Modern Optics
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Lecture – 58
Magneto-optic Effect

Now, we will discuss Magneto-optic Effect.

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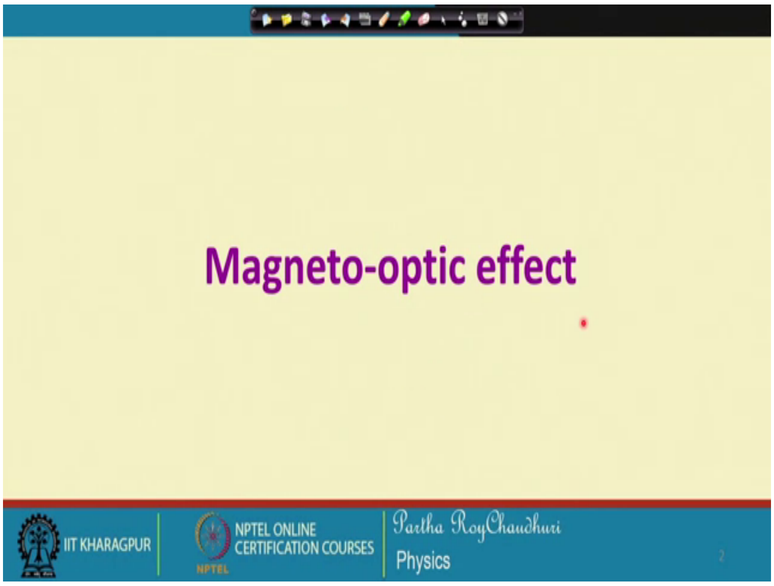

Magneto-optic effect

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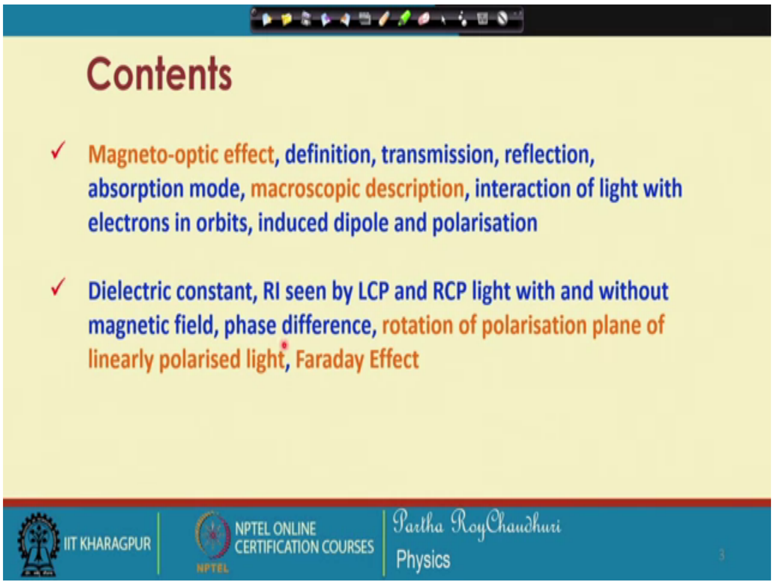

Contents

- ✓ Magneto-optic effect, definition, transmission, reflection, absorption mode, macroscopic description, interaction of light with electrons in orbits, induced dipole and polarisation
- ✓ Dielectric constant, RI seen by LCP and RCP light with and without magnetic field, phase difference, rotation of polarisation plane of linearly polarised light, Faraday Effect

And for magneto-optic effect we will discuss the basic definition and the three categories. That is the transmission, reflection, and absorption mode, of this effect. We look at the microscopic description considering the interaction of light with electron orbits. And induced dipole polarization and from there we will calculate the dielectric constant and refractive index in by the left circularly polarized and right circularly polarized light with and without magnetic field. Then we look at the phase difference between these two lights. And then we look at the net rotation of polarization plane of the input linearly polarized light. We will calculate then we will look at the Faraday rotation effect.

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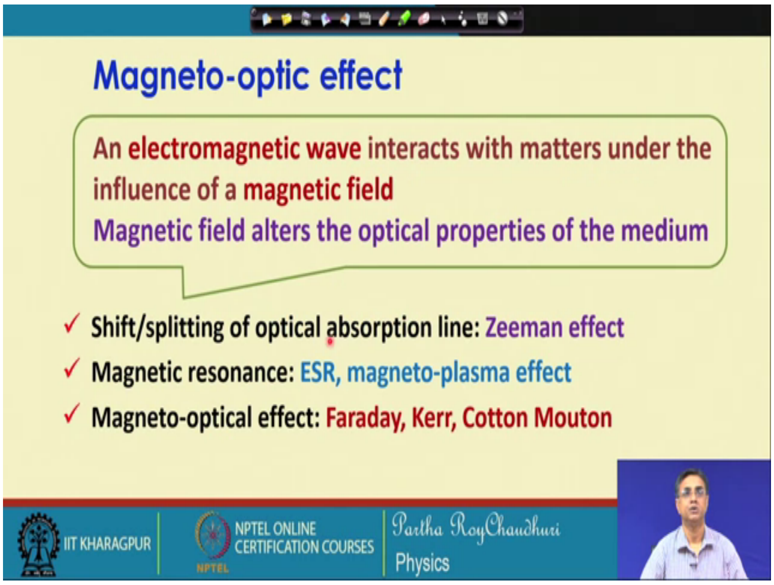

Magneto-optic effect

An electromagnetic wave interacts with matters under the influence of a magnetic field
Magnetic field alters the optical properties of the medium

- ✓ Shift/splitting of optical absorption line: Zeeman effect
- ✓ Magnetic resonance: ESR, magneto-plasma effect
- ✓ Magneto-optical effect: Faraday, Kerr, Cotton Mouton

So, the first thing that an electromagnetic wave interacts with matter under the influence of a magnetic field, magnetic field alters the optical properties of the medium. And this optical property is in terms of the polarization primarily and also the change in the intensity of the input light. So, this appears in the form of phase in the form of shift or splitting of the optical absorption line which is very popularly known as the Zeeman Effect. We will describe in terms of in the light of Zeeman effect. Then magnetic resonance these are very useful instrument ESR, magneto-plasma effect. Magneto-optical effect primarily will be concerned with this Faraday and Kerr effect and cotton mouton effect also.

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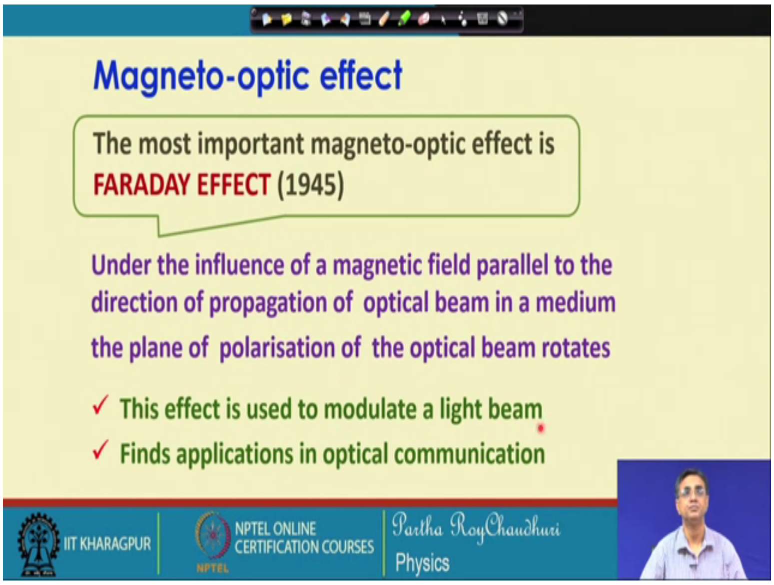

Magneto-optic effect

The most important magneto-optic effect is **FARADAY EFFECT** (1945)

Under the influence of a magnetic field parallel to the direction of propagation of optical beam in a medium the plane of polarisation of the optical beam rotates

- ✓ This effect is used to modulate a light beam
- ✓ Finds applications in optical communication

So, the most important magneto-optic effect is Faraday Effect which was discovered in the year of 1945 under the influence of a magnetic field parallel. The magnetic field is parallel to the direction of propagation of the optical beam in a medium and then the plane of polarization of the optical beam rotates. This effect is used to modulate light beam and it finds number of applications in optical communication and instrumentation also for measurement of high current etcetera.

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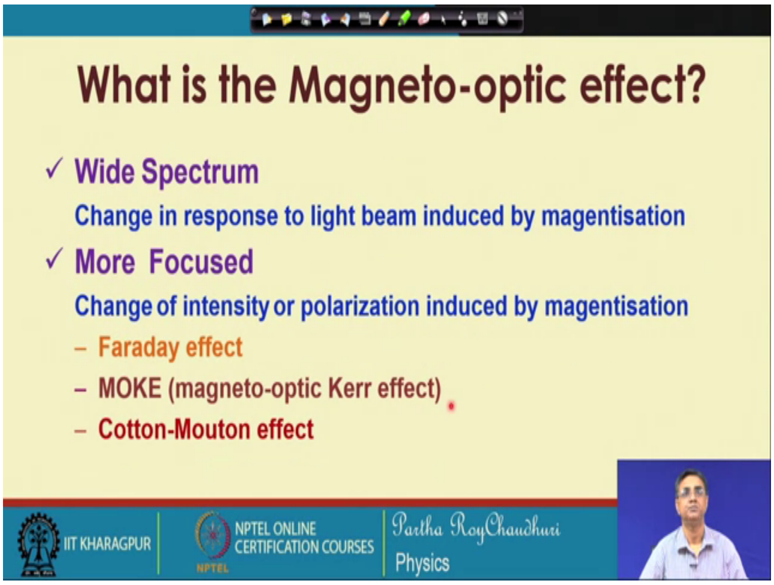

What is the Magneto-optic effect?

