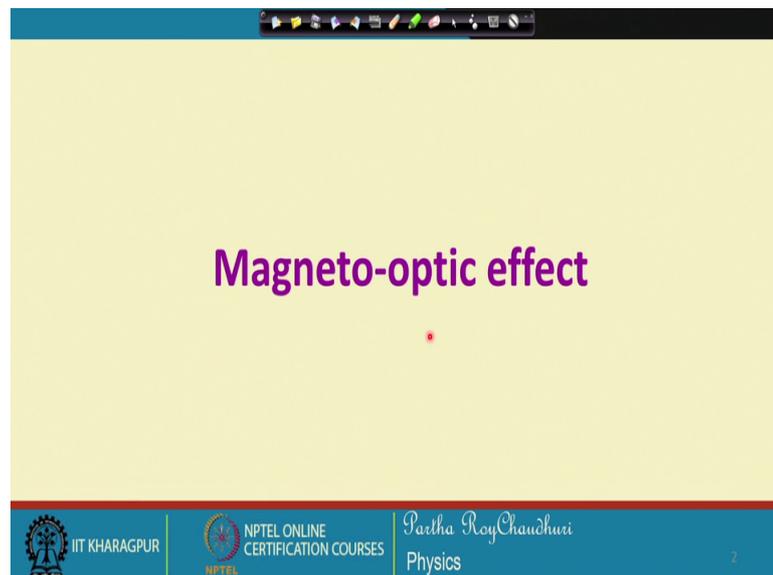


Modern Optics
Prof. Partha Roy Chaudhuri
Department of Physics
Indian Institute of Technology, Kharagpur

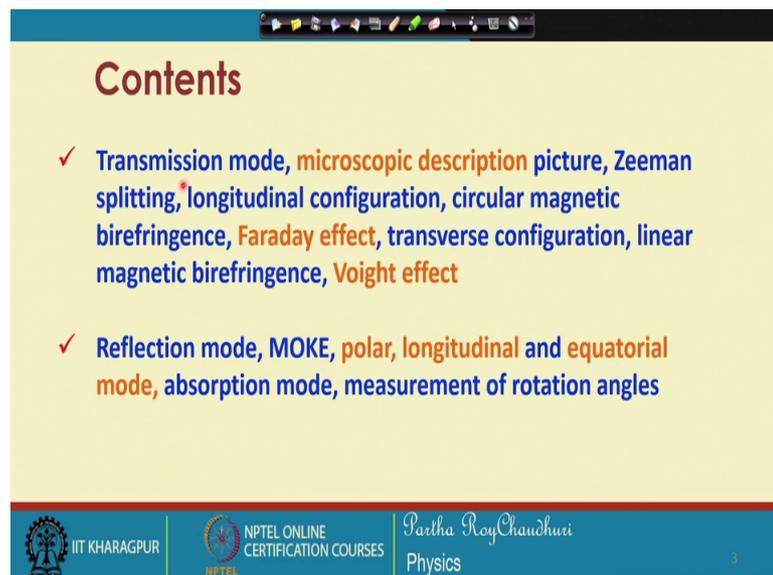
Lecture – 59
Magneto-optic Effect (Contd.)

We will continue with this Magneto-optic Effect with the Faraday rotation.

(Refer Slide Time: 00:18)



(Refer Slide Time: 00:21)



Now, this transmission mode, look at the microscopic description picture, Zeeman splitting, then other configurations like longitudinal configuration, circular magnetic birefringence, Faraday Effect we will continue with that. Then the transverse configuration, linear magnetic birefringence, Voigt effect, reflection mode, this MOKE, polar, longitudinal and equatorial mode, absorption mode, measurement of rotation angles.

(Refer Slide Time: 00:54)

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 Voigt effect

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | Partha RoyChaudhuri
Physics

So, as I mentioned that the parallel configuration is known as the Faraday Effect which we will again continue for the perpendicular configuration Voigt effect will we will take up next.

(Refer Slide Time: 01:12)

Magneto-optic effect: microscopic

Phenomenologically:
This effect is related to the normal Zeeman effect

Magnetic field causes splitting of the energy levels
shifts the original resonant frequency ν of an absorption line
to slightly higher and lower frequencies ν_1 and ν_2

Therefore, a double dispersion effect is generated
LCP light is dispersed at ν_1 and RCP light is dispersed at ν_2

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | Partha RoyChaudhuri
Physics

So, this magneto optic effect phenomenologically this is related to the normal Zeeman effect. Magnetic field causes the splitting of the energy levels which shifts the original resonant frequency ν of an absorption line to slightly higher and lower frequencies ν_1 and ν_2 .

Therefore, a double dispersion effect is generated LCP light is dispersed at a frequency ν_1 , whereas, the right circularly polarized light will be dispersed at a frequency ν_2 . So, effectively the 2 frequencies of the light will be different.

(Refer Slide Time: 01:55)

Microscopic description

Electron theory : Electronic polarisability

Wave function perturbed by electric field

Unperturbed Wave function

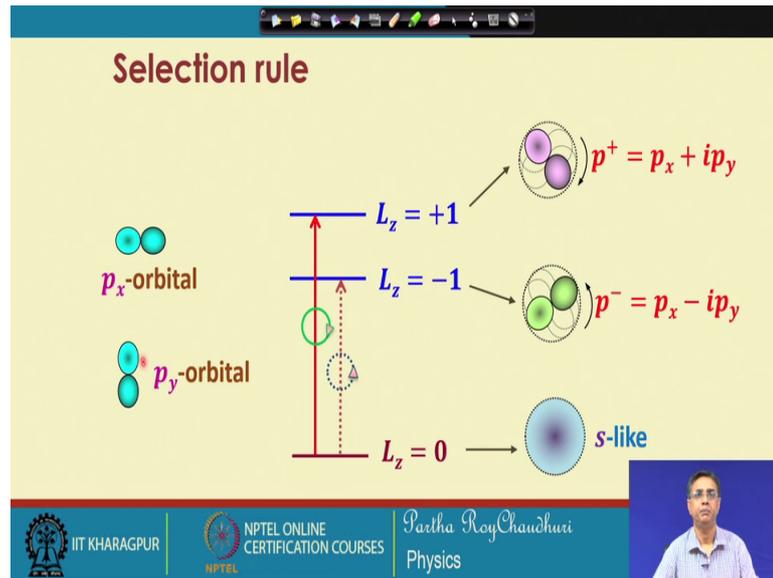
Expansion by unperturbed orbitals

S-like P-like

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | Partha RoyChaudhuri
Physics

Therefore, there will be a birefringence. See that when it is unperturbed then you have this wave function. And when it is perturbed then this wave function in presence of this there is there has been a shift, there has been a small dipole which will be the superposition of this S like and P like orbitals. So, this is expansion of the unperturbed orbitals.

