Text Books:

Book No.	Title	Author (s)	Edition
T-1	Physics for Engineers	Dr. Giasuddin Ahmad	1st
T-2	A Text Book of Optics	N. Subrahmanyam, Brijlal	22nd
T-3	Fundamentals of Optics	Francis A. Jenkins, White	4th

Polarization of light

Ordinary light consists of transverse vibration, that is, the vibrations are at right angles to the direction of propagation of the wave. An ordinary beam of light consist millions of such waves, each with its own plane of vibration. If by some means the vibrations constituting the beam of ordinary unpolarized light are confined to one plane, the light is said to be plane polarized.

The process by which light vibrations are confined to one particular direction is known as polarization.

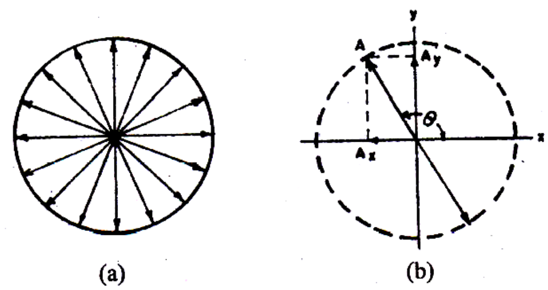


Fig.-1.1: Polarization of light

By properly constructed nicol prism of tourmaline crystal and quarter wave plate, polarized light can be obtained. Also, polarized light can be obtained Also; polarized light can be produced by reflection, refraction, and double- refraction. Polarized light are of three types, that are circularly polarized, elliptically polarized and plane polarized.

From the properties of interference and diffraction we are led to conclude that light is a wave phenomenon and we utilize these properties to measure the wavelength. These effects tell us nothing about the type of waves with which we are dealing-whether they are longitudinal or transverse, or whether the vibrations are linear, circular or torsoinal. The phenomenon of polarization has helped to establish beyond doubt that light waves are transverses waves.

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com

Polarization of transverse waves:

Let light from a source S fall on a tourmaline crystal A which is cut parallel to its axis (fig.-1.2). The crystal A will act as the slit S_1. On rotating the crystal A, no remarkable change is noticed. Now place the crystal B parallel to A.

(i) Rotate both the crystals together so that their axes are always parallel. No change is observed in the light coming out of B.

(ii) Keep the crystal A fixed and rotate the crystal B. The light transmitted through B becomes dimmer and dimmer. When B is at right angles to A, no light emerges out of B (fig.-1.2).

If the crystal B is further rotated, the intensity of coming out of it gradually increases and is maximum again when the two crystals are parallel.

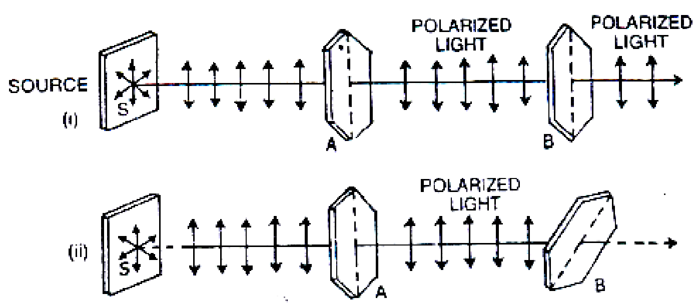


Fig.-1.2: Light waves are transverse waves

This experiment shows conclusively that light is not propagated as longitudinal or compressional waves. If we consider the propagation of light as a longitudinal wave motion then no extinction of light should occur when the crystal B is rotated. It is clear that after passing through the crystal A, the light waves vibrate only in one direction. Therefore light coming out of the crystal A is said to be polarized because it has acquired the property of one sidedness with regard to the direction of the rays.

This experiment proves that light waves are transverse waves, otherwise light coming out of B could never be extinguished by simple rotating the crystal B.

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com

Plane of polarization and vibration:

Ordinary or unpolarized light is many-sided-the many-sided being in respect of direction of vibration. When ordinary light is passed through a tourmaline crystal, the light is polarized and vibrations are confined to only one direction perpendicular to the direction of propagation of light. This is plane polarized light and it has acquired the property of sidedness.

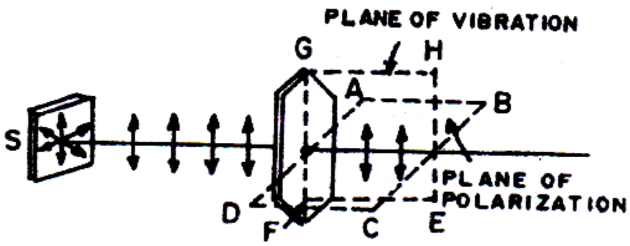


Fig.-1.3: Plane of polarization and Plane of vibration

The plane in which vibrations take place is known as the plane of vibration. The plane in which no vibrations occur is the plane of polarization and is obviously at right angles to the plane of vibration. The plane ABCD in fig-1.3 is the plane of polarization. The EFGH in fig-1.3 is the plane of vibration.

Methods of producing plane-polarized light:

There are three important methods for producing plane-polarized light. These are:

(i) by reflection: Polarization of light by reflection was first noted by Malus in 1808.

(ii) by refraction: Brewster discussed thoroughly the phenomenon of polarization by refraction in 1812.

(iii) by double refraction: The phenomenon of polarization by double refraction was first observed by Bartholinus in 1669. However, comprehensive investigations were carried out by Huygens in 1690.

Besides the methods mentioned above, polarization may also be produced by selective absorption and scattering of light.