- ✓ Wide Spectrum
  Change in response to light beam induced by magentisation
- ✓ More Focused
  Change of intensity or polarization induced by magentisation
  - Faraday effect
  - MOKE (magneto-optic Kerr effect)
  - Cotton-Mouton effect

What is magneto-optic effect? The broad spectrum is that it is the change in the response to the light beam which is induced by the magnetization of the matter through which the light is propagating. And if we look at a more narrower vision of this magneto-optic effect, then it is the change in the polarization. Or the resulting intensity induced by this magnetization of the material through which this light beam is propagating. And these are categorized under this Faraday effect which was first observed then MOKE, that is magneto-optic Kerr effect, then Cotton-Mouton effect.

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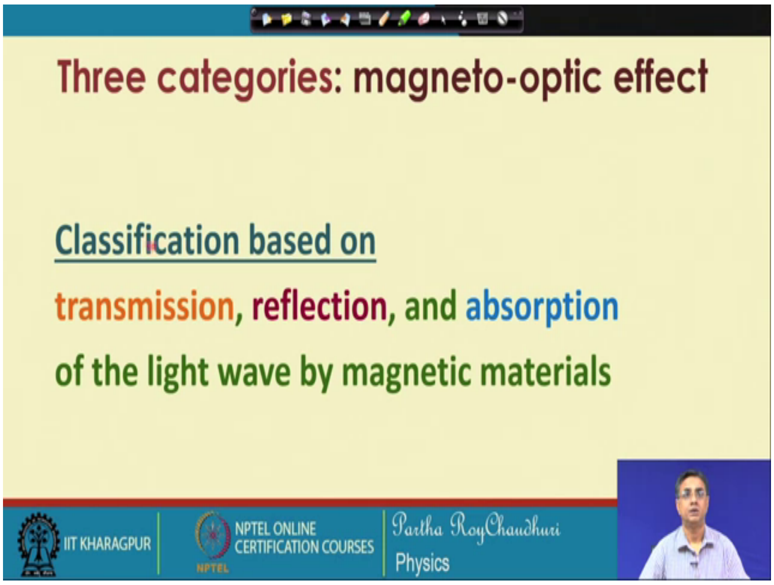

Three categories: magneto-optic effect

Classification based on

transmission, reflection, and absorption

of the light wave by magnetic materials

So, classification of this magneto-optic effect based on this transmission, reflection, and absorption under this headings we will discuss this.

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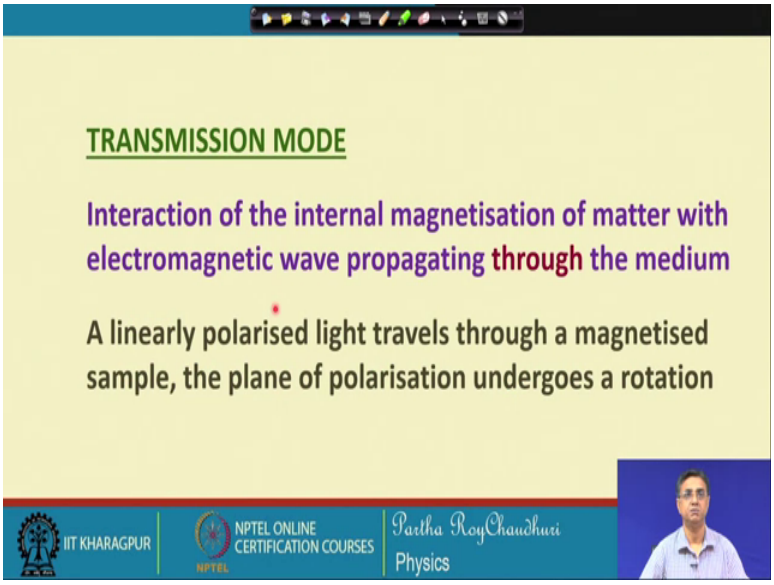

TRANSMISSION MODE

Interaction of the internal magnetisation of matter with electromagnetic wave propagating through the medium

A linearly polarised light travels through a magnetised sample, the plane of polarisation undergoes a rotation

First we will take up this transmission mode, interaction of internal magnetization of matter with the electromagnetic wave propagating through the medium. That is when the electromagnetic wave is propagating through the medium. Then how these optical properties are changed altered as a result the light beam which is propagating through this is also changed in terms of its polarization. A linearly polarized light wave travels through a magnetized sample; the plane of polarization undergoes a rotation. This is precisely the, what is this magneto-optic effect.

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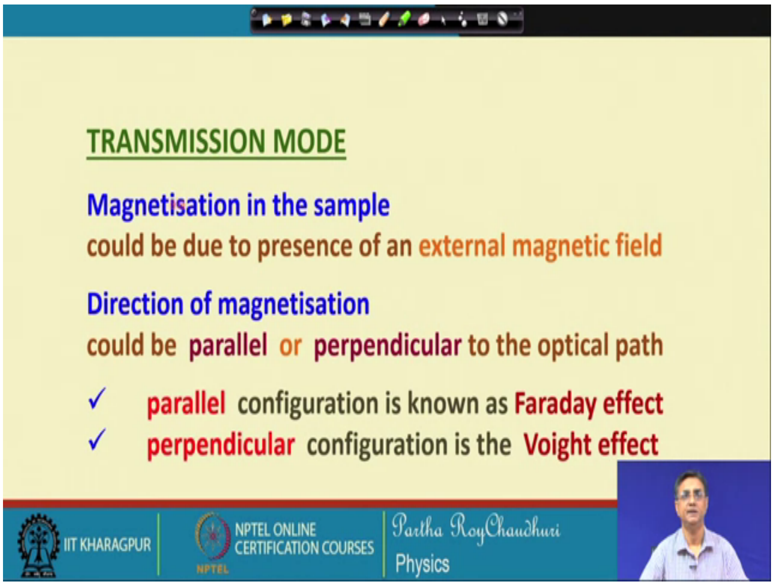

TRANSMISSION MODE

Magnetisation in the sample
could be due to presence of an external magnetic field

Direction of magnetisation
could be parallel or perpendicular to the optical path

- ✓ parallel configuration is known as Faraday effect
- ✓ perpendicular configuration is the Voight effect

Magnetization in the sample could be due to the presence of an external magnetic field or it could be because of its internal magnetization. Direction of magnetization could be parallel or perpendicular to the optical paths. So, these are the conditions for this transmission mode of the magneto-optic effect. When the magnetic field is parallel that is a parallel configuration parallel to the optical path that is the direction of propagation of the optical beam. Then the effect is known as Faraday Effect and if the magnetic field and the light path they are perpendicular to each other that configuration is the Voight effect.

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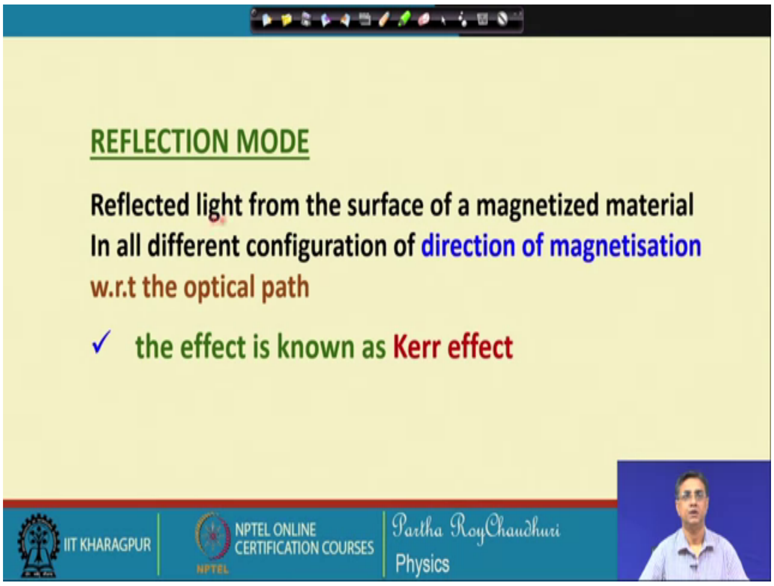

REFLECTION MODE

Reflected light from the surface of a magnetized material
In all different configuration of direction of magnetisation w.r.t the optical path

✓ the effect is known as Kerr effect

So, in the reflection mode the reflected light from the surface of a magnetized material that happens and it changes the property of the light which is reflected from the surface of the magnetized material. In all different configurations of the direction of magnetization with respect to the optical path and this effect is known as Kerr effect; which is unlike the Kerr effect that we observed in the electro optic case, electro optic effect. Where it was proportional to the square of the electric field, but this time it is not it is unlike.