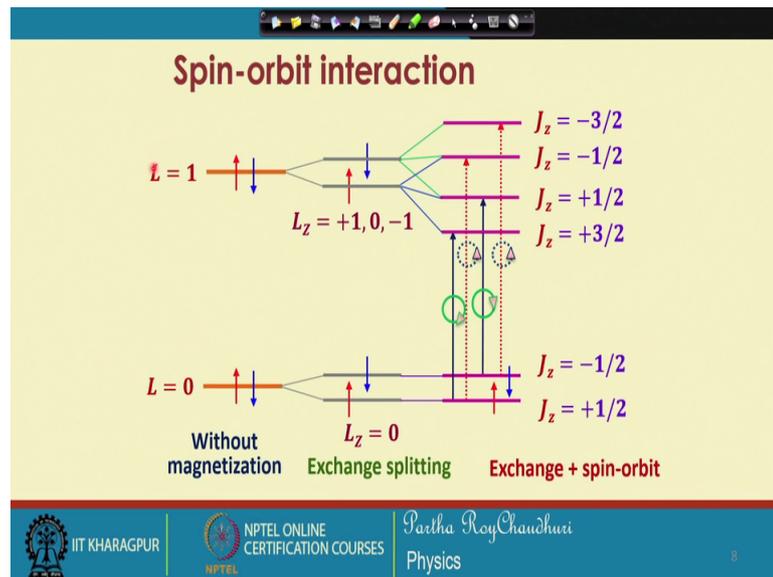
(Refer Slide Time: 02:33)



Now, this p orbitals p_x and p_y they will correspond to this p^+ which is p^+ plus which is equal to $p_x + ip_y$ and p^- these are the 2 different sense of rotation you can see that p_x this is minus of ip_y , this is plus of ip_y .

So, these 2 and they will correspond to the transition which are this right circularly and left circularly polarized light will be the interaction.

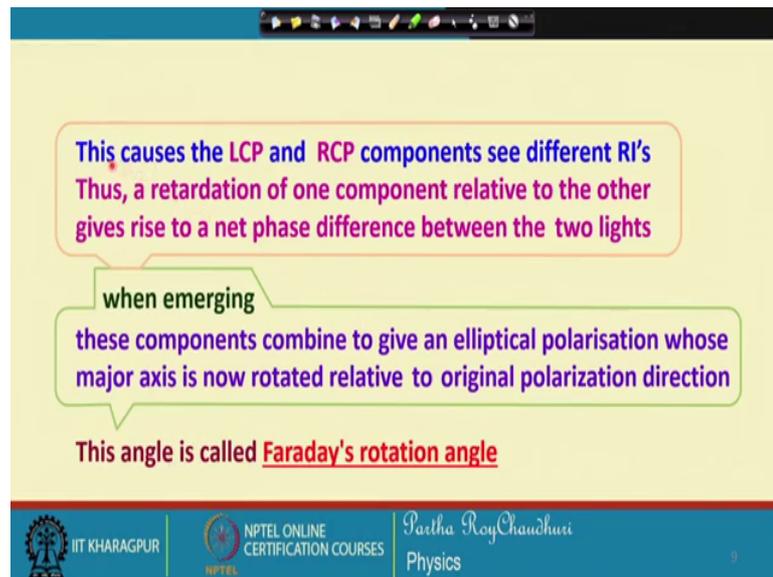
(Refer Slide Time: 03:07)



So, now the spin orbit coupling will split this L equal to 1 into effectively 4 lines 4 energy levels which are given by this. These are already known and there will be transitions from this to this which corresponds to this right circularly, from here to here this corresponds to this right circularly.

Whereas, this transition will correspond to this left circularly and similarly this transition will also correspond to the left circularly. So, without magnetization these are the energy level and then with exchange splitting you have each of them split into 2 energy levels with upward and downward transition and then this is the exchange plus spin orbit coupling, it results into this 4 transitions.

(Refer Slide Time: 04:10)



This causes the LCP and RCP components see different RI's
Thus, a retardation of one component relative to the other gives rise to a net phase difference between the two lights

when emerging
these components combine to give an elliptical polarisation whose major axis is now rotated relative to original polarization direction

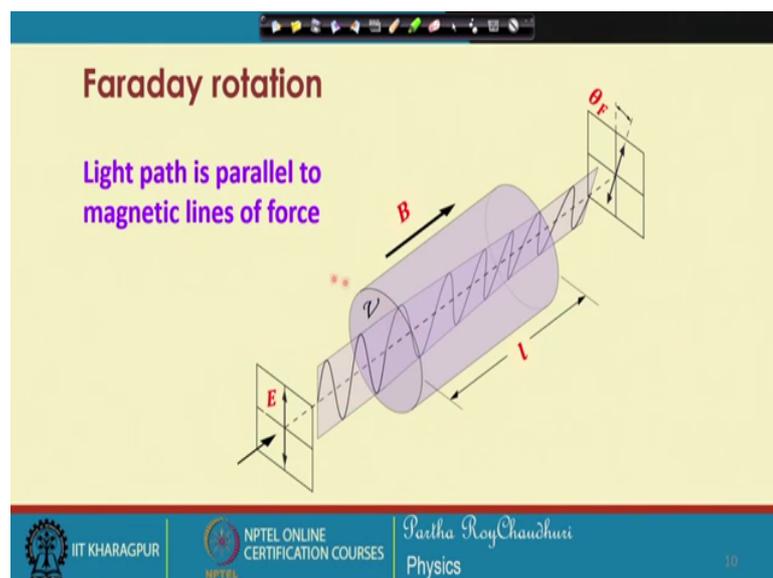
This angle is called Faraday's rotation angle

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | Partha RoyChaudhuri
Physics

Now, this causes the LCP and RCP components, different refractive indices thus a retardation of one component relative to the other that gives rise to a net phase difference between the 2 lights. And when these lights are emerging these components combine to give an elliptical polarization whose major axis is now rotated relative to the original polarization direction.

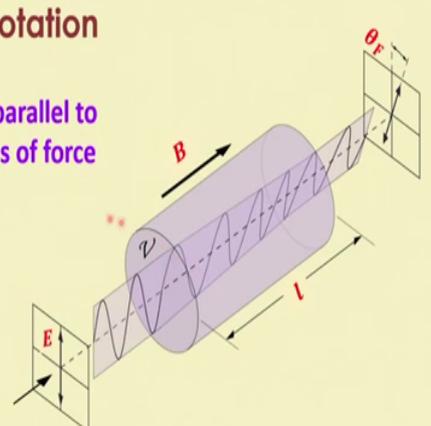
So, the angle is called the Faraday rotation angle.