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com

Polarization by reflection:

Polarization of light by reflection from the surface of glass was first discovered by Etienne Louis Malus in 1808. He observed that when a beam of natural light is incident on a glass surface CD along the path AB, both the reflected light along BE and the transmitted light along BM are partially polarized (fig.-1.4). The reflected light consists mostly of dot components along with a few arrow components. The transmission light mostly consists of arrow components along with a good number of dot components. This is true for all angles of incidence except one particular angle. At this particular angle of incident, none of the arrow components is reflected; they are all transmitted. Of the dot components about 15% are reflected in the case of the glass surface (The fraction refracted depends upon the refractive index of the reflecting surface), the rest being transmitted along with the arrow components. The reflected light, although weak, is completely polarized (fig.-1.4b).

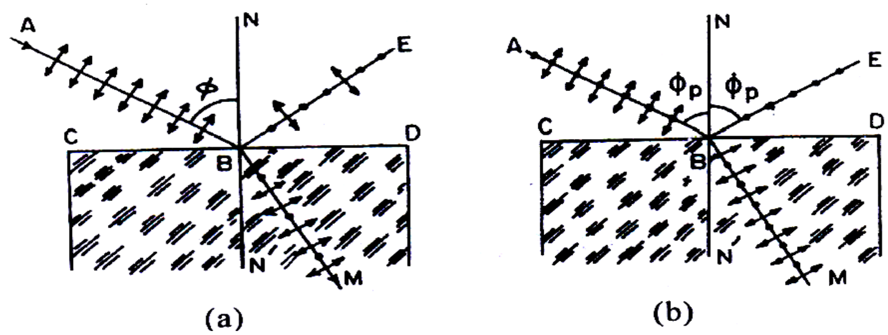


Fig.-1.4: Polarization by reflection and refraction

On the other, refracted light is strong but only partially polarized. This particular angle of incidence at which the reflected light becomes completely polarized is known as the polarized angle and is equal to 57^0 for a glass surface. At any other angle of incidence, the reflected light will not be completely polarized and will always contain a certain amount of arrow components.

Brewster's law:

Sir David Brewster, a Scottish Physicist, found experimentally in 1812 that the polarizing angle depends upon the refractive indices of the refracting material and the surrounding medium in which it is placed. According to Brewster, the tangent of the polarizing angle

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com

is equal to the refractive index of the refracting material with respect to its surroundings. This is known as Brewster's law.

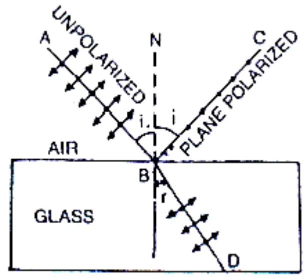


Fig.-1.5: Brewster's law for the polarizing angle

Statement:

When the angle of incidence is equal to the angle of polarization for a transparent substance, the tangent of the angle of polarization will be equal to the refractive index (μ) of the substance. Moreover, the reflected and the refracted rays are perpendicular to each other.

If ϕ be polarizing angle and μ be the refractive index of the medium, then according to the Brewster's law,

$$\mu = \tan\phi$$

Explanation:

Let an unpolarized light is incident at an angle equal to the polarizing angle on the glass-surface It is reflected along BC and refracted along BD. From Snell's law,

$$\mu = \frac{\sin i}{\sin r} = \frac{\sin\phi}{\sin r} \dots\dots\dots\dots\dots(1) \qquad [\ \phi = i\ ]$$

From Brewster's law

$$\mu = \tan\phi$$

$$= \frac{\sin\phi}{\cos\phi} \dots\dots\dots\dots\dots\dots(2)$$

Comparing equation (1) and (2), we get

$$\Rightarrow \frac{\sin\phi}{\cos\phi} = \frac{\sin\phi}{\sin r}$$

$$\Rightarrow \cos\phi = \sin r$$

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com

$$\Rightarrow \cos\phi = \cos\left(\frac{\pi}{2} - r\right)$$

$$\Rightarrow \phi = \frac{\pi}{2} - r$$

$$\Rightarrow \phi + r = \frac{\pi}{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

As $\phi + r = \frac{\pi}{2}$, $\angle CBD$ is also equal to $\frac{\pi}{2}$. Therefore, the reflected and the refracted rays are at right angles to each other.

It is not difficult to understand the physical reason why the light vibrating in the place of incidence is not reflected at Brewster's angle. The incident light sets the electrons in the atoms of the material into oscillation, and it is the re-radiation from these that generates the reflected beam. When the latter is observed at 90^0 to the refracted beam, only the vibrations that are perpendicular to the plane of incidence can contribute. Those in the plane of incidence have no component traverse to the 90^0 direction and hence cannot radiate in that direction. The reason is the same as that as that which causes the radiation from a horizontal radio-transmitter antenna to drop to zero along the direction of the wires.

Intensity of polarized light or Malus Law:

We have seen before that light, polarized by a tourmaline crystal, will pass through a second tourmaline crystal if the optic axis of this second crystal is parallel to that the first crystal. This first crystal is referred to as the polarizer while the second crystal is known as the analyzer as it helps to detect polarized light since the eye alone cannot detect if light is polarized. When the optic axes of both the polarizer and the analyzer are parallel to each other, the intensity of the emergent polarized light is maximum. Let this maximum intensity be I_o. As the analyzer is gradually rotated, the intensity of the transmitted light goes on decreasing until it becomes zero, when the optic axes of the two crystals are at right angles to each other. If the rotation of the analyzer is continued, then light gradually re-appears until the original intensity of the emergent light is restored when the analyzer has turn through 180^0 with respect to the polarizer i.e., the two optic axes again become parallel to one another. Consider the case when the analyzer has been

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com

rotated through an angle θ from its position of maximum intensity. The amplitude A of the plane polarized light incident on the analyzer can be resolved into two components perpendicular to each other. The component $A\cos\theta$ is transmitted while the component $A\sin\theta$ is either rejected or absorbed. Since the intensity is proportional to the square of the amplitude, the intensity I of the transmitted light at this position is given by

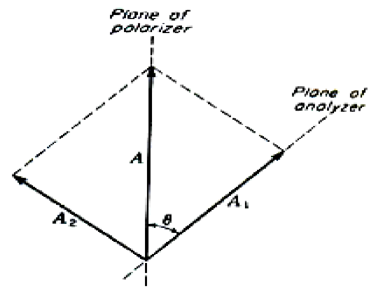


Fig.-1.6: Malus Law

$I \propto A^2 \cos^2\theta$

And also $I_0 = A^2$

$I = I_0 \cos^2\theta$; or, $\dfrac{I}{I_0} = \cos^2\theta$

This is known as Malus's cosine law according to which the intensity of the polarized light emerging from, the analyzer is proportional to the square of the cosine of the angle between the polarizer and the analyzer.

