Engineering Physics 1
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Module-01
Lecture-05
Optical Activity

This is the fifth lecture, the last one of the five lecture series on polarization. In the last lecture which was the fourth one, we studied interference of plane polarized light and considered different types of polarizations and their analysis. See, we studied the working of quarter wave plate and halfway place. These are the plates made of calcite or quartz cut such as that the optic axis is in the plane; the incidence is kept normal.

The propagation is along the optic axis. The extraordinary and ordinary within the crystal, they travel with different speeds.

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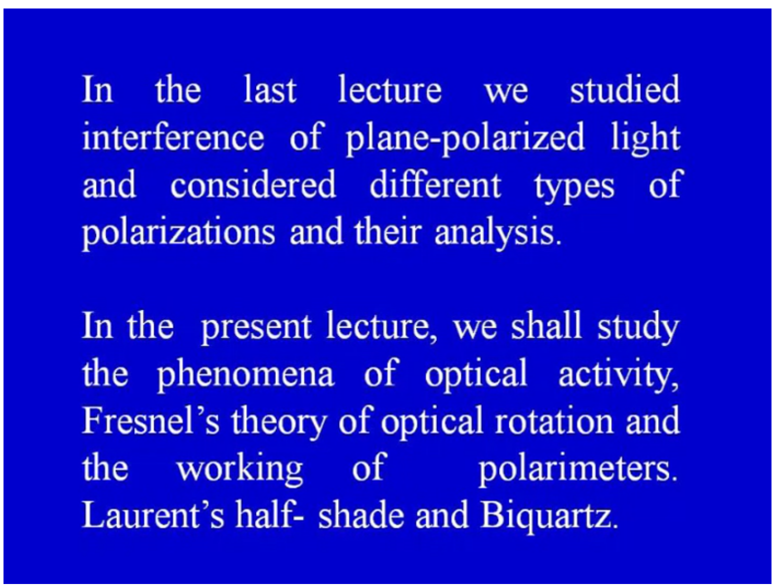

There is no separation between them. And when they come out, there is a phase difference between them, depending on the thickness. It is of a cone of lambda by 2 path difference in a half wave plate and lambda by 4 path difference in the quarter wave plate, leading to, reducing light of different polarizations. We also studied analysis of bed of different types of polarizations, the mixtures of them plane polarized, circularly polarized, elliptically polarized lights.

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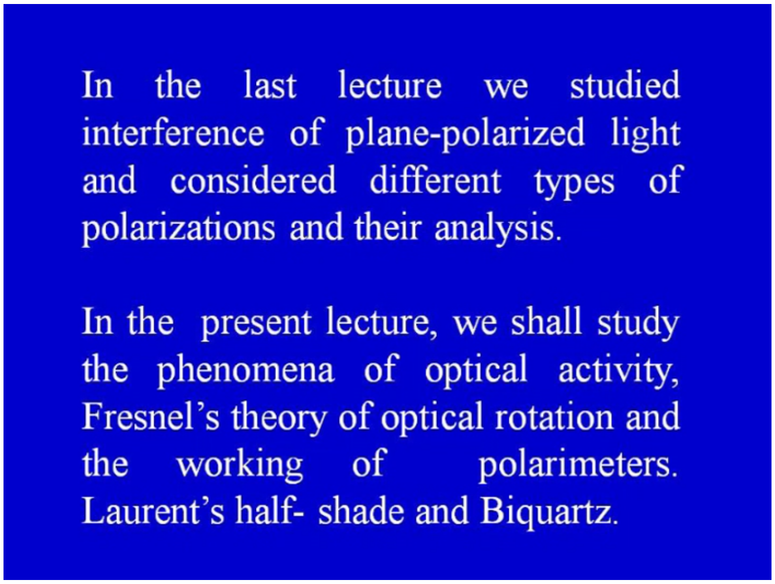

Just with the help of a polarizer working as an analyzer and a quarter wave plate. Now, in the present lecture, which is the last one, we shall study the phenomena of optical activity, the very interesting property of some substances. We shall go through Fresnel's theory of optical rotation which explains the phenomena and then, the working of polarimeters, half-shade polarimeter and Biquartz polarimeter.

Polarimeters are the instruments which measure the optical activity which measure the angle through which the plane of polarization gets rotated.