(Refer Slide Time: 04:42)



Faraday rotation

Light path is parallel to magnetic lines of force



θ_F

B

E

l

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | Partha RoyChaudhuri
Physics

You can see this you have an input polarized light and the magnetic field is applied along the length of the medium. And you can see that the plane of polarization slightly rotates and when emerging from the crystal this has undergone a neat rotation of this much that is represented by Faraday theta f which is due to the. And this depends on the interaction length of the magnetic field with the optical light that is l and the magnetic field.

So, this we have seen.

(Refer Slide Time: 05:16)

Faraday rotation is directly proportional to the magnetization M , directly proportional to the length of light path in the material l

$$\theta_F = VML$$

The proportionality constant is known as the Verdet constant V

Because of linear dependence of θ on the internal magnetization, or in most cases, on the external magnetic field, Faraday effect is called an "odd" effect

The Faraday effect is referred to as circular magnetic birefringence : CMB

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | Partha Roy Chaudhuri
Physics

Now, Faraday rotation is directly proportional to the magnetization M and it is also directly proportional to the length of the light path within the material. So, this we have represented in terms of the external magnetic field b and now it is in terms of the magnetization of the material. This proportionality constant as I have mentioned is called the Verdet constant, it can be represented by the related parameters.

Because of the linear dependence of theta on the internal magnetization or in most cases on the external magnetic field Faraday Effect is called an odd effect because, it linearly the defect the rotation is linearly proportional to the magnetization M or the magnetic field b . So, it is linearly proportional.

The Faraday effect is referred to as the circular magnetic birefringence or magnetic Dichroism CMB.

(Refer Slide Time: 06:21)

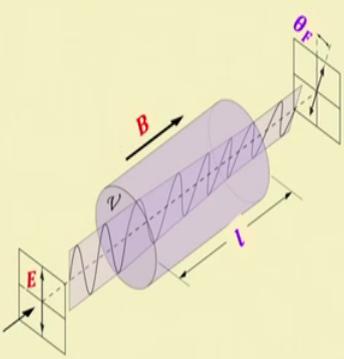
Faraday rotation

- Light path is parallel to magnetic lines of force

$$\theta_F = VMI$$

V: Verdet Constant

depends on medium properties, ambient temperature, and wavelength of light



The diagram illustrates Faraday rotation. A cylindrical medium of length l is placed between two polarizers. A magnetic field B is applied parallel to the light's path. The electric field vector E of the light wave rotates by an angle θ_F as it passes through the medium.

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | Partha RoyChaudhuri
Physics

Faraday rotation this we have seen that this Verdet constant it depends on the magnet medium properties, ambient temperature and also the wavelength of the light that is used to interact with the magnetic field within the medium.

(Refer Slide Time: 06:41)

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

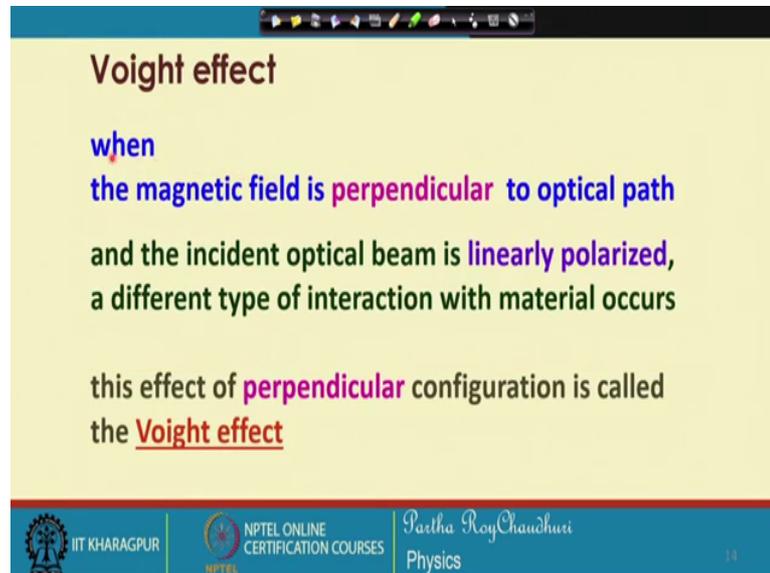
- ✓ parallel configuration is known as Faraday effect
- ✓ perpendicular configuration is the Voight effect

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | Partha RoyChaudhuri
Physics

Now, we will continue this magnetization the transmission mode magnetization in the sample could be due to the presence of external magnetic field or it could be because of the internal magnetization as I have mentioned. This magnetization could be parallel and

perpendicular, now we will consider the perpendicular configuration which is the Voigt effect.

(Refer Slide Time: 07:07)



Voigt effect

when
the magnetic field is **perpendicular** to optical path
and the incident optical beam is **linearly polarized**,
a different type of interaction with material occurs

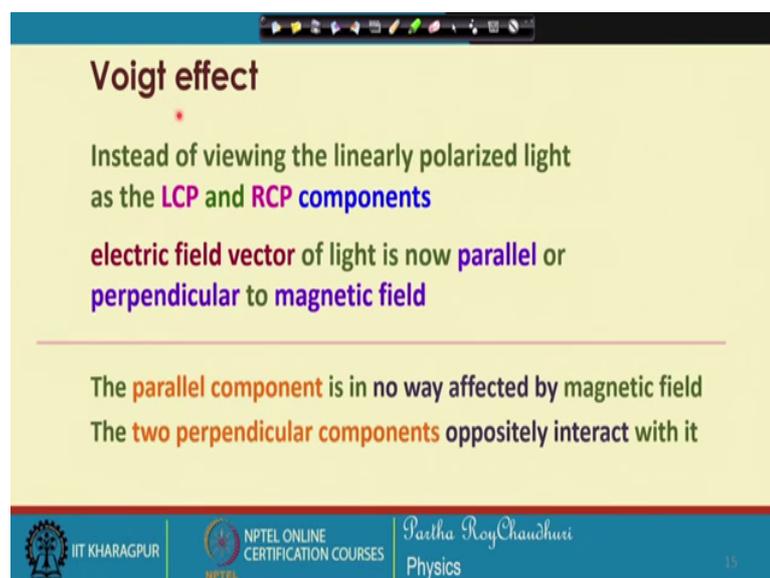
this effect of **perpendicular** configuration is called
the **Voigt effect**

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | Partha RoyChaudhuri
Physics | 14

And when the magnetic field is perpendicular to the optical path the incident optical beam is linearly polarized then a different type of interaction with the material occurs.

This effect of perpendicular configuration is known as this is the this is the definition of this Voigt effect.