Optic axis of a crystal

Calcite and quartz are examples of anisotropic crystals, or ones in which the physical properties vary with direction. All crystals except those belonging to the cubic crystal system are anisotropic to a greater or less degree. Furthermore, the two examples chosen show the simple type of anisotropy which characterizes uniaxial crystals. In these there is a single direction called the optic axis, which is an axis of symmetry with respect to both the crystal form and the arrangement of atoms. If any property, such as the heat conductivity, is measured for different directions, it is found to be same be the same along any line perpendicular to the optic axis. At other angles it changes, reaching a maximum or a minimum along the axis. The directions of the optic axes in calcite and quartz are shown in fig.-1.7. Crystals having one optic axis are called uniaxial crystals

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com

(e.g., quartz and calcite) and those having two optic axes are called biaxial crystals (e.g., mica).

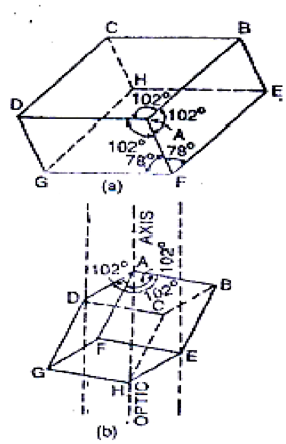


Fig.-1.7: Optic axis. The direction of the optic axis is indicated by broken line.

At two opposite corers A and H, of the rhombohedron all the angles of the faces are obtuse fig.-1.7. These corners A and H are known as the blunt corners of the crystal. A line draw through A making equal angles with each of the three edges gives the direction of the optic axis. In fact any line parallel to this line is also an optic axis. Therefore, optic axis is not a line but it is a direction. Moreover, it is not defined by joining the two blunt corners. Only in a special case, when the three edges of the crystal are equal, the line joining the two blunt corners A and H coincides with the crystallographic axis of the crystal and it gives the direction of the optic axis. If a ray of light is incident along the optic axis, then it will not split into two rays. Thus, the phenomenon of double refraction is absent when light is allowed to enter the crystal along the optic axis.

Polarization by double refraction

In 1669, Erasmus Bartholinus discovered double refraction in crystal.

When a ray of light is refracted by a crystal of calcite it gives two refracted rays. This phenomenon is known as a double refraction. The ray of light which obeys the ordinary laws of refraction is called the ordinary ray and other is called the extra-ordinary ray. The ordinary and extraordinary rays are both plane polarize.

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com

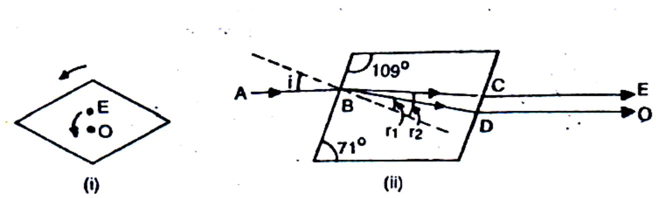


Fig.-1.8: Production of O-ray and E-ray

Marking an ink dot on a piece of paper, a calcite crystal over this dot on the paper is placed. Two images will be observed. Rotating the crystal slowly it is seen that, one image remains stationary and the second image rotates with the rotation of the crystal. The stationary image is known as the ordinary image while the second one is known as the extra ordinary image.

When a ray of light AB is incident on the calcite crystal making an incidence = i, it is refracted along two paths inside the crystal,

i. along BC making an angle of refraction $= r_2$ and

ii. along BD making an angle of refraction $= r_1$.

These two rays emerge out along DO and CE which are parallel.

The ordinary ray has a refractive index $\mu_o = \frac{\sin \mathrm{i}}{\sin \mathrm{r}_1}$, that is constant according to Snell's law. The extra-ordinary ray has a refractive index, $\mu_e = \frac{\sin \mathrm{i}}{\sin \mathrm{r}_2}$. It is found that the ordinary ray obeys the laws of refraction and its refractive index is constant. In the case of the extraordinary ray, its refractive index varies with the angle of incidence and it is not fixed. Both the rays are plane polarized. The vibrations of the ordinary ray are perpendicular to the principal sections of the crystal while vibrations of the extra-ordinary ray are in the plane of the principal sections of the crystal. Thus, the two rays are plane polarized, their vibrations being at right angles to each other.

In the case of calcite $\mu_o > \mu_e$ because r_1 is less than r_2. Therefore the velocity of light for the ordinary ray inside the crystal will be less compare to the velocity for the extraordinary ray. In calcite, the extraordinary ray travels faster as compare to the

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com

ordinary ray. Moreover, the velocity of the extraordinary ray is different in different directions because its refractive index varies with the angle of incidence.

It has been found that the rays are plane polarized. The vibrations of the ordinary ray are perpendicular to the principal section of the crystal while the vibrations of the extraordinary ray are in the plane of the principal section of the crystal. Thus, the two rays are plane polarized, their vibration being at right angles to each other.

It should be remembered that a ray of light is not split up into ordinary and extraordinary components when it is incident on calcite parallel to its optic axis. In this case, the ordinary and extraordinary rays travel along the same direction with the same velocity.