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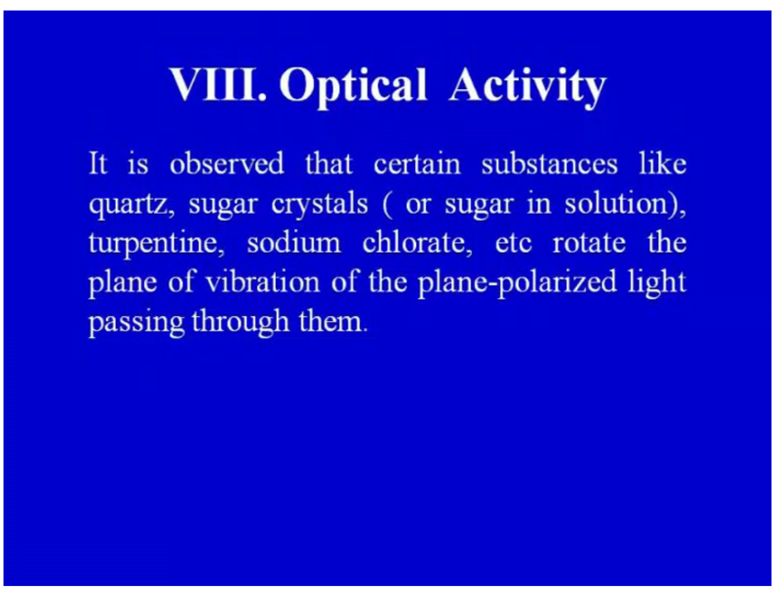

So, let us consider what is Optical activity? It is observed that certain substances like quartz, sugar crystals or even sugar in a solution, turpentine, sodium chlorate, many other substances, they rotate the plane of vibration of the plane polarized light passing through them.

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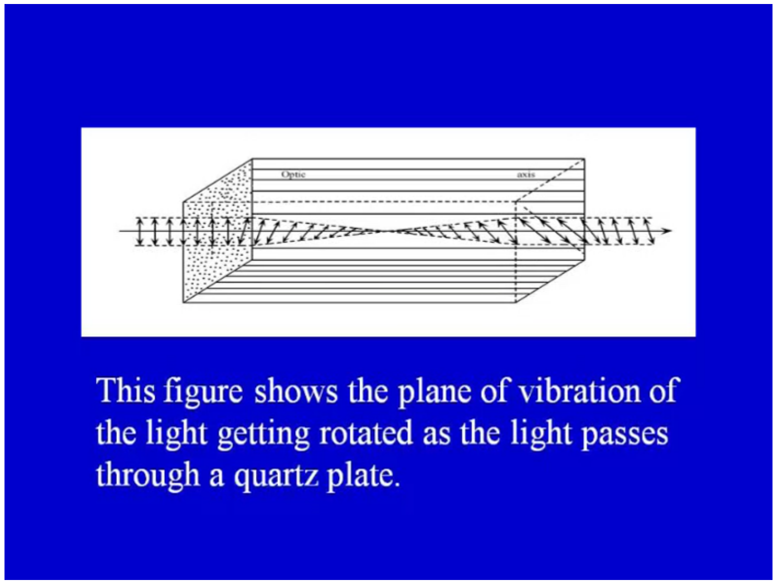

This figure shows the plane of vibration of the light getting rotated as the light passes through a quartz of a quartz plate. Remember, the propagation is along the optic axis.

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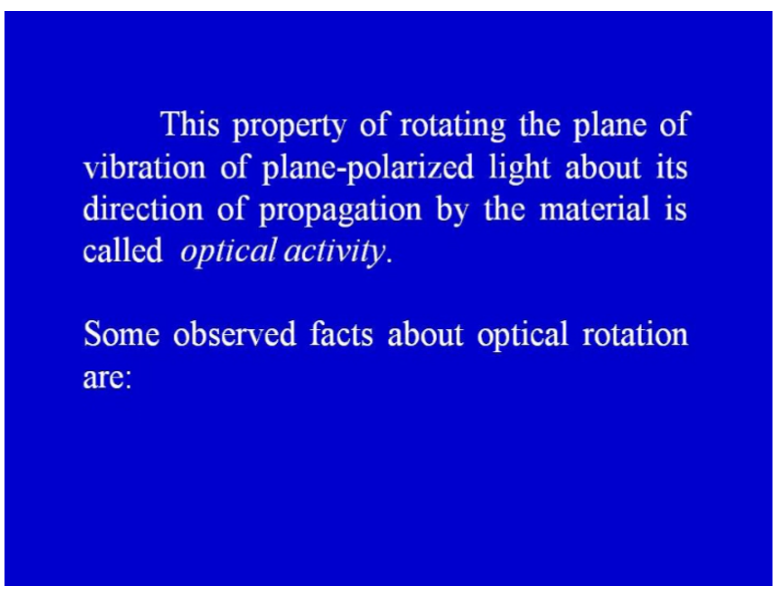