(Refer Slide Time: 07:27)



Voigt effect

Instead of viewing the linearly polarized light
as the **LCP** and **RCP** components
electric field vector of light is now **parallel** or
perpendicular to magnetic field

The **parallel component** is in no way affected by magnetic field
The **two perpendicular components** oppositely interact with it

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | Partha RoyChaudhuri
Physics | 15

Instead of now, this mechanism for this we will look at in a slightly different way that instead of looking at the decomposition of a linear or a plane polarized light into the left circularly polarized light and right circularly polarized components we will see that the electric field of the light is now either parallel or perpendicular to the magnetic field.

The parallel component is no way affected by the magnetic field as you know that this electric field which is parallel to the magnetic field will not affect this. Whereas, the cross magnetic and electric field that is the 2 perpendicular components they will oppositely interact with.

(Refer Slide Time: 08:13)

Voigt effect

- ✓ Discovered in 1899
- ✓ Unequal absorption or phase shift for linear polarizations parallel and perpendicular to the magnetization direction
- ✓ Quadratic in $\sim M$ (M^2)
- ✓ Also called Cotton-Mouton effect or Linear Magnetic Dichroism (LMD)

Diagram: A purple rectangular block with an upward-pointing arrow labeled M . A red arrow labeled E_{\parallel} points along the magnetization direction, and a blue arrow labeled E_{\perp} points perpendicular to it. A dashed line indicates the intensity difference $I_{\perp} - I_{\parallel}$.

$$\begin{bmatrix} \epsilon_{xx}(m, m_j) & 0 & 0 \\ 0 & \epsilon_{yy}(m, m_j) & 0 \\ 0 & 0 & \epsilon_{zz}(m, m_j) \end{bmatrix}$$

Footer: IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | Paatha Roy Chaudhuri | Physics | 10

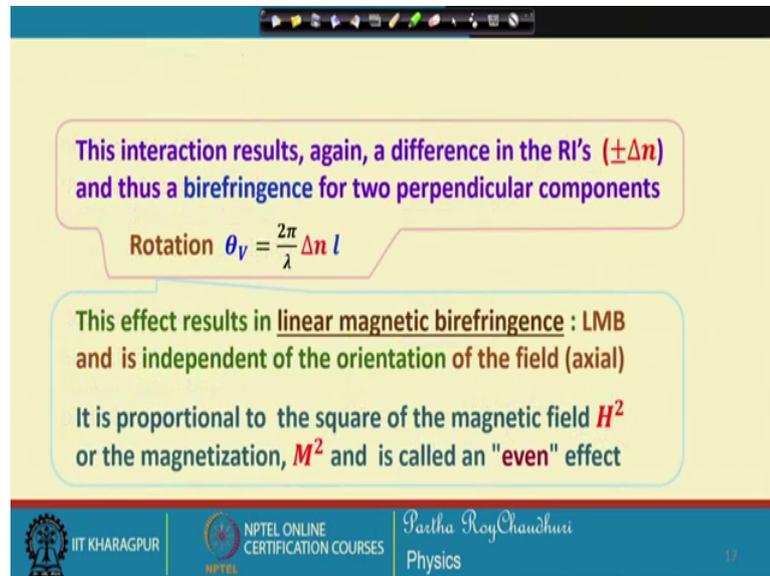
So, this effect was discovered later in 1899 the unequal absorption or phase shift of the linear polarizations which are parallel and perpendicular to the magnetization direction.

So, the light beam or the polarization of the light beam is parallel and perpendicular, it may be it may be somewhere in between this. So, we will decompose this polarization of the linear polarized light into parallel and perpendicular components. They the relevant permittivity of the medium in presence of the magnetic field we will not talk about this. This is the direction of the magnetization and this effect is quadratic in the magnetization that is the M square.

And this is also called the cotton mouton effect or linear magnetic Dichroism. So, in that case this intensity the difference of the intensity due to the perpendicular polarization and

parallel polarization will be the effective intensity available when the light beam is exiting from the medium of interaction.

(Refer Slide Time: 09:29)



This interaction results, again, a difference in the RI's ($\pm\Delta n$) and thus a birefringence for two perpendicular components

Rotation $\theta_V = \frac{2\pi}{\lambda} \Delta n l$

This effect results in **linear magnetic birefringence : LMB** and is independent of the orientation of the field (axial)

It is proportional to the square of the magnetic field H^2 or the magnetization, M^2 and is called an "even" effect

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | Partha RoyChaudhuri
Physics

So, this interaction results again in a difference of the refractive indices that is plus minus delta n.

Thus a birefringence of the 2 perpendicular components will be observed. This will lead to a rotation of the plane of polarization that is theta V this which will be equal to your $\theta_V = \frac{2\pi}{\lambda} \Delta n l$ and is proportional to the length of the medium in which the optical beam interacts with the magnetic field.

This effect results in a linear magnetic birefringence and is independent of the orientation of the field which is axial. It is proportional to the square of the magnetic field M^2 if it is we call the if we look at the magnetization of the material and if we consider the field, external magnetic field then it is proportional to H^2 . And that is why this effect is called the even effect.

(Refer Slide Time: 10:43)

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**

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | Partha RoyChaudhuri
Physics

The slide features a yellow background with a blue header and footer. The text is in various colors (green, orange, blue, brown, red) to highlight key terms. A small video inset of the presenter is visible in the bottom right corner.

So, in the reflection mode now we have reflected light from the surface of the magnetized material in all different configurations of the direction of magnetization with respect to the optical path. This effect is known as the Kerr effect magneto optic Kerr effect.

(Refer Slide Time: 11:02)

Magneto-optic Kerr effect

Kerr effect measured in reflection discovered in 1876	Faraday effect measured in transmission discovered in 1845
--	---

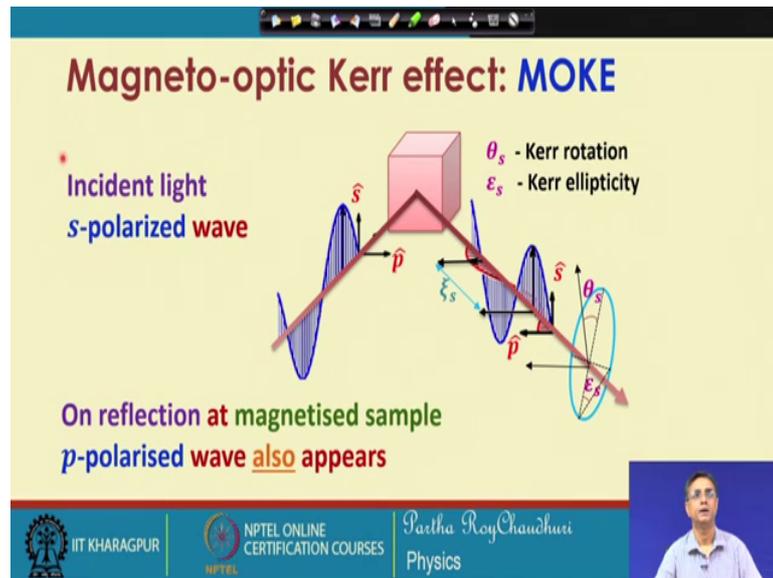
IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | Partha RoyChaudhuri
Physics

The slide has a yellow background with a blue header and footer. It compares the Kerr effect (reflection, 1876) and Faraday effect (transmission, 1845). Diagrams illustrate light reflecting off a surface with a magnetic field for the Kerr effect, and light passing through a material with a magnetic field for the Faraday effect.