When a ray of light is incident perpendicular to the optic axis on the calcite crystal, the ray of light is not spit up into ordinary and extraordinary components. It means that the ordinary and the extraordinary rays travel in the same direction but with different velocities.

Thus, double diffraction obtained the double refraction method.

Nicol prism

In 1882, Nicol prism was invented by William Nicol.

Nicol prism is an optical device used for producing and analyzing polarized light. When a beam of light is transmitted through a calcite crystal, it is breaks up into two rays, one is Ordinary ray and another is extra-ordinary ray. Nicol prism is made in such a way that it eliminates one of the rays by Total Internal Reflection. It is eliminated and only extra-ordinary ray is transmitted through the Crystal.

Basic Principle

The basic principle behind Nicol Prism is based on its unique behaviour on the event of incidence of light rays on its surface.

When an ordinary ray of light is passed through a calcite crystal, it is broken up into two rays:

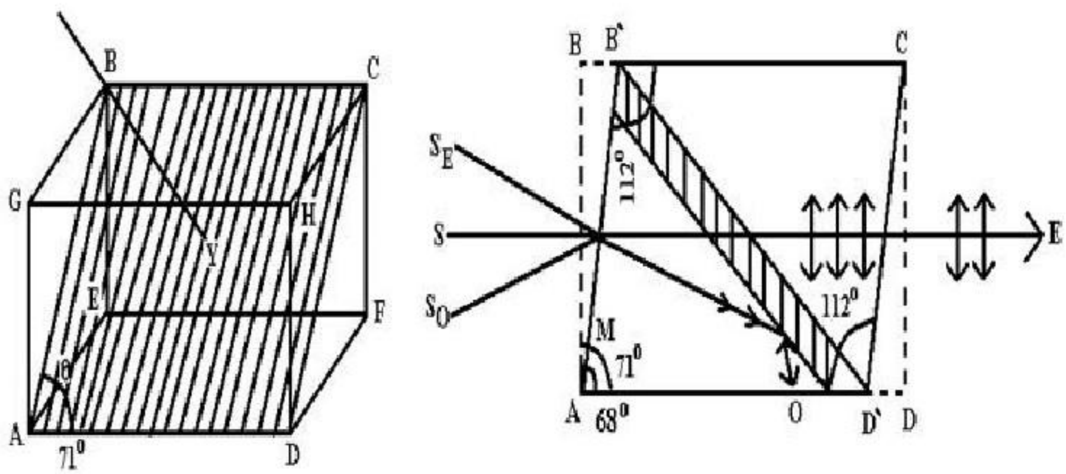
- An ‘Ordinary ray’ which is polarized and has its vibrations perpendicular to the principle section of the crystal and

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com

- An extra-ordinary ray which is polarized and whose vibration is parallel to the principle section of the prism. If by some optical means, one of the two rays eliminates, the ray emerging through the crystal will be Plane polarized. In Nicol Prism, ordinary ray is eliminated and Extra-ordinary ray, which is plane polarized, is transmitted through the prism.

Construction

A calcite crystal's length is three times its breadth. Let ADFGBC be such a crystal having ABCD as a principle section of the crystal with BAD = 70^0.



The end faces of the crystal are cut in such a way that they make angles of 68^0 and 112^0 in the principle section instead of 71^0 and 109^0. The crystal is then cut into two pieces from one blunt corner to the other along two pieces from one blunt corner to the other along a plane perpendicular to the extra ordinary rays.

1. Refractive index of Calcite for O ray, $\mu_o = 1.65836$
2. Refractive index of Canada balsam, $\mu = 1.55$
3. Refractive index Calcite of E ray, $\mu_e = 1.48641$

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com

Thus we see that the Canada Balsam is optically denser than calcite for E ray and rarer for O ray. Finally the crystal is enclosed in a tube blackened inside.

Unpolarized light incidence

When a ray SM of unpolarised light parallel to the face AD' is incident on the face AB' of the prism, it splits up into two refracted rays, the ordinary ray and the extra ordinary. Both of the O and E ray are plane polarized the vibrations of O ray being perpendicular to the principal section of the crystal; while that of E ray being in the principal section. The ordinary ray in going from calcite to Canada balsam travels from optically denser medium to a rarer medium.

The refractive index of ordinary ray with respect to Canada Balsam,

$$= \frac{\mu_0}{\mu} = \frac{1.66}{1.55}$$

$\therefore$ If θ is critical angle, we have

$$\sin\theta = \frac{1.66}{1.55} = 0.933$$

$$\theta = \sin^{-1}(0.933) = 69^o$$

As the length of calcite crystal is large, the angle of incidence at Calcite – Balsam surface for the ordinary ray is greater than the critical angle. Therefore when O ray is incident on Calcite – Balsam surfaces it is totally reflected and is finally absorbed by the side AD' which is blackened. The extra ordinary ray travels from an optically rare medium to a denser medium, therefore it is not affected by the Calcite – Balsam surface and it is therefore transmitted through the prism. This "E ray is plane polarized and had vibration, in the principal section parallel to the shorter diagonal of the end face of the crystal. Thus by Nicol prism we are able to get a single beam of place polarized light. Thus Nicol prism can be used as a polarizer.

Limitations

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com

When the angle of incidence at the crystal surface is increased, the angle of incidence at Calcite – Balsam surface decreases. When the angle S_0MS becomes greater than 14^o, the angle of incidence of Calcite – Balsam surface becomes less than the critical angle. In this position ordinary ray is also transmitted through the prism along with extraordinary ray so light emerging from Nicol prism will not be plane polarized.

When angle of incidence at crystal surface is decreased, the extraordinary ray makes less angle with the optic axis, as a result its refractive index increase, because the refractive index of calcite crystal for E ray is different in different directions through the crystal being maximum when the E ray travels at right angles to the optic axis and minimum when E ray travels along with O ray and no light emerges from the prism.