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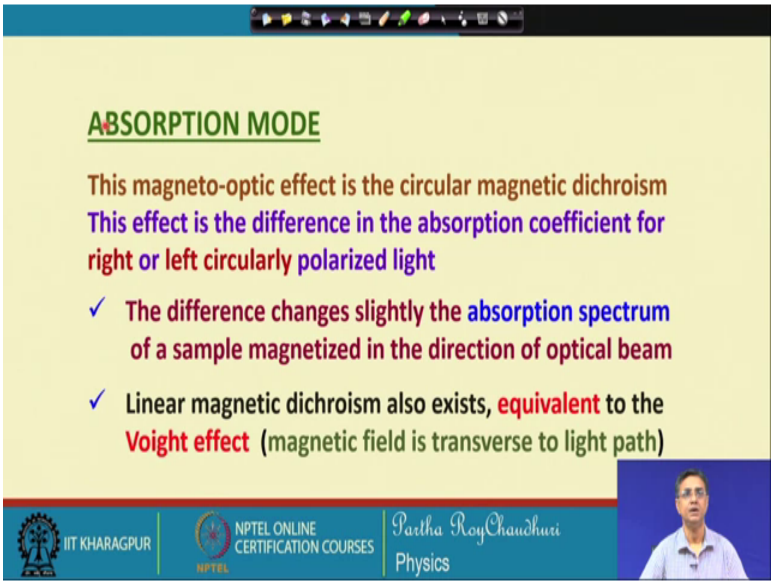

ABSORPTION MODE

This magneto-optic effect is the circular magnetic dichroism
This effect is the difference in the absorption coefficient for right or left circularly polarized light

- ✓ The difference changes slightly the absorption spectrum of a sample magnetized in the direction of optical beam
- ✓ Linear magnetic dichroism also exists, equivalent to the Voight effect (magnetic field is transverse to light path)

And for absorption mode this magneto-optic effect is the circular magnetic dichroism. And this effect is the difference in the absorption coefficient for the LCP and RCP the left circularly and right circularly polarized light which is passing through the medium which is which has magnetization. The difference changes slightly the absorption spectrum of the sample magnetized in the direction of the optical beam. Linear magnetic dichroism also exists and which is equivalent to Voight effect magnetic field is transverse to the light path.

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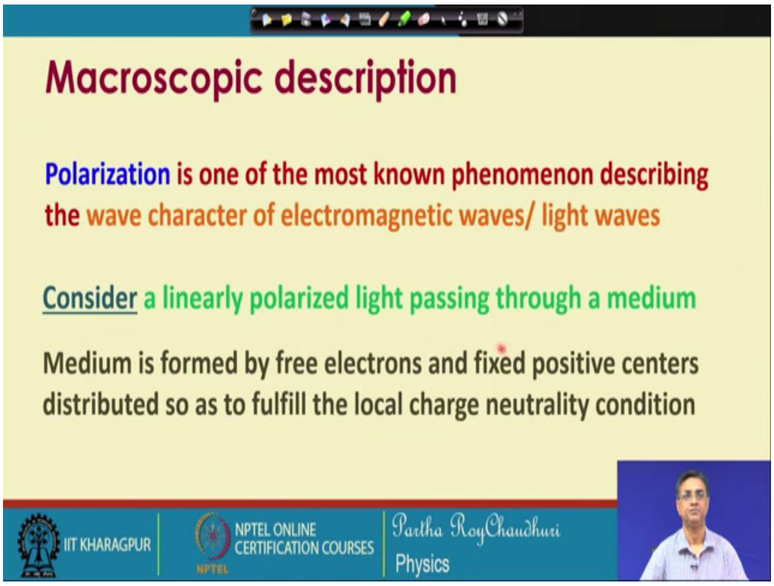

Macroscopic description

Polarization is one of the most known phenomenon describing the wave character of electromagnetic waves/ light waves

Consider a linearly polarized light passing through a medium

Medium is formed by free electrons and fixed positive centers distributed so as to fulfill the local charge neutrality condition

Now we look at the description how to analyze this, the effect to have a basic understanding of this. We know that polarization is one of most known phenomena describing the wave character of the electromagnetic waves light waves. Consider a linearly polarized light which is passing through a medium and the medium is considered to be formed by free electrons and the fixed positive charge centers which are distributed in such a way that it fulfills the local charge neutrality conditions. So, overall charge neutrality is maintained, but the electrons are distributed over the medium.

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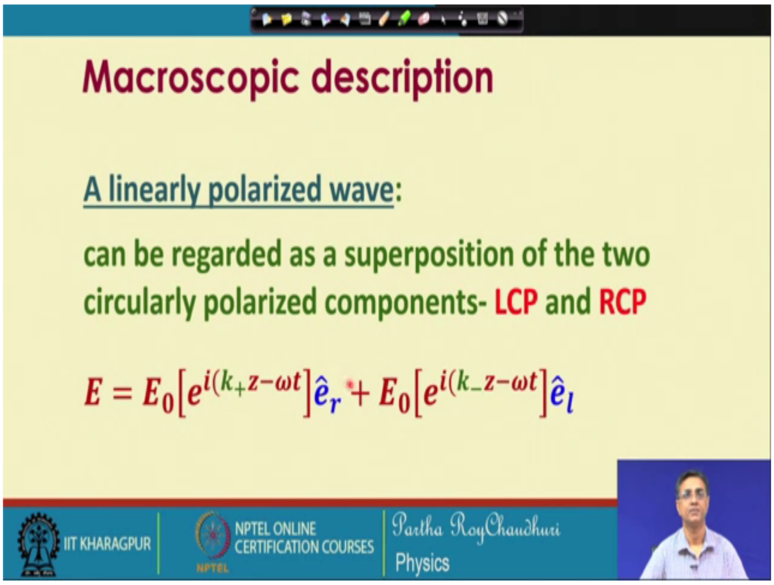

Macroscopic description

A linearly polarized wave:

can be regarded as a superposition of the two circularly polarized components- LCP and RCP

$$E = E_0\left[e^{i(k_+ z-\omega t)}\right]\hat{e}_r + E_0\left[e^{i(k_- z-\omega t)}\right]\hat{e}_l$$

A linearly polarized light can be regarded as a superposition of the two circularly polarized light. One left circularly and another is right circularly polarized light.

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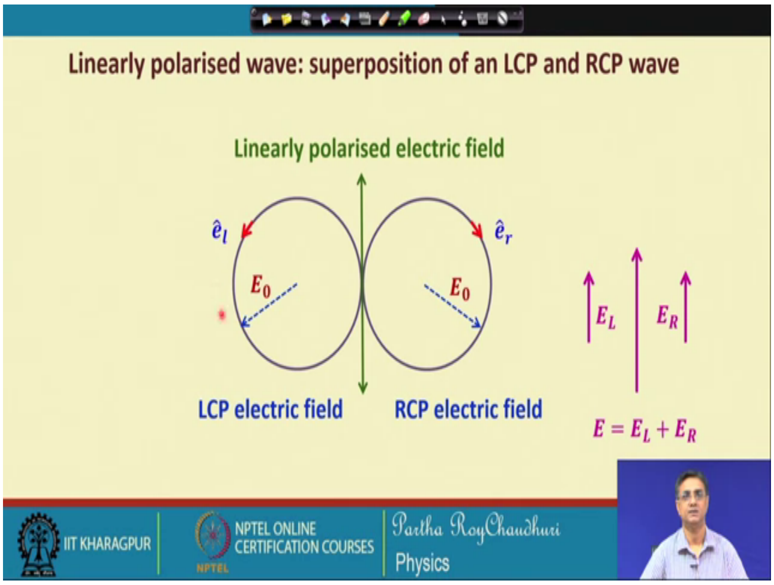

Linearly polarised wave: superposition of an LCP and RCP wave

Linearly polarised electric field

$\hat{e}_l$

$\hat{e}_r$

E_0

E_0

LCP electric field

RCP electric field

E_L

E_R

$E = E_L + E_R$

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Physics

So, let us have a look at this, this is the direction unit vector, this one also. And if you have a linearly polarized light then it can be decomposed into one left circularly polarized light and another right circularly polarized; who are having the same frequency same amplitude and everything same, except the sense of rotation of the tip of the electric field vector.

So, at any instant of time the left circularly the total electric field of the linearly polarized will be a vector sum of the right circularly polarized lights amplitude and left circularly polarized amplitude. So, E equal to E L plus E R such that E L equal to E R equal to E by 2 so, a linearly polarized light can be decomposed into 2 circularly polarized light having opposite sense.