You see in Kerr effect measured in the reflected light and it was discovered in the year 1876 an incident beam is incident and is reflected in presence of the magnetic field which is intersecting with this material.

And the result will be the change in the polarization properties. Whereas, in the Faraday Effect which we have seen that an optical beam is passing through the medium and the medium properties will be affected the optical properties of the medium will be influenced by the external magnetic field.

(Refer Slide Time: 11:42)



So, this magneto optic Kerr effect are called MOKE this you have an incident at as. Suppose, you have an incident s polarized light we have learnt what is s polarized light and p polarized light in the beginning of this lectures; s polarized light this is the input polarization and the perpendicular component is the p polarized light. So, when they are incident on the surface of a material or of a medium which is in a magnetic field then the reflected light will also contain p polarized light. Because, there was no p polarized light initially it was purely s polarized light and now that on reflection we can see a small component of the p polarization has appeared because of the reflection.

And there has been an effective rotation of the plane of polarization. You can see that there has been an effective rotation of the plane polarized light. On reflection at magnetized sample p polarized wave also appears as a result of this.

(Refer Slide Time: 12:54)

Magneto-optic Kerr effect: MOKE

three different configurations of the light with respect to the magnetisation in the sample:

polar, longitudinal and equatorial mode

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | Partha RoyChaudhuri Physics

Three different configurations of the light with respect to the magnetization in the sample, this tells you that when the light is incident there could be 3 possible configurations with respect to the magnetic field, magnetic field could be along this, could be along this or could be along this.

(Refer Slide Time: 13:16)

MOKE configurations

Polar MOKE **Longitudinal MOKE** **Transverse MOKE**

$M \perp$ sample surface $M \parallel$ plane of incidence $M \perp$ plane of incidence

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | Partha RoyChaudhuri Physics

So, you have 3 possible orientation of the magnetic field these are these are the orientations let us suppose we call this is x, y and z axis. So, along z axis, if the magnetic field exists then, and the incident light is being incident on this surface at this point and

getting reflected. So, this configuration is the is the polar configuration. Whereas, if the magnetic field is along this direction that is along y direction and the light beam is incident and reflected this configuration is called the longitudinal configuration.

It is it is along the along the plane of the incidence of the light beam. The other configuration is the transverse MOKE configuration that is in which the magnetic field is now perpendicular to the plane of incidence and you have the optical beam which is incident here and reflected this. So, these 3 effects are in general different.

(Refer Slide Time: 14:20)

MOKE configurations: permittivity tensors

Polarisation induced by magnetization $\Delta \vec{P}_M = \vec{M} \times \vec{E}$

$\begin{bmatrix} \epsilon_0 & -\epsilon_1 m_z & 0 \\ \epsilon_1 m_z & \epsilon_0 & 0 \\ 0 & 0 & \epsilon_0 \end{bmatrix}$	$\begin{bmatrix} \epsilon_0 & 0 & \epsilon_1 m_y \\ 0 & \epsilon_0 & 0 \\ -\epsilon_1 m_y & 0 & \epsilon_0 \end{bmatrix}$	$\begin{bmatrix} \epsilon_0 & 0 & 0 \\ 0 & \epsilon_0 & -\epsilon_1 m_x \\ 0 & \epsilon_1 m_x & \epsilon_0 \end{bmatrix}$
$\varphi_{s/p}(m_z)$	$\varphi_{s/p}(m_y)$	Δr_{pp}

IIT KHARAGPUR
NPTEL ONLINE CERTIFICATION COURSES
Partha RoyChaudhuri
Physics

So, these are the corresponding permittivity relations which are used to analyze the properties of the reflected light in presence of the in presence of magnetization of the material in 3 different orientations.

(Refer Slide Time: 14:36)

Understanding reflection mode: polar

Analysis of reflection mode is involved because of oblique incidence
One expects a mixture of all possible polarizations in each direction

A simplified analysis based on electromagnetic boundary conditions at reflecting surface for the polar configurations at normal incidence gives some insight into the effect

Fresnel coefficient for this case representing reflected amplitude is

$$r = \frac{n - 1}{n + 1}$$

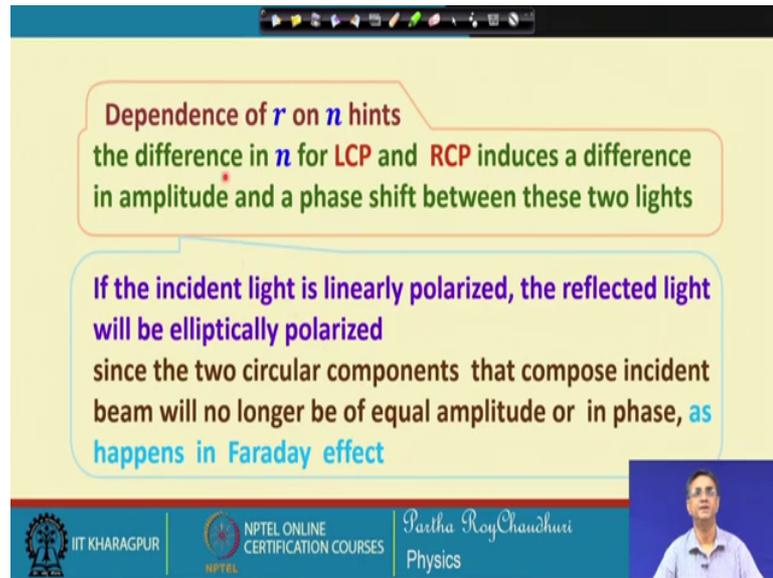
IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | Partha RoyChaudhuri
Physics 24

So, analysis of the reflection mode is actually quite involved because of the oblique nature of incidence and one expects a mixture of all possible polarizations in each direction.

A simplified analysis which is based on the electromagnetic boundary conditions at the reflecting surface for polar configurations at normal incidence give some insight into the effect. For example, if you consider the Fresnel coefficient for this case for the case of polar incidence you see this one this polar incidence you have incident light and you have reflected light. It can have s polarized light and p polarized light both the components could be present in that case because of reflection the Fresnel coefficients for normal incidence the reflected amplitude will contain this refractive index term.

And this gives the hints.