Nicol prism as polarizer

From the construction of nicol prism, it is clear that Canada balsam acts as a rarer medium for an Ordinary ray and acts as a denser medium for the extra-ordinary ray.

Therefore, when an ordinary ray passed from a portion of the crystal into the layer of Canada balsam, it passes from denser to a rarer. When the angle of incidence is grater than the critical angle θ, the ray is totally internal reflected and is not transmitted. The extra-ordinary ray is not affected and is therefore transmitted through the prism. Therefore a ray of unpolarized light on passing through the nicol in this position became plane polarized, i.e., the nicol prism act as a polarizer.

Nicol prism as analyzer

Consider two Nicol prisms arranged coaxially one after another. When a beam of unpolarized light is incident on the first prism P, the emergent beam is plane polarized with its vibrations in principal section of first prism. This prism is called polarizer. When principal sections of both prisms are parallel then intensity of emergent light is maximum. But when the principal sections are at right angles to each other the, intensity of emergent light is minimum i.e., there no light it transmitted through the second prism. Here first prism produced plane polarized light and 2nd prism detects and analyses it.

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com

Application:

A Nicol prism can be used for the production (polarizer) and detection (analyzer) of plane polarized light. Two Nicol prisms are frequently lined up co-axially one behind the other in an arrangement as shown in fig.-1.9.

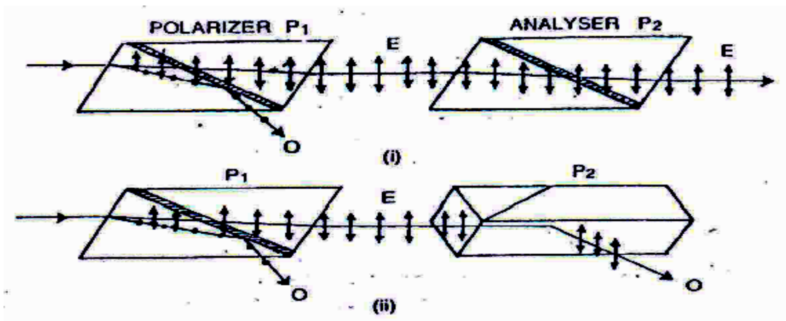


Fig.-1.9: The position of the polarizer and analyzer

This arrangement is frequently used in specially constructed instruments for studying the optical properties of other crystals. The first crystal N_1 which produces plane polarized light is called the polarizer while the second Nicol N_2 which analyzes the incoming light is called the analyzer. When the two Nicol prisms are places with their principle sections parallel to each other, Then the vibrations of the E-ray which is in the principle section of N_1 is freely transmitted by N_2. This setting of the Nicols is known as parallel position and the intensity of the light in this position is maximum. If the second Nicol is gradually rotated, the intensity of the transmitted E-ray goes on decreasing in accordance with Malus Law till it becomes zero when the principle sections of the two Nicols are at right angle to each other. This is so because the E-ray coming out from the first Nicol becomes an O-ray for the second Nicola and is, therefore, totally internal reflected. This position of the Nicols is known as crossed position. If I_o be the intensity of transmitted light in the parallel position of the Nicols and I_θ the intensity when the principle sections are inclined at an angle θ, then according to Malus cosine law

$$I_\theta = I_o \cos^2\theta$$

If is further rotated so that it has turned through an angle 180^o, the E-ray will be freely transmitted again.

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com

Retardation plates:

If natural light is allowed to fall normally on a plate of doubly refracting uni-axial crystal whose refracting faces are cut parallel to its optic axis, then the ordinary and extra-ordinary lights travel along the same path but with different speeds. As they travel through the crystal, increasing path difference and hence phase difference is produces between the two rays are called Retardation plates. The path difference produced may be deduced in the following manner.

If t is the thickness of the plate then, within the plate, the optical path for the E-ray is $\mu_e t$ and that for the O-ray is $\mu_o t$, where μ_e and μ_o are the refactive indices for the extra-ordinary and ordinary rays respectively. The path difference is, therefore,

$$\Delta = (\mu_o - \mu_e)\, t \qquad \text{where } \mu_o > \mu_e$$

$$\Delta = (\mu_e - \mu_o)\, t \qquad \text{where } \mu_e > \mu_o$$

The corresponding phase difference between the two rays is, therefore, given by

$$\delta = \frac{2\pi}{\lambda}\Delta = \frac{2\pi}{\lambda}(\mu_o - \mu_e)\mathrm{t} \qquad \text{where } \mu_o > \mu_e$$

$$\delta = \frac{2\pi}{\lambda}\Delta = \frac{2\pi}{\lambda}(\mu_e - \mu_o)\mathrm{t} \qquad \text{where } \mu_e > \mu_o$$

Two such retardation plates are commonly used. They are

(1) Quarter-wave plate:

$$(\mu_o - \mu_e)\mathrm{t} = \frac{\lambda}{4} \quad \text{or,}\ \mathrm{t} = \frac{\lambda}{4(\mu_o - \mu_e)}$$

And (2) Half-wave plate:

$$(\mu_o - \mu_e)\mathrm{t} = \frac{\lambda}{2} \quad \text{or,}\ \mathrm{t} = \frac{\lambda}{2(\mu_o - \mu_e)}$$

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com

Dichroism-polarization by selection by selective absorption:

When ordinary light enters certain crystals and minerals such as tourmaline, double refraction takes place in much the same way that it does in calcite, but with his difference: the O-ray is much strongly absorbed than the E-ray. Hence if such a crystal is cut of the proper thickness, the O-ray is completely extinguished by absorption while the E-ray is transmitted in appreciable amount.