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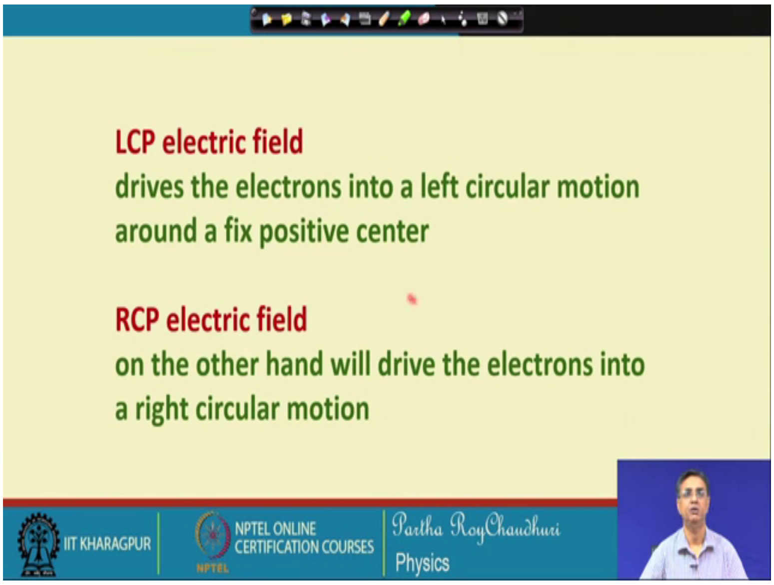

LCP electric field
drives the electrons into a left circular motion around a fix positive center

RCP electric field
on the other hand will drive the electrons into a right circular motion

With this notion now we will look at the configuration of the medium that LCP electric field drives the electrons into left circular orbit around a fixed positive center. And RCP electric field on the other hand will drive the electrons into a right circular motion. So, the electrons who are in the atomic configuration they will be affected differently by two polarized light; one is left circularly polarized, another is right circularly polarized light.

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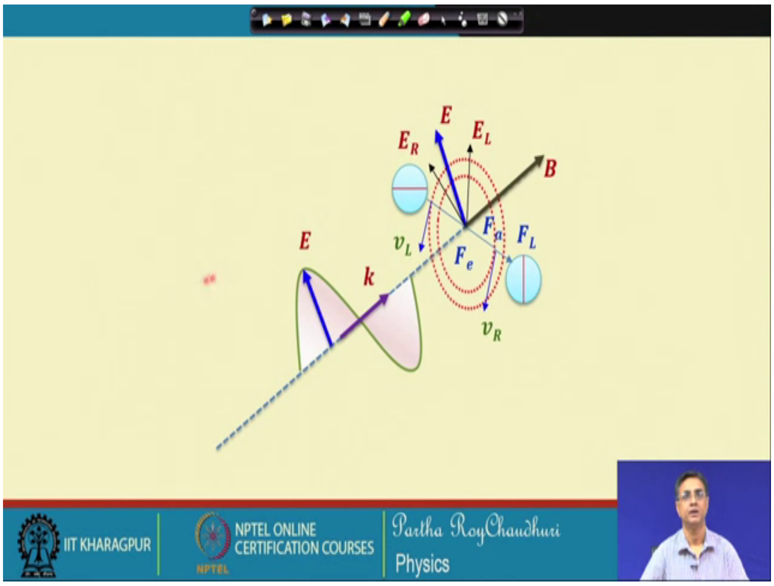

So, you have a linearly polarized light which is composed of which can be decomposed into which can be thought of constituting, which can be thought of a combination, of a right circularly polarized light and a left circularly polarized light giving the resultant which is the same as the linear polarization.

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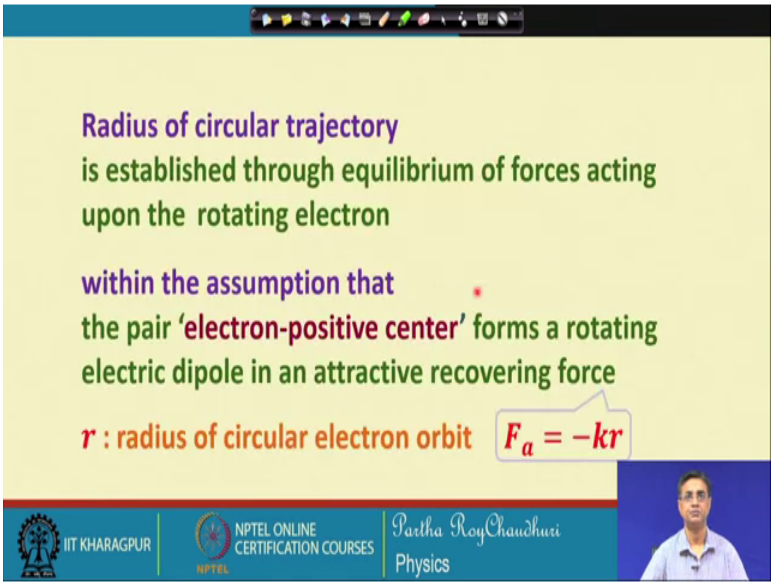

Radius of circular trajectory
is established through equilibrium of forces acting upon the rotating electron

within the assumption that
the pair 'electron-positive center' forms a rotating electric dipole in an attractive recovering force

r : radius of circular electron orbit $F_a = -kr$

So, radius of the circular trajectory is established through the equilibrium of forces acting upon the rotating electron. And this is under the assumption that the pair of electron positive center forms a rotating electric dipole in an attractive recovering force which is the, which involves the radius of the circular orbit.

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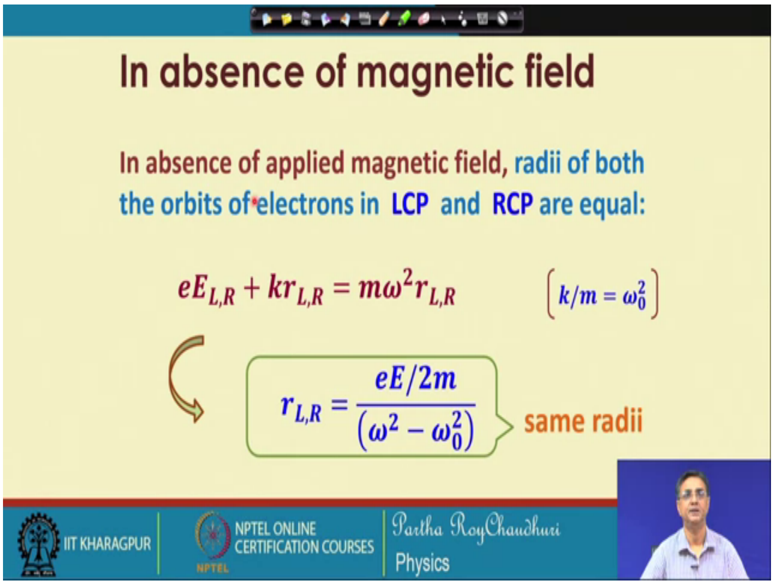

In absence of magnetic field

In absence of applied magnetic field, radii of both the orbits of electrons in LCP and RCP are equal:

$$eE_{L,R} + kr_{L,R} = m\omega^2 r_{L,R} \qquad \left(k/m = \omega_0^2\right)$$

$$\boxed{r_{L,R} = \frac{eE/2m}{\left(\omega^2 - \omega_0^2\right)}}$$

same radii

So, let us see that how we write this equation in absence of any, in absence of any applied magnetic field radii of both the orbits of the electrons in LCP; that is left handed motion of the electron and right handed motion of the electron. They have the same radii in absence of any magnetic field and you can write this equation in this form. This is the force which is experienced by the electron due to the electric field of the left circularly polarized light and right circularly polarized light.

This will be r L, R will describe the radii of these two electron orbits, k is the restoring force constant. And m omega square r is the necessary centrifugal force to balance this centrifugal force which will balance this equation. So, from here we get that r L R that is the radii of the left circularly polarized a left circular left handed motion of the electron and right handed motion of the electron they will have the same radii, e L R is equal to E by 2 so we have substituted. So, this tells you that radii of both the electrons in left handed motion and right handed circular motion are the same.

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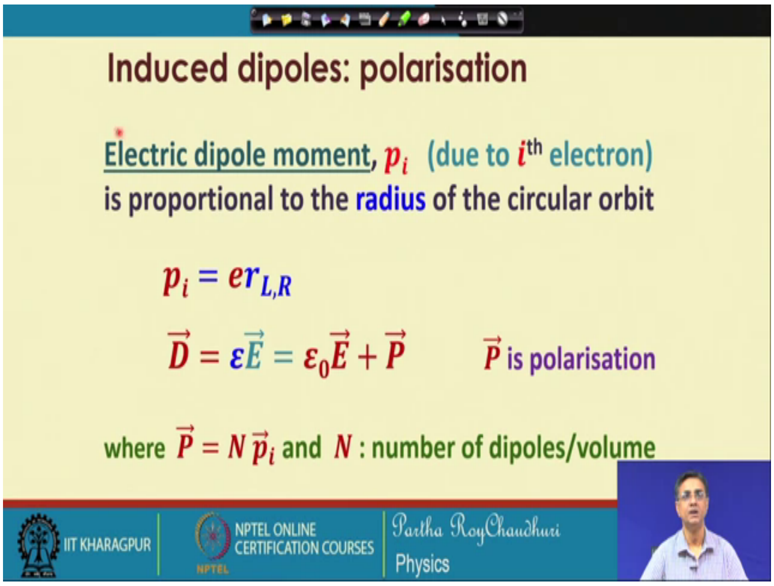

Induced dipoles: polarisation

Electric dipole moment, p_i (due to i^{th} electron) is proportional to the **radius** of the circular orbit

$$p_i = er_{L,R}$$

$$\vec{D} = \varepsilon\vec{E} = \varepsilon_0\vec{E} + \vec{P}$$ $\vec{P}$ is polarisation

where $\vec{P} = N\vec{p}_i$ and N : number of dipoles/volume

Now, from here we can calculate having known the value of R we can calculate the electric dipole due to the ith electron. So, p i equal to e into r L R and then the displacement vector can be written as e epsilon into E, where this is the free space permittivity into E plus P. This is again a known relation in electrodynamics. Now, P the polarization is equal to total number of induced dipole moments. So, this is the number of dipole moments per unit volume and this is the dipole moment so this gives you the polarization.