(Refer Slide Time: 15:40)

The image shows a slide from an NPTEL presentation. At the top, there is a navigation bar with various icons. The main content is on a light yellow background. A red-bordered box contains the text: "Dependence of r on n hints the difference in n for LCP and RCP induces a difference in amplitude and a phase shift between these two lights". Below this, a blue-bordered box contains the text: "If the incident light is linearly polarized, the reflected light will be elliptically polarized since the two circular components that compose incident beam will no longer be of equal amplitude or in phase, as happens in Faraday effect". At the bottom, there is a blue footer bar with the IIT Kharagpur logo, the NPTEL logo, the text "NPTEL ONLINE CERTIFICATION COURSES", the name "Partha RoyChaudhuri", and the word "Physics". A small video inset of the speaker is visible in the bottom right corner of the slide area.

Dependence of r on n the reflectivity, this reflection coefficient it depends on n that gives you the hints that the difference in the value of n for the LCP and RCP because, LCP and RCP they will be again composed of the polarizations and as a result there will be a difference in the amplitude and phase shift between the 2 lights.

If the incident light is now linearly polarized the reflected light will be elliptically polarized because of the difference the difference in the amplitude. And also the phase since the 2 circular components that compose the incident beam will no longer be of equal amplitude because of the reflection. So, because of the reflection coefficient the 2 components will have different amplitudes on reflection from the surface and as a result their amplitudes are different and also they are in phase not equal in phase and this will lead to that is as it has happened in the case of Faraday Effect. So, there will be a change in the polarization.

(Refer Slide Time: 16:57)

Magneto-optic Kerr rotation

The main axis of the ellipse rotates by an angle θ_K relative to original direction of polarization

angle θ_K is very small, of the order of minutes

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | Partha RoyChaudhuri Physics

The main axis of the ellipse now rotates by an angle theta K, this K is for Kerr rotation. So, which is relative to the original direction of our polarization angle theta K is very small of the order of minutes.

(Refer Slide Time: 17:20)

Understanding reflection mode: equatorial

In the equatorial configuration

the components of reflected lights as calculated show that **only the component parallel to the field is affected by magnetization** and its **amplitude is linearly proportional to the magnetization**

$$R_{\parallel} \propto M$$

unlike quadratic Voigt effect which has a similar configuration

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | Partha RoyChaudhuri Physics

In the equatorial configuration the components of the reflected lights as calculated show that the only component parallel to the field is affected by magnetization. And the reflected light will the amplitude of the reflected light is linearly proportional to the

strength of magnetization that is the parallel component of the reflected light the amplitude would be proportional to the magnetization value.

So, this is unlike this quadratic Voigt effect and which has a thus configuration is similar, but the effect is different.

(Refer Slide Time: 18:07)

Understanding reflection mode: equatorial

Because of this uniaxiality
when magnetization direction is reversed (antiparallel) effects directly the intensity of the reflected light

This change can be detected without using an analyser, which means considerable increase in efficiency

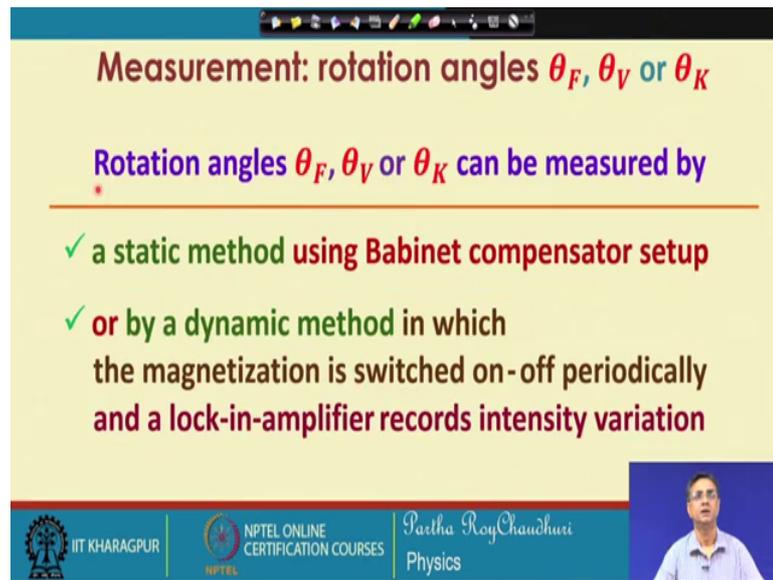
A typical value for θ_K in the visible range is about 10 minutes

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | Partha Roy Chaudhuri
Physics

Because, of the uniaxiality in the reflection mode for this equatorial configuration when magnetization direction is reversed that is anti parallel then effect this directly the intensity of the reflected light. And this change can be detected without using an analyzer which means that considerably increase in the efficiency.

This intensity measurement will be visible and that tells that the rotation is quite large a typical value of theta K in the visible range is about 10 minutes is about 10 minutes.

(Refer Slide Time: 18:47)



Measurement: rotation angles θ_F , θ_V or θ_K

Rotation angles θ_F , θ_V or θ_K can be measured by

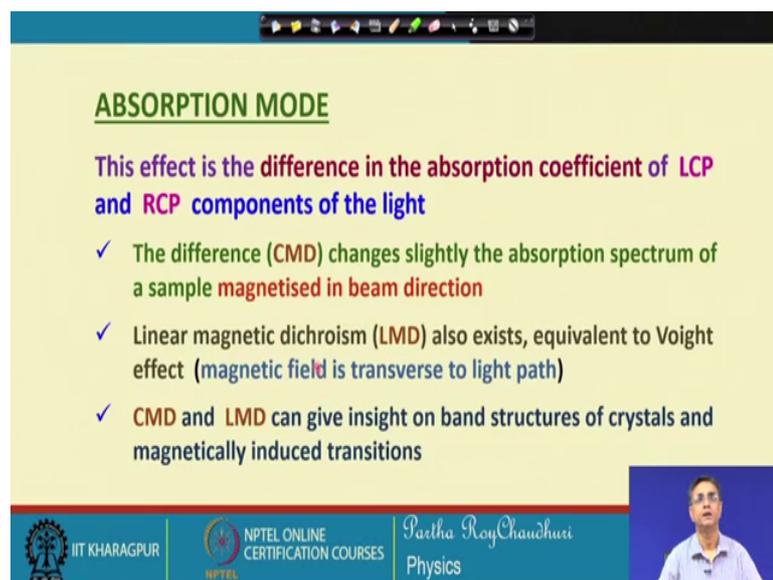
- ✓ a static method using Babinet compensator setup
- ✓ or by a dynamic method in which the magnetization is switched on-off periodically and a lock-in-amplifier records intensity variation

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | Partha RoyChaudhuri
Physics

Now, this measurement of rotation angles θ_F , θ_V and θ_K . So, rotation they can be measured by different methods static method involves using Babinet compensator polarizer and analyzer setup as a function of the change in the magnetic field.