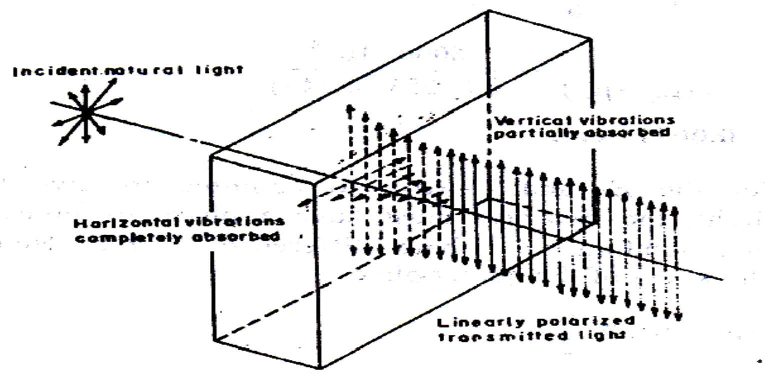


Fig.-1.10: Dichroic

Polaroid:

In 1852, W. H. Herapath, an English physicist, discovered that small crystals of quinine iodosulphate, called herapathite after its discover, exhibit strong dichroism-they completely absorb one component of polarization while transmitting the other with transmission close to the ideal 50 percent for all wavelengths of visible light. But these crystals are not stable and are affected by slightest strain. They are, therefore, quite useless as such. But the potential usefulness of this material led to extensive research, culmination in the invention by E. H. Land in 1932 of a process which arranges herapathite crystals side by side, oriented with their optic axis all parallel, so that they function as a single crystal of large dimension. This is achieved by preparing a paste of the crystals in nitrocellulose, which is then squeezed out through a fine slit. Obviously, only those crystals pass whose axis are parallel to the length of the slit, thereby producing fine sheet of millions of tiny crystals, with their optic axis parallel to each other. This fine sheet, about 0.001 to 0.004 inches thick, is then mounted between two thin sheets of glass forming what is now called Polaroid.

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com

More recently Polaroid materials have been prepared by aligning molecules rather than the tiny crystals. One of these consists of aligned molecules of polymeric iodine in a sheet of polyvinyl alcohol. Polyvinyl alcohol films are stretched to line up the complex molecules and then are impregnated with iodine. It was discovered by X-ray diffraction studies of these dichroic films that the iodine is present in polymeric form, i.e., as independent long strings of iodine atoms all lying parallel to the fiber axis, with a periodicity in this direction of about 3.12 A.U.. Films prepared in this way are called H-Polaroid. It was subsequently found by Land and Rogers that when an oriented transparent film of polyvinyl alcohol is heated in presence of an active dehydrating catalyst such as hydrogen chloride, the film darkness slightly and becomes strongly dichroic. Such a film becomes very stable and having no dyestuffs, is not bleached by strong sunlight. This is referred to as K-Polaroid.

Although the light transmitted by the Polaroid is slightly coloured, they fine wide applications in everyday life. The most common use of Polaroid is in sun-glasses.

Polaroids are fitted in motor car head-lights and wind-screen so that the driver can see the light of his own head-light while that from the oncoming car is cut off. They are also used in glass windows of train and aeroplanes. In aeroplanes one of the Polaroids is fixed while the other can be rotated to control the amount of light coming in. Polaroid films are used to produce three-dimensional motion picture.

Optical activity:

If a plane-polarized light be made pass through some substances, then it will be found that the direction of vibration of the emergent light is not the same as that of incident light. The direction of vibration of the incident light has rotated by a certain angle, after being transmitted through the substance. This phenomenon is called optical activity or rotation of the plane polarization and the substances which rotates the direction of vibration of the incident polarized light is called optically active substances like sugar crystals, sugar solution, turpentine, sodium chlorate and cinnabar.

The property of rotating the plane of vibration plane polarized light about its direction of propagation possessed by certain crystals or substances is known as optical activity.

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com

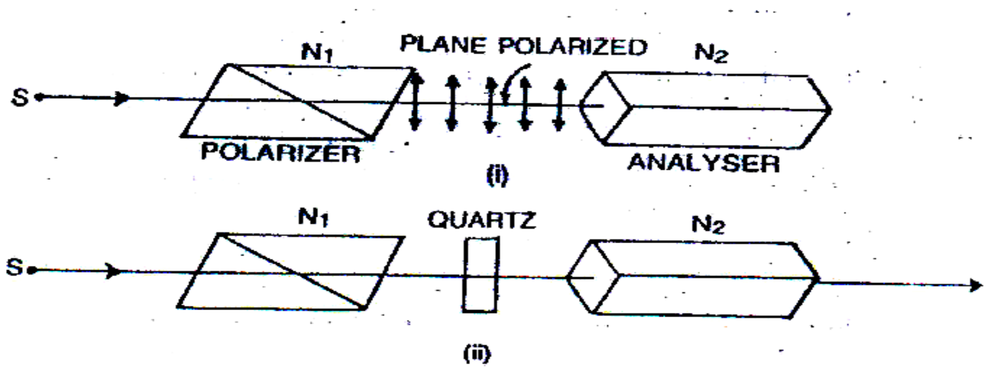


Fig.-1.11: Optical activity

Optical activite substance:

We know that when the light travels along the optical axis there is no double refraction. In this particular direction one expects that any kind of light will be propagated without changes. As early as 1811, however Arago discovered exceptions to this simple rule. He found that certain substance, notably crystalline quartz, will restore the light when placed between crossed Nicols even through the optic axis is parallel to the direction of light.

Specific Rotation:

Liquids containing an optically active substance, e.g., sugar solution, camphor in alcohol, etc, rotate the plane of the linearly polarized light. The angle through which the plane polarized light is rotated depends upon

1) The thickness of the medium.

2) Concentration of the solution or density of the active substance in the solvent.

3) Wavelength of light and

4) Temperature.

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com

Thus $\theta \propto l\,c$

$$\theta = S l\,c$$

$$S = \frac{\theta}{l c}$$

Where θ is the angle of rotation produced, l is the length of the solution through which the plane polarized light passes in decimeters, c is concentration of the active substance in gm/cm^3 in the solution and S is a constant called specific rotation and depends upon the nature of the substance.

