you take a video of this tip, then the tip will trace a helical structure, right circularly polarized will form one type of helical structure, left circularly polarized have the opposite sense of rotation therefore, the helical structure would be formed differently. This is all for today, I end my lecture with this and thank you all for your presence and listening me.