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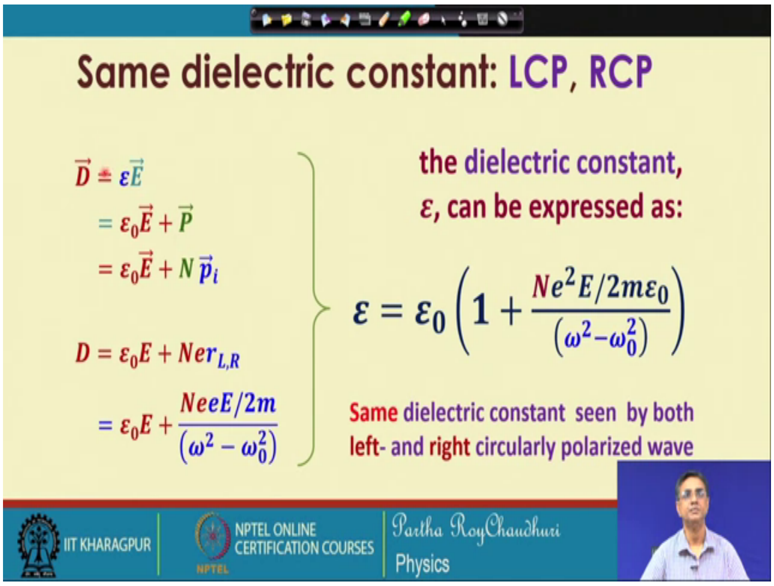

Same dielectric constant: LCP, RCP

$$\vec{D} \doteq \varepsilon\vec{E}$$
$$= \varepsilon_0\vec{E} + \vec{P}$$
$$= \varepsilon_0\vec{E} + N\vec{p}_i$$

$$D = \varepsilon_0 E + Ner_{L,R}$$
$$= \varepsilon_0 E + \frac{NeeE/2m}{(\omega^2 - \omega_0^2)}$$

the dielectric constant, ε, can be expressed as:

$$\varepsilon = \varepsilon_0\left(1 + \frac{Ne^2E/2m\varepsilon_0}{(\omega^2 - \omega_0^2)}\right)$$

Same dielectric constant seen by both left- and right circularly polarized wave

The same dielectric constant will be seen by both left circularly polarized light and right circularly polarized light because there is no change in the radii of the two electrons. So, D we can calculate from here, just by substituting the values for P r i we can get that D equal to this. So, this is N e square E by twice m omega square minus omega naught square. Omega naught we have defined as k by m which is very common in simple harmonic motion k by m is the natural frequency square.

Therefore, the dielectric constant epsilon can be expressed in this form epsilon equal to epsilon 0 and this we have taken from here. So, 1 plus N e square E by twice m epsilon naught by omega minus omega naught square. So, this is the dielectric constant which is seen by both the left circularly polarized light and right circularly polarized. And you can see that the same dielectric constant is seen by both of them. Therefore, there is no change in the polarization properties of the circularly polarized lights.

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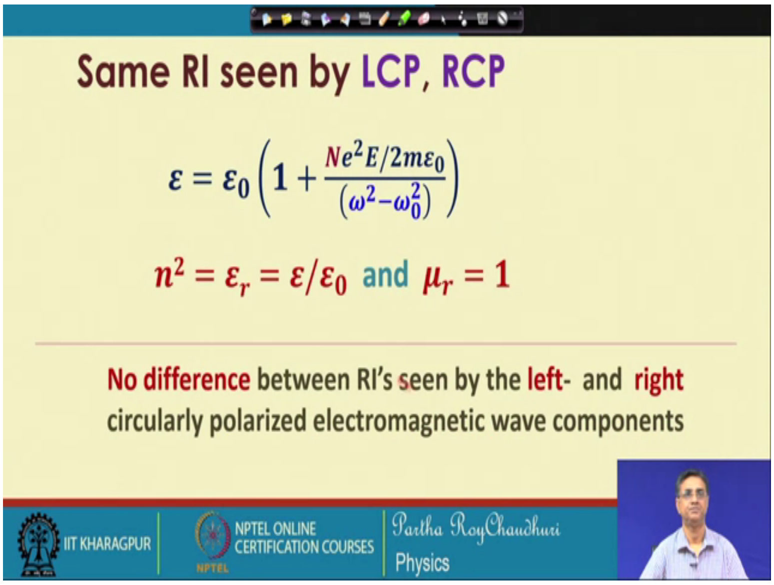

Same RI seen by LCP, RCP

$$\varepsilon = \varepsilon_0\left(1 + \frac{Ne^2E/2m\varepsilon_0}{(\omega^2 - \omega_0^2)}\right)$$

$$n^2 = \varepsilon_r = \varepsilon/\varepsilon_0 \text{ and } \mu_r = 1$$

No difference between RI's seen by the left- and right circularly polarized electromagnetic wave components

Now from here we can calculate the refractive indices of both of them and which turns out to be same. In this case: when there is no magnetic field and n square equal to epsilon r equal to e by epsilon naught and mu r the permeability is taken to be 1. So, finally, we see that there is no difference between the refractive indices those are seen by the left and right circularly polarized electromagnetic waves which is passing through the medium.

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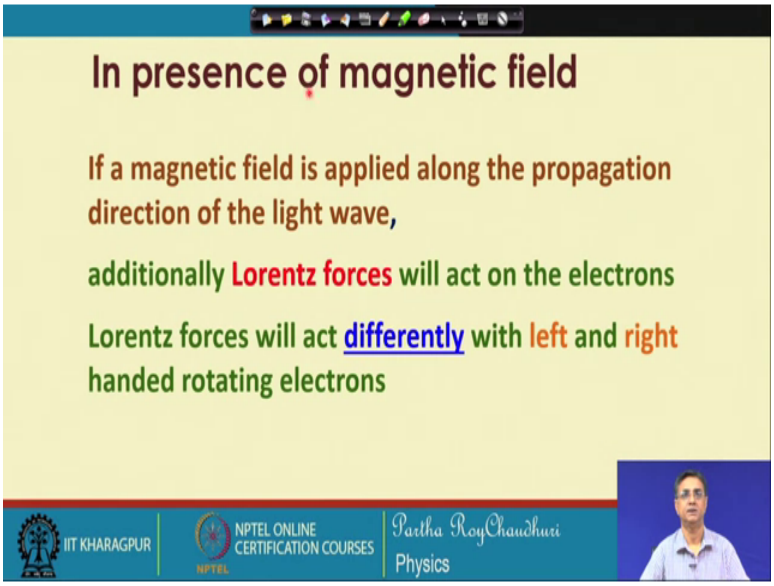

In presence of magnetic field

If a magnetic field is applied along the propagation direction of the light wave,

additionally Lorentz forces will act on the electrons

Lorentz forces will act differently with left and right handed rotating electrons

Now, we will consider the presence of the magnetic field and we will see how these radii and then the displacement vector then dielectric constant and finally, the refractive index all of them are modified in presence of the magnetic field. So, in a magnetic field if the magnetic field is applied along the direction of propagation of the light additional Lorentz forces will be acting on the electrons. And this Lorentz forces will act in a different way because of the rotation of the electrons in two different senses. That is the left and right handed rotating electrons will be affected differently by the presence of the magnetic field.

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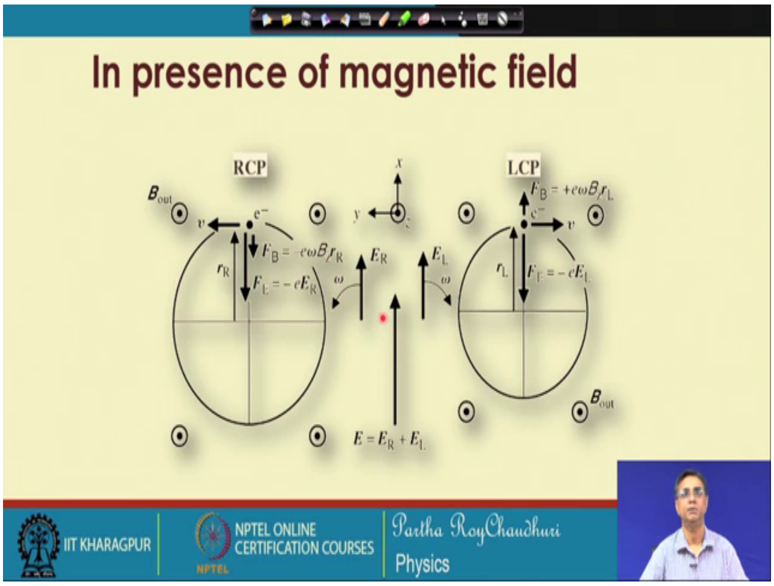

In presence of magnetic field

So, this is the configuration you have the electric field because these are the polarization left circularly a right circularly polarized light left circularly polarized light. And then you have the electric field at any instant of time will be given by this will be given by this vector the tip of the vector. And the sum of this E R and E L will be the resultant field which is due to the input plane polarized light you have magnetic fields which are perpendicular to the plane of this paper. And then because of the magnetic field this will experience this additional low range force which is electron charge e omega b and then r L. In this case, in this case it will be minus e omega B L r R.