It could be by a dynamic method in which the magnetization is periodically switched on and off and one can use a lock in amplifier that records the intensity variation as a function of the change in the magnetic field.

(Refer Slide Time: 19:31)



ABSORPTION MODE

This effect is the difference in the absorption coefficient of LCP and RCP components of the light

- ✓ The difference (CMD) changes slightly the absorption spectrum of a sample magnetised in beam direction
- ✓ Linear magnetic dichroism (LMD) also exists, equivalent to Voigt effect (magnetic field is transverse to light path)
- ✓ CMD and LMD can give insight on band structures of crystals and magnetically induced transitions

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | Partha RoyChaudhuri
Physics

So, this absorption mode in this case the this effect is the difference in the absorption coefficient of the polarizations that is polarized light that is LCP and RCP components of the light. This the difference of the polarization they slightly they are absorbed by different amount by sample of magnetized which is in the beam direction.

Then linear magnetic Dichroism that also exists which is similar to the Voight effect and magnetic field is transverse to the light path in this in this particular configuration. CMD and LMD that is this circular magnetic Dichroism, linear magnetic Dichroism they can give some insight on the they are used to can be used as in experiments to have an insight of the band structures of crystals.

And the magnetically induced transition levels to study this property they are used this circular magnetic Dichroism and linear magnetic Dichroism properties.

(Refer Slide Time: 20:47)

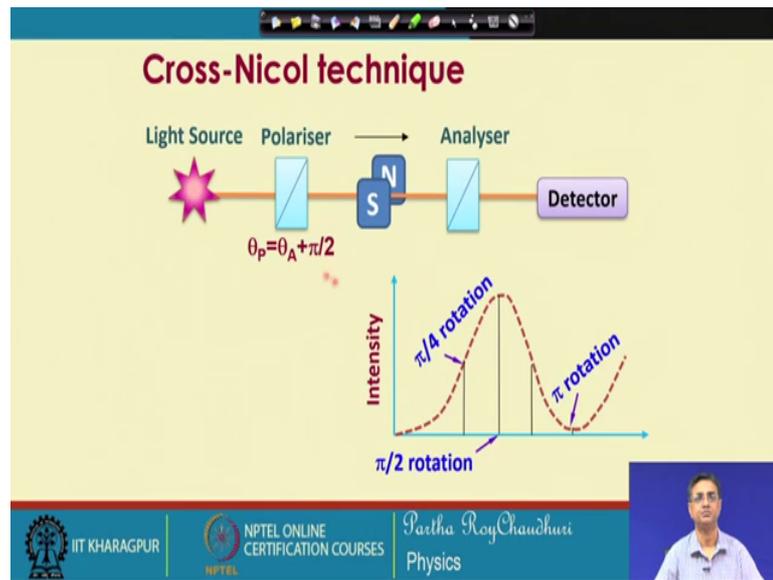
Measurement of magneto-optic effect

- ✓ Cross-polarizer technique
- ✓ Vibrating polarizer technique
- ✓ Rotating analyzer technique
- ✓ Faraday modulation technique
- ✓ Measuring system for MO spectrum
- ✓ Measurement of ellipticity

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | Partha Roy Chaudhuri
Physics

Magnetic field used problem, now this we will just look at the few methods of magneto optic measurements using cross polarizer, vibrating polarizer, measurement of ellipticity.

(Refer Slide Time: 21:04)

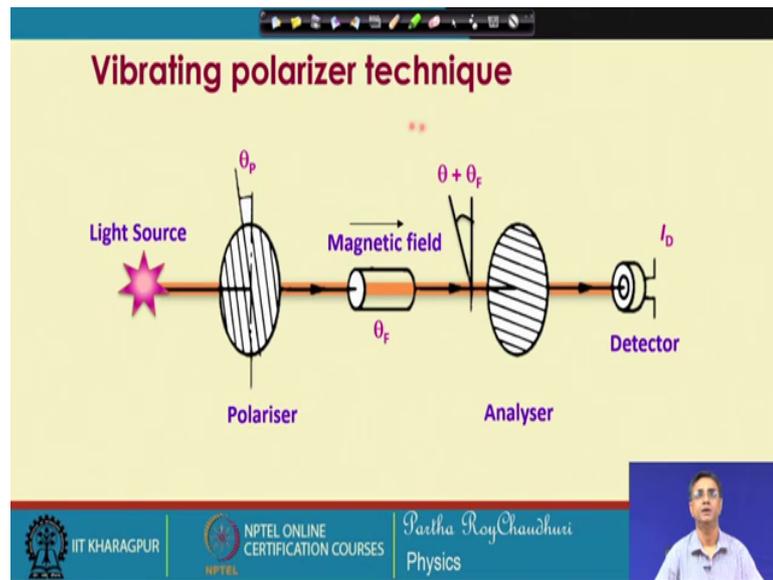


So, this crossed nicol prism technique here you have the source of light then you have a pair of nicol prisms, one is the polarizer, the other one is the analyzer. And you have a magnetic field which is perpendicular to the direction of the beam path and you measure the intensity of the light because this because of this crossed nicol prism um.

You know for this kind of amplitude modulation setup we have a pair of polarizer polarizers, one is called polarizer the other one is analyzer. And if there is a rotation of the of the polarization axis of the optical beam then the intensity varies which is detected by a detector placed in the path of the exiting light and the intensity variation as a as a function of the rotation of the plane of polarization of the optical beam is shown here.

So, this is how this is the rotation angle and this is the intensity. So, it goes through a maxima and then it becomes a minima and this will be periodically as you keep on increasing the magnetic field. So, this is again the depends on the length of interaction of the magnetic field with the with the optical beam.

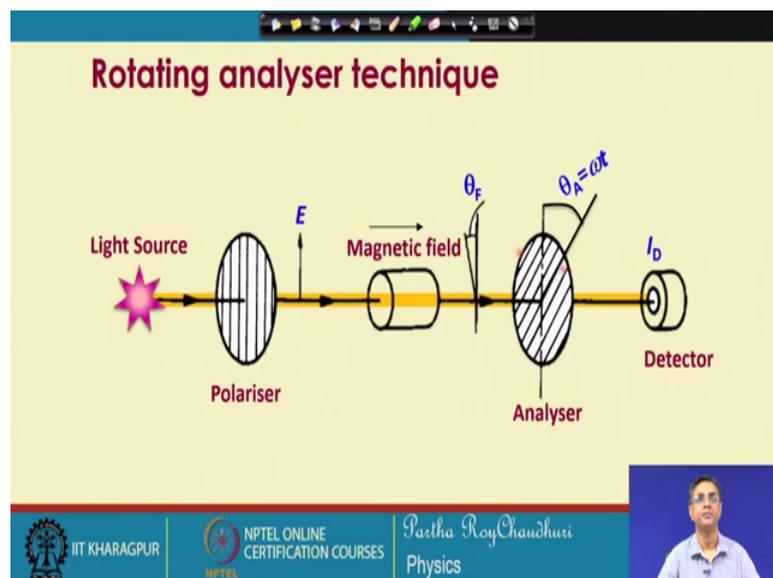
(Refer Slide Time: 22:43)



Vibrating polarizer technique here also you have a pair of polarizer and analyzer.