If l = 1 decimeter and c = 1 gm/cm^3 then specific rotation may defined as the rotation produced while traversing a path of one decimeter (10 cm) length in the solution containing 1 gm of the optically active substance per cm^3 of the solution (density in unit). The amount of rotation depends upon (a) the temperature and (b) wavelength of the light used. So for a given temperature and a given wavelength

$$Specific rotation = \frac{\text{Rotation produced by 1 decimeter length of the solution}}{\text{Density of the solution in gm. per c.c.}}$$

$$= \frac{\theta}{l/10} \div c = \frac{10\,\theta}{l\,c}$$

$$S_\lambda^t = \frac{10\,\theta}{l\,c} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where S_λ^t represents the specific rotation at temperature t^oC for a wavelength λ. Specific rotation is a constant for a specific solution and also called rotatory power of the solution.

The specific rotation of dextro-rotatory substance is taken as positive while that of a laevo-rotatory substance is considered as negative.

Instrument used for determining the angle through which plane of polarization is rotated by the optically active substance are called polarimeter.

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com

Laurent's half –shade polarimeter:

Construction:

The essential parts of a Laurent half-shade polarimeter is shown in Fig.-1.12. It consists of a Nicol prism N_1 which acts as the polarizer while the second Nicol prism N_2 which can be rotated, acts as the analyzer. Behind N_1, there is a plate QG which is known as the Laurent's half-shade plate and is used for accurately adjusting the two Nicols in the crossed position. T is a hollow glass tube having a comparatively larger bore at its middle portion T_1. When the tube is filled with the solution containing the optically active substance and the two ends are closed with cover-slips and metal covers, there should not be any air bubble in the path of the light. If there are any air bubbles, they will appear at the upper portion of the wide bore T_1 of the tube. This will ensure that there will not be any air bubble in the path of light. SC is a circular scale for measuring the angle of rotation of N_2. The emergent light is viewed by thy telescope E.

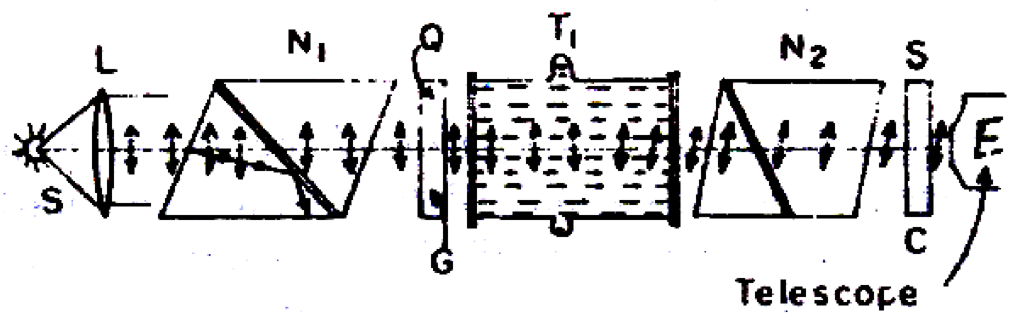


Fig.-1.12: Laurent's half –shade polarimeter

Working Details:

light from a monochromatic source S (usually a sodium flame) is rendered parallel by the collimating lens L and falls on the polarizing Nicol N_1 .After passing through N_1 ,the beam becomes plane polarized and falls on the Laurent's half-shade plate. By placing this plate in front of the Nicol N_2 the accuracy with which the position of minimum intensity for the analyzing Nicol N_2 can be determined is greatly increased. Laurent's half-shade plate consists of two semi-circular plates, one ADB of glass and the other ACB of quartz cemented together along their diameter AB (fig.-1.13).

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com

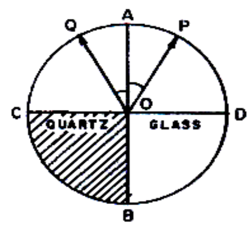


Fig.-1.13: Laurent's half –shade plate

This glass plate is of such thickness that it absorbs and transmits the same amount of light as done by the quartz portion. Half the beam of plane polarized light passes through the quartz plate and the other half passes through the glass plate. Let the optic axis of the quartz plate lie along the line AB and let its thickness be such that it corresponds to a path difference of half wave-length ($\lambda/2$) of the light used.

Let OP be the direction of vibration of the plane polarized light just before it enters the half shade plate. In the glass half the light will be transmitted with direction of vibration unchanged i.e., along OP inclined at an angle θ to the optic axis AB of the quartz half. But the plate is so constructed that in the quartz half, the direction of vibration of the emergent beam will be along OQ making the same angle θ with the optic axis as does OP i.e., inclined at 2θ to OP. Now, if the analyzing Nicol N_2 is placed with its principal plane perpendicular to OP, then it will stop all light in the glass half, but transmit some light in the quartz half. On the other hand, if it is held perpendicular to OQ, the quartz half will be completely dark but the glass half will transmit some light. The Nicol N_2 is usually adjusted midway between these two contrasts so that both halves are equally bright, and obviously the principal plane of the Nicol is parallel to OA. If the analyzing Nicol is slightly rotated towards the right then the right side will be much brighter than the left and vice versa. Thus any slight rotation of the analyzer in either direction of AB produces sharp differences in the illumination of the two halves.