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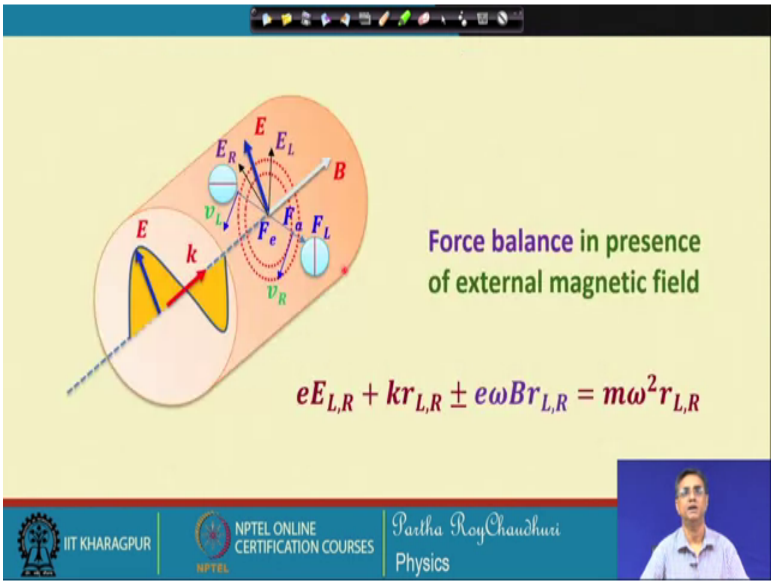

Force balance in presence of external magnetic field

$$eE_{L,R} + kr_{L,R} \pm e\omega B r_{L,R} = m\omega^2 r_{L,R}$$

So, that is very clear and we can write down the equation of motion of the two electrons e E L R plus k r L R plus minus e omega B r L R and so on.

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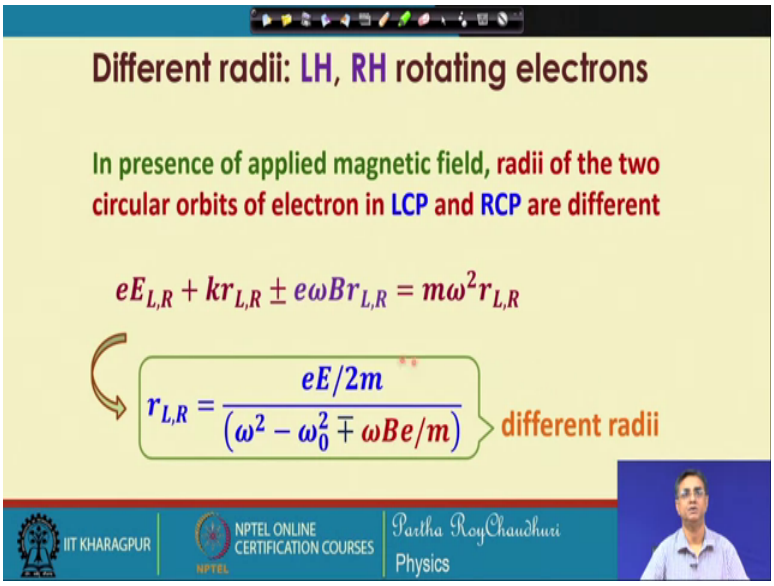

Different radii: LH, RH rotating electrons

In presence of applied magnetic field, radii of the two circular orbits of electron in LCP and RCP are different

$$eE_{L,R} + kr_{L,R} \pm e\omega B r_{L,R} = m\omega^2 r_{L,R}$$

$$\boxed{r_{L,R} = \frac{eE/2m}{\left(\omega^2 - \omega_0^2 \mp \omega Be/m\right)}}$$

different radii

So, from this equation now we can again calculate determine the values of L and R which will turn out to be different you can see that L R, r of L R is equal to now you have a plus minus sign plus for this left handed rotation of the electron and R for the right handed rotation of the electron. So, these two electrons who are rotating in the opposite sense will now their orbits will be different the radius of their circular path will be different because, of the presence of the magnetic field.

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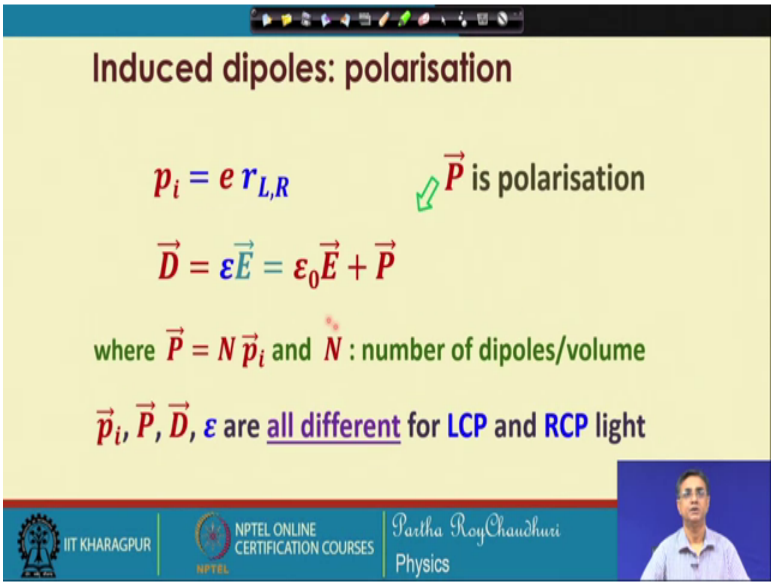

Induced dipoles: polarisation

$p_i = e\, r_{L,R}$

$\vec{P}$ is polarisation

$\vec{D} = \varepsilon\vec{E} = \varepsilon_0\vec{E} + \vec{P}$

where $\vec{P} = N\vec{p}_i$ and N : number of dipoles/volume

$\vec{p}_i, \vec{P}, \vec{D}, \varepsilon$ are all different for LCP and RCP light

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So, the interaction will be different as a result the dipole moment will change for the left handed rotation of the electron and for the right handed motion of the electron. The polarization P we can calculate in the same way which will eventually give you the displacement vector.

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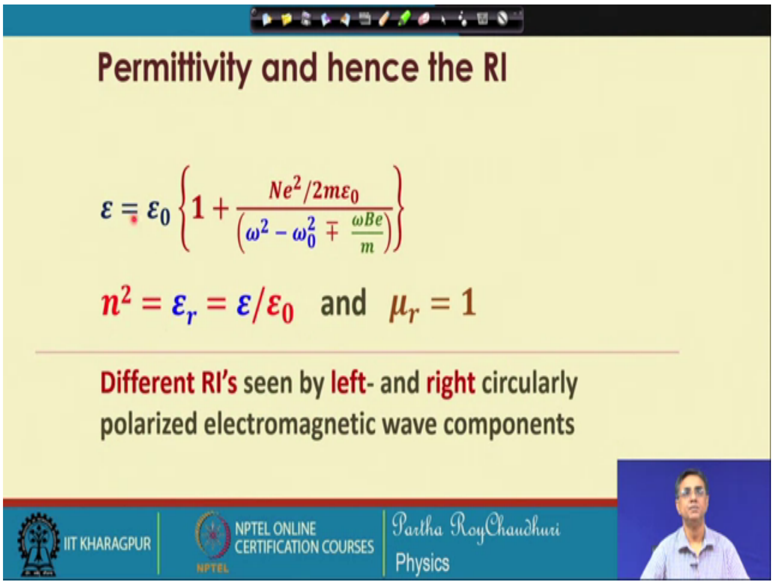

Permittivity and hence the RI

$$\varepsilon = \varepsilon_0\left\{1 + \frac{Ne^2/2m\varepsilon_0}{\left(\omega^2 - \omega_0^2 \mp \frac{\omega Be}{m}\right)}\right\}$$

$n^2 = \varepsilon_r = \varepsilon/\varepsilon_0$ and $\mu_r = 1$

Different RI's seen by left- and right circularly polarized electromagnetic wave components

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And also from here we can calculate the permittivity of the medium in presence of the magnetic field. So, you can see that this additional term has appeared because of the presence of the magnetic field which has affected the electrons in the circular motions in terms of the Lorentz force experienced by them which are now acting differently on the two electrons. As a result we can calculate the refractive indices of the medium seen by the left circularly polarized light and right circularly polarized.

So, finally, we see that different refractive indices are seen by the left and right circularly polarized electromagnetic waves, while passing through the medium in presence of the magnetic field.