This property of rotating the plane of vibration, a plane polarized light about its direction of propagation by the material is called optical activity. Some observed facts about this optical rotation are:

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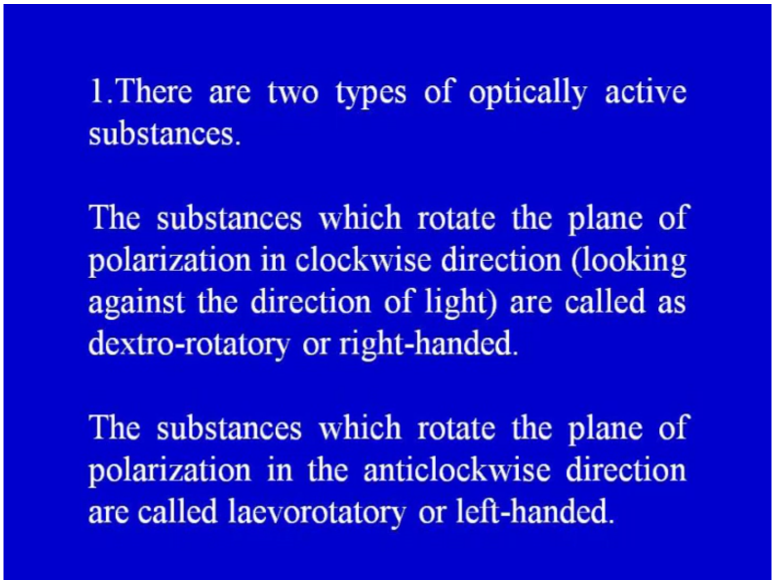

Number 1: There are two types of optically active substances. The substances which rotate the plane of polarization in clockwise direction looking at this direction of light they are called dextro-rotatory or right handed. And then, there are substances which rotate the plane of polarization in the anti-clockwise direction and they are called laevorotatory or left handed.

Number 2: The amount of rotation theta produced by an optically active substance, the sound to be proportional to its thickness, theta is proportional to vapor.

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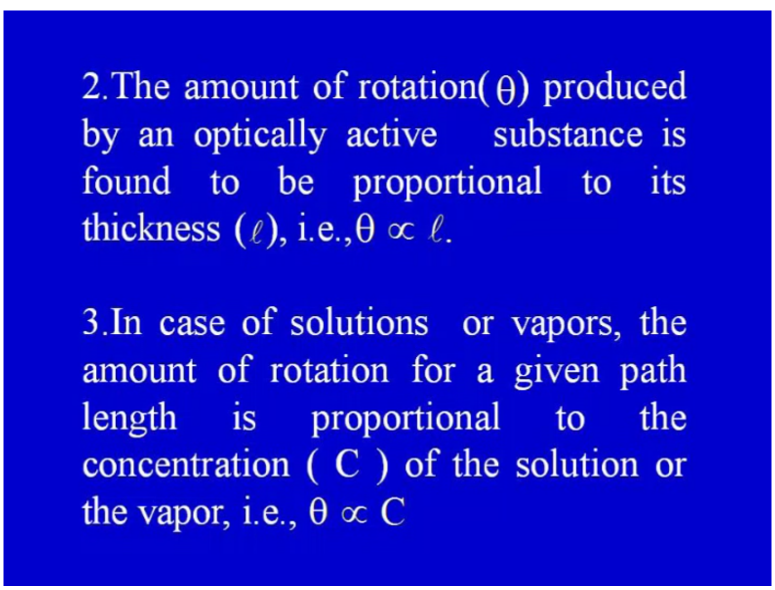

I mean proportional to the distance traveled in an optically active substance. Number 3: In case of solutions or vapors, the amount of rotation for a given path length, a proportional to the concentration C of the solution, or the vapor the theta is the proportional to C. C is measured in grams per CC.

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