To determine the specific rotation of an optically active substance, e.g., a sugar solution, the procedure to be adopted is as follows:

The Nicol N_1 is illuminated with some monochromatic light. The analyzer N_2 is set in the position for equal brightness (or darkness) in the field of view, first without any solution in the tube T. The reading in the circular scale SC is noted. Then the tube T is filled up with a solution of known concentration. On introducing the tube T filled with the solution, the field of view will no longer be equally bright (or dark). The analyzer is

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com

rotated in the clockwise direction until the whole field of view is again equally bright (or dark). The reading in the circular scale is noted again. The difference between the two readings i.e., the angle through which the analyzer has been rotated, gives the angle through which the plane of vibration of the incident beam has been rotated by the sugar solution. In actual experiment, angles of rotations are determined corresponding to various concentrations of sugar solution. When θ is plotted against concentration c, the graph is straight line (Fig.-1.14). Specific rotation is then determined from the relation

$$S = \frac{10\theta}{l\,c}$$

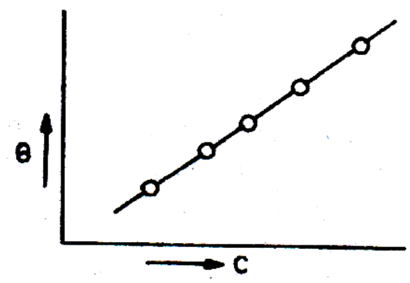


Fig.-1.14

where θ is the angle of rotation corresponding to a concentration as obtained from the graph.

The specific rotation of a substance depends upon the wavelength of light used and the temperature of the substance. It is usually denoted by S_{λ}^{t}.

<u>Mathematical problem:</u>

1. The refractive index for glass is **1.52**. Calculate its polarizing angle and angle of refraction for a ray of light incident.

Solution:

From Brewster's Law, $\mu = \tan\phi$

$or, \phi = \tan^{-1}\mu = \tan^{-1}(1.52) = 56.7^0$

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com

Now $\phi + \text{r} = 90^0$

or, $\text{r} = 90^0 - \phi = 90^0 - 56.7^0 = 33.3^0$

2. A quartz quarter-wave plate and half-wave plate with refractive indices $\boldsymbol{\mu_o} = \mathbf{1.544}$ and $\boldsymbol{\mu_e} = \mathbf{1.553}$ is to be used with sodium light $(\boldsymbol{\lambda} = \mathbf{5893}\text{Å})$. Calculate the thickness of the plate.

Solution:

Here $\mu_o = 1.544$ and $\mu_e = 1.553$ and $\lambda = 5893\text{Å} = 5893 \times 10^{-8}\,cm$

Quarter-wave plate:

$$\text{t} = \frac{\lambda}{4(\mu_e - \mu_0)} = \frac{5893 \times 10^{-8}}{4(1.553\text{-}1.544)} = 1.637 \times 10^{-3}\,cm.$$

Half-wave plate:

$$\text{t} = \frac{\lambda}{2(\mu_e - \mu_0)} = \frac{5893 \times 10^{-8}}{2(1.553\text{-}1.544)} = 3.27 \times 10^{-3}\,cm.$$

3. A tube of sugar solution **20 cm** long is placed between crossed nicols and illuminated with light of wavelength $\mathbf{6 \times 10^{-5}}$ **cm.** If the optical rotation produced is $\mathbf{13^o}$ and the specific rotation is $\mathbf{65^o}$, determine the strength of the solution.

Solution:

Here $S = 65^0$, $l = 20\,\text{cm}$ and $\theta = 13^0$

$$S = \frac{10\,\theta}{l\,c}$$

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com

$$\text{or, } c = \frac{10\theta}{l\,S} = \frac{10\times 13}{20\times 65} = 0.1\,\text{gm}/\text{cm}^3.$$

4. Calculate the specific rotation of sugar if the plane of vibration is turned through **26.4^0**, traversing **20 cm** length of **20%** sugar solution.

Solution:

Here $c = 20\% = 0.2\,\text{gm}/\text{cm}^3$, $l = 20\,\text{cm}$ and $\theta = 26.4^0$

$$S = \frac{10\theta}{l\,c}$$

$$\text{or, } S = \frac{10\times 26.4}{20\times 0.2} = 66^0.$$

5. How will you orient the polarizer and the analyzer so that a beam of natural light is reduced to (i) 0.125. (ii) 0.25, (iii) 0.5 and (iv) 0.75 of its original intensity?
6. Intensity of light through a polarizer and analyzer is maximum when their principal planes are parallel. Through what angle the analyzing nicol must be rotated so that the intensity gets reduced to 1/4 of the maximum value.
7. The critical angle for certain wavelength of light in the case of a piece of glass is 40^0. Find the polarizing angle for glass.

<u>Physics for Engineers- Dr. Giasuddin Ahmad (1st Edition)</u>

Mathematical Problem:
Example: 30.1-30.12.

<u>A Text Book of Optics- N. Subrahmanyam, Brijlal (22nd Edition)</u>
Mathematical Problem:
Example: 10.2-10.11, 10.14-10.19.

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com

Exercises

1. Discuss polarization of light.
2. Describe an experiment that can prove that light wave is transverse in nature.
3. Explain plane of polarization and plane of vibration.
4. Describe how plane polarized light can be produce by reflection.

or,

4. How will you obtain and detect plane polarized light by reflection?

or,

4. Describe the process of production of plane polarized light by reflection.
5. Explain Brewster's Law. From this law, show that when light is incident on a transparent substance at the polarizing angle, the reflected and refracted rays are at right angles.

or,

5. State Brewster's Law. Show that at the polarizing angle of incidence, the reflected and refracted rays are mutually perpendicular to each other.
6. Explain the phenomenon of double refraction in a calcite crystal.

or,

6. Describe how plane polarized light can be produce by double refraction.
7. Define Nicol prism. Describe its basic principle.

or,

7. Describe the construction of a Nicol prism and explain how it can be used as a polarizer and analyzer.

or,

7. Write short note on Nicol prism.
8. Describe specific rotation.
9. Describe construction and working formula (principle) of Laurent's half–shade polarimeter.

Prof. Dr. H. M. A. R. Maruf
Department of Physics, CUET
E-mail: hasnatmaruf@gmail.com