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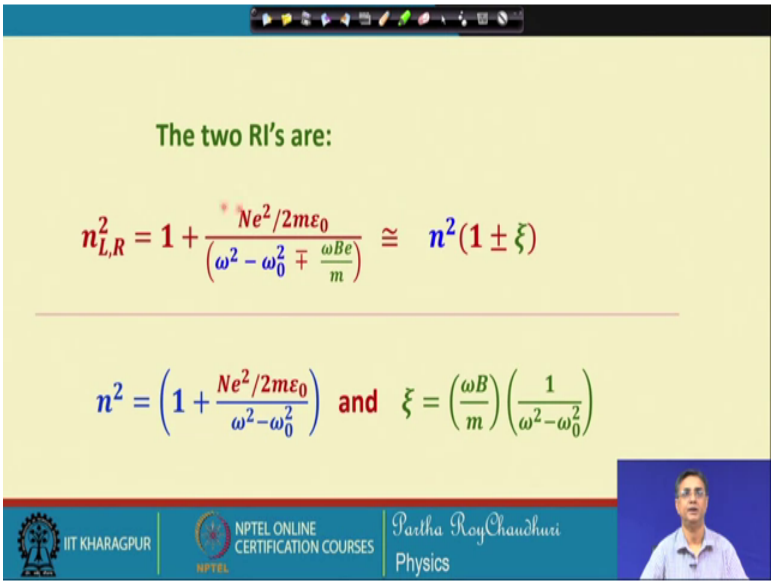

The two RI's are:

$$n_{L,R}^2 = 1 + \frac{Ne^2/2m\varepsilon_0}{\left(\omega^2 - \omega_0^2 \mp \frac{\omega Be}{m}\right)} \cong n^2(1 \pm \xi)$$

$$n^2 = \left(1 + \frac{Ne^2/2m\varepsilon_0}{\omega^2 - \omega_0^2}\right) \text{ and } \xi = \left(\frac{\omega B}{m}\right)\left(\frac{1}{\omega^2 - \omega_0^2}\right)$$

So, these two refractive indices are now written in this form you can say this is a consequence of this expression. So, epsilon by epsilon naught is equal to n square which is the relative permittivity and square of that will be the square of n the n square will be equal to that. So, we can approximately write this equation equal to n square 1 plus minus xi plus and minus they take care for the left handed left circularly polarized light and right circularly polarized light. Therefore, we can write this n square equal to this and xi is equal to this which is straight forward from this.

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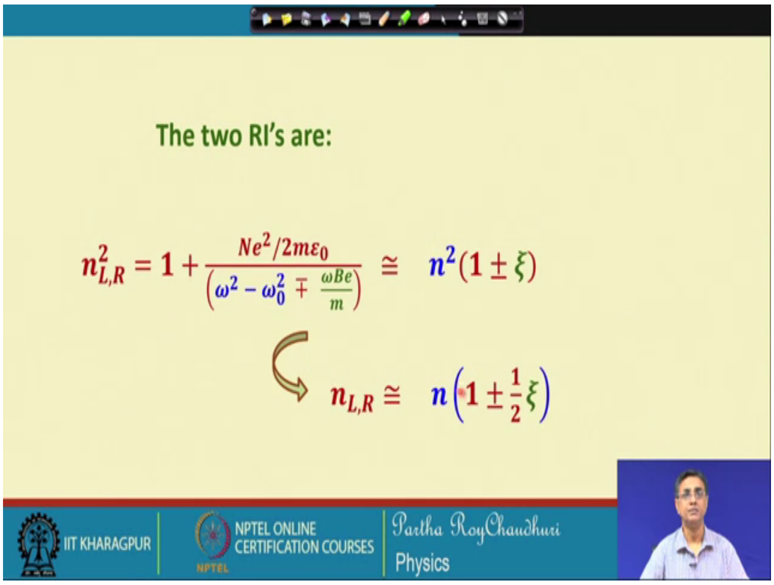

The two RI's are:

$$n_{L,R}^2 = 1 + \frac{Ne^2/2m\varepsilon_0}{\left(\omega^2 - \omega_0^2 \mp \frac{\omega Be}{m}\right)} \cong n^2(1 \pm \xi)$$

$$n_{L,R} \cong n\left(1 \pm \frac{1}{2}\xi\right)$$

Now, these two RI's two refractive indices are at length it is known n square from here we can write n R doing some approximation. That if you take the under root of this then it will be n 1 plus minus half of xi. And this value of xi and n they are known from these expressions.

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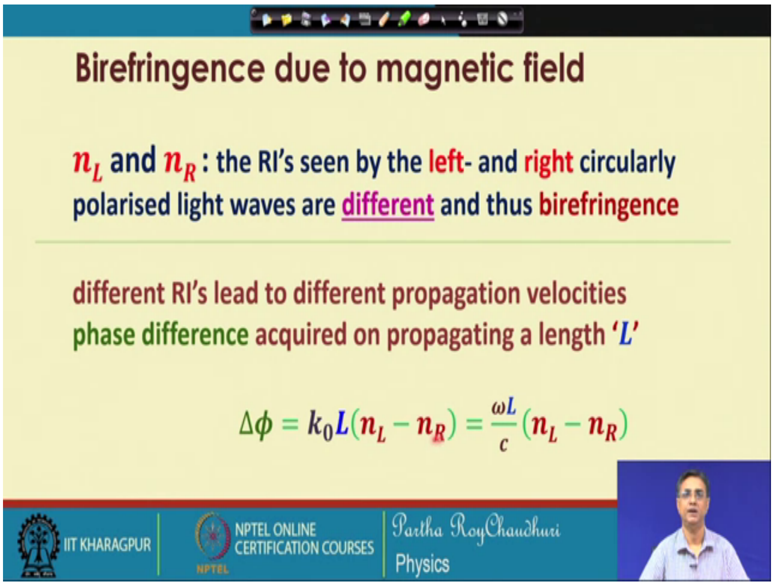

Birefringence due to magnetic field

n_L and n_R : the RI's seen by the left- and right circularly polarised light waves are different and thus birefringence

different RI's lead to different propagation velocities
phase difference acquired on propagating a length 'L'

$$\Delta\phi = k_0 L(n_L - n_R) = \frac{\omega L}{c}(n_L - n_R)$$

So, now effectively we see that the refractive indices seen by the left and right circularly polarized waves, which are passing through the medium in presence of the magnetic field are different which are represented by n L and n R. The different refractive indices will lead to different propagation velocities and there and as a result there will be phase difference which will be acquired by acquired by the two circularly polarized light propagating over a length of L.

And this is straight forward that the phase difference delta phi will be equal to k 0 L. And, the birefringence that is difference of the two refractive indices seen by the seen in the left circularly and right circularly polarized light which can be expressed in this form.

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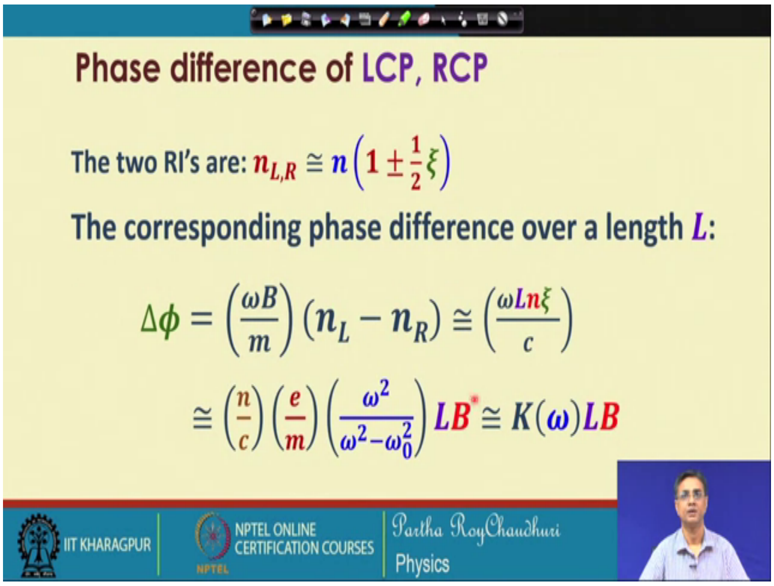

Phase difference of LCP, RCP

The two RI's are: $n_{L,R} \cong n\left(1 \pm \frac{1}{2}\xi\right)$

The corresponding phase difference over a length L:

$$\Delta\phi = \left(\frac{\omega B}{m}\right)(n_L - n_R) \cong \left(\frac{\omega L n \xi}{c}\right)$$

$$\cong \left(\frac{n}{c}\right)\left(\frac{e}{m}\right)\left(\frac{\omega^2}{\omega^2 - \omega_0^2}\right) LB \cong K(\omega)LB$$

So, this is the two refractive indices are this and the corresponding phase difference over this length. We can express in this form delta phi equal to this birefringence into omega into B by m. You can see that this omega this B accounts for the magnetic field and as a result if we arrange these terms by putting the values of xi into this equation. Then we can write this delta phi equal to K which is a function of omega the entire thing we call the constant K which is a function of omega. And then L is the length of the medium through which this along which this electromagnetic wave interacts, with the magnetic field and B is the strength of the magnetic field.