But, this time this magnetic field is along the along the direction of the light propagation. You can see this, you have a crystal magneto optic crystal and the light is traveling through it and you measure the detected intensity as a function of the magnetic field by a detector at the light output.

(Refer Slide Time: 23:14)

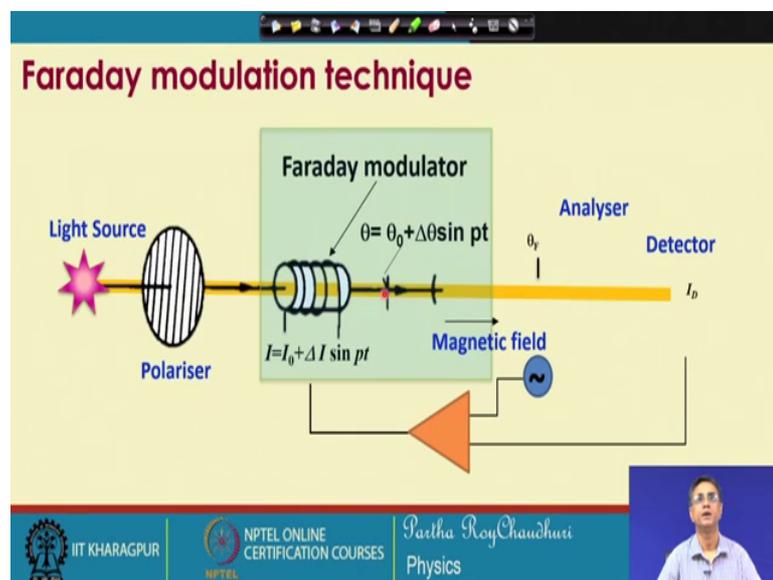


The rotating analyzer technique in this case you have the polarizer which is fixed and the analyzer is as a as a function of magnetic field because, this is again the you know

parallel configuration Faraday configuration in which the magnetic field is along the direction of the light propagation and as a function of the strength of the magnetic field the rotation occurs and because of the rotation there will be a fall in the light intensity.

But, if you rotate the analyzer then you can measure the same intensity at different rotation angle of the analyzer. So, and you note down the angle of rotation of the analyzer. So, from there we can make an estimate of the estimate of the magnetic field the rotation as a function of the magnetic field.

(Refer Slide Time: 24:19)



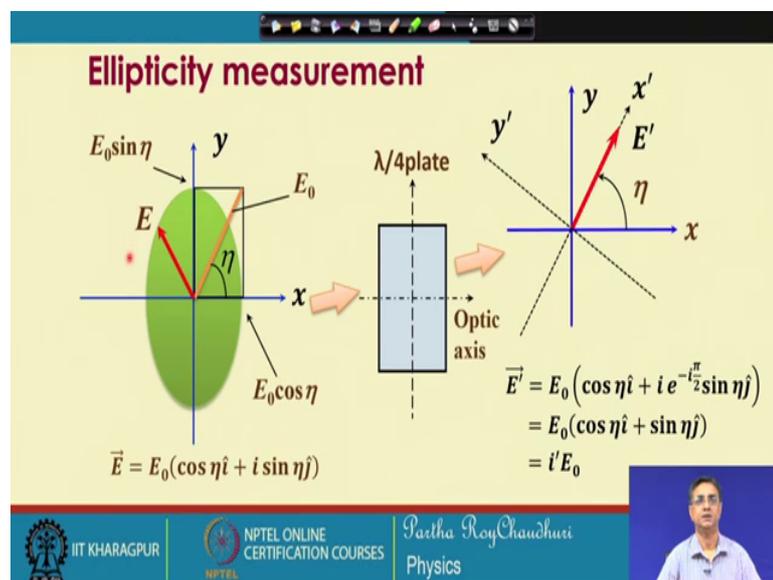
Then this Faraday rotation this is also a very good and interesting laboratory experiment. You have a polarizer and the source of light is passing through the polarizer. So, therefore, the exiting light is a plane polarized light. You have a magneto optic material and or else it could be a current passing through current passing through a solenoid which is given by I equal to I_0 plus $\Delta I \sin pt$. And as a result if the because of the variation of the current the plane of polarization variation of the current the magnetic field also varies.

And the which will result in the change in the periodic change in the plane of polarization which is detected by a detector. this magnetic field and this detector current they are fed into an Op-amp which is again connected to the system.

So, in this way which is called a Faraday modulator in which as a function of the input current the magnetic field changes. Magnetic field in turn changes varies the plane of polarization and because you have an analyzer. So, this is placed between a polarizer and analyzer therefore, the intensity also changes.

This change in the intensity will change the detector current which will which will be added through an Op-amp and then in the differential mode and you get this Faraday rotation measurement.

(Refer Slide Time: 26:19)



Now, this ellipticity measurement in this setup you have the electric field E_0 which of this of this elliptically polarized which can be decomposed into $E_0 \sin \eta$ and $E_0 \cos \eta$.

This one and you have another component. So, this goes through a quarter wave plate the resulting light can again be decomposed. So, this is the direction of the electric field E' which can be written as this because, it passes through a quarter wave plate we add a phase $\pi/2$ to the power of i and effectively this becomes $\cos \eta + \sin \eta$.

So, this is the direction of the rotation of this plane polarized light. So, in this way we can measure the ellipticity of the elliptically polarized light which is due to the as a function of the magnetic field.

(Refer Slide Time: 27:35)

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

- ✓ Transmission mode, microscopic description picture, Zeeman splitting, longitudinal configuration, circular magnetic birefringence, Faraday effect, transverse configuration, linear magnetic birefringence, Voigt effect
- ✓ Reflection mode, MOKE, polar, longitudinal and equatorial mode, absorption mode, measurement of rotation angles

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | Partha RoyChaudhuri
Physics

So, we discussed this transmission mode the microscopic description from the Zeeman splitting longitudinal and circular magnetic birefringence, Faraday rotation, Voigt effect in the 3 different configurations of the reflection mode polar longitudinal and equatorial mode, absorption mode measurement of the rotation angles because of the magnetic field.

Thank you very much.