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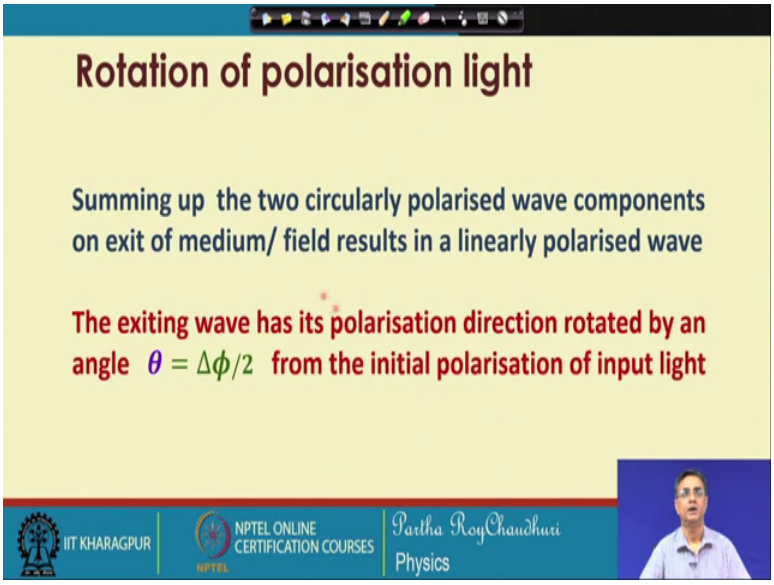

Rotation of polarisation light

Summing up the two circularly polarised wave components on exit of medium/ field results in a linearly polarised wave

The exiting wave has its polarisation direction rotated by an angle $\theta = \Delta\phi/2$ from the initial polarisation of input light

So, if we sum up the two circularly polarized wave components on the (Refer Time: 21:02) of the medium, this will result to a linearly polarized wave again. We will get back the linearly polarized wave because again they are having the same frequency sense of rotation different. And, but the two, but the difference in the phase between the two circularly polarized light is delta phi. So, which will effectively rotate the plane of polarization of the exiting beam which will be equal to theta is equal to delta phi by 2. And this is with respect to the original input polarization.

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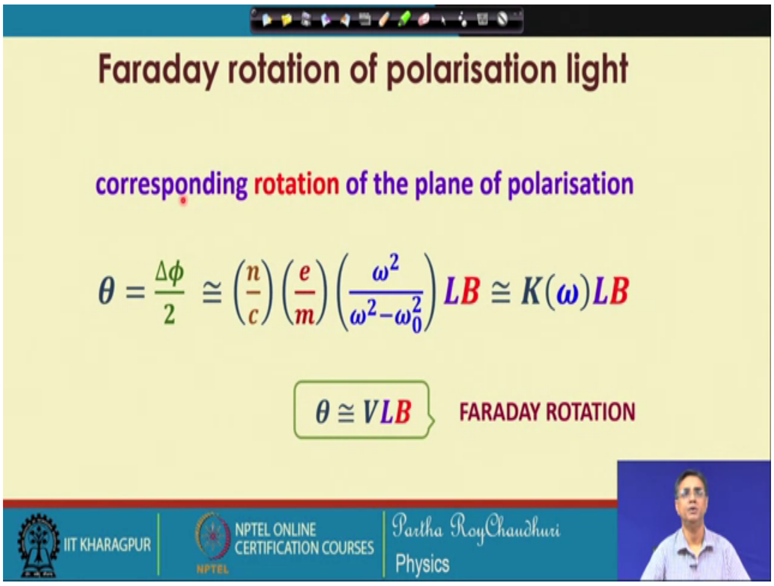

Faraday rotation of polarisation light

corresponding rotation of the plane of polarisation

$$\theta = \frac{\Delta\phi}{2} \cong \left(\frac{n}{c}\right)\left(\frac{e}{m}\right)\left(\frac{\omega^2}{\omega^2-\omega_0^2}\right) LB \cong K(\omega)LB$$

$$\boxed{\theta \cong VLB}$$ FARADAY ROTATION

Therefore, by doing this we find that this corresponding rotation of the plane of polarization is theta is, is equal to BLV. And this is the common way of writing this rotation of the plane polarized wave in presence of the magnetic field which is along the direction of the optical path. The direction of propagation of the optical beam in the medium, that is to say that this magnetic field and the light propagation directions are parallel.

Then we get this effect and this is called the Faraday rotation; which is which is very well known. And you see that this constant V, this is the length of the length of interaction of the optical beam with the magnetic field; B is the strength of the magnetic field and V is the constant which is known as the Verdet constant. So, by doing this we could see that you have a left circularly polarized light you have a right circularly polarized light which are the consequence of an input plane polarized light.

And they will see different refractive indices while passing through the medium in presence of the magnetic field. But otherwise they will see the same refractive index and therefore, there will be no rotation in absence of magnetic field. When the magnetic field is present then these two circularly polarized light in the medium will see different refractive indices and they will develop a phase difference because they develop a birefringence. And over the propagation length this phase difference will lead to a rotation of the plane of polarization, and that is what is called the Faraday rotation.

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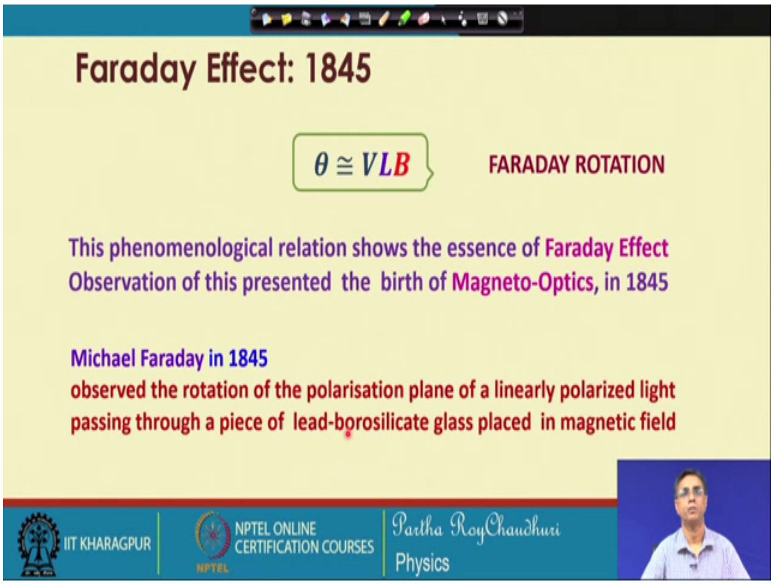

Faraday Effect: 1845

$\theta \cong VLB$ FARADAY ROTATION

This phenomenological relation shows the essence of Faraday Effect
Observation of this presented the birth of Magneto-Optics, in 1845

Michael Faraday in 1845
observed the rotation of the polarisation plane of a linearly polarized light passing through a piece of lead-borosilicate glass placed in magnetic field

So, this Faraday Effect was discovered as I mentioned that it is in the year of 1845. And this is the very well known form of expressing this Faraday rotation theta equal to BLV. This phenomenological relation shows the essence of Faraday effect by describing the electrons in circular motions and interacting with the left and right circularly polarized light, we see the essence of the Faraday effect. And there this observation presented the birth of magneto-optics in the year of 1845. So, he observed first time the rotation of the plane polarization a plane polarized light while it was passing through a piece of lead borosilicate glass, which was placed in a magnetic field.

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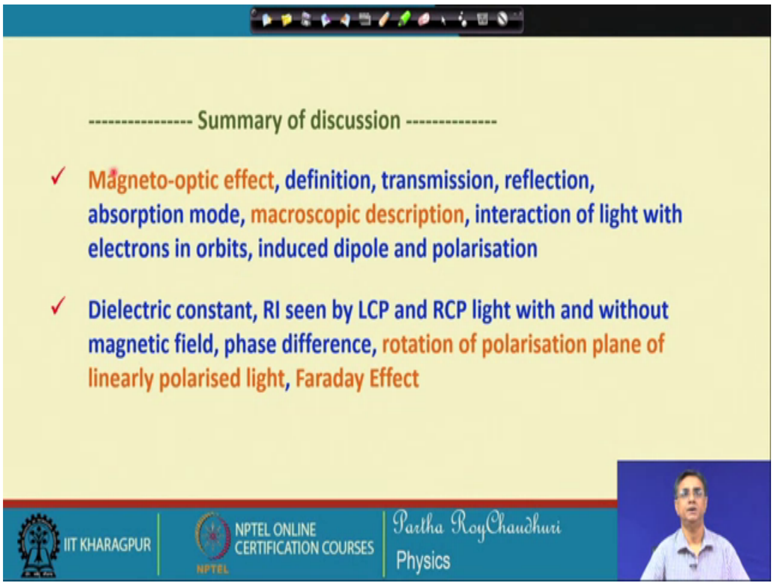

--------------- Summary of discussion -------------

- ✓ Magneto-optic effect, definition, transmission, reflection, absorption mode, macroscopic description, interaction of light with electrons in orbits, induced dipole and polarisation
- ✓ Dielectric constant, RI seen by LCP and RCP light with and without magnetic field, phase difference, rotation of polarisation plane of linearly polarised light, Faraday Effect

So, we discussed the first part that is the basic definition of magneto-optic effect and then considered the three modes of the magneto-optic effect in terms of the transmission, reflection, and absorption mode. We look at the macroscopic description of this Faraday rotation that is the interaction of light with electron orbits, induced dipole and polarization. And the circular birefringence for the LCP and RCP left circularly and right circularly polarized light which is with and without magnetic field. Then we looked at the change in the plane of polarization and that is what we call this Faraday Effect.

Thank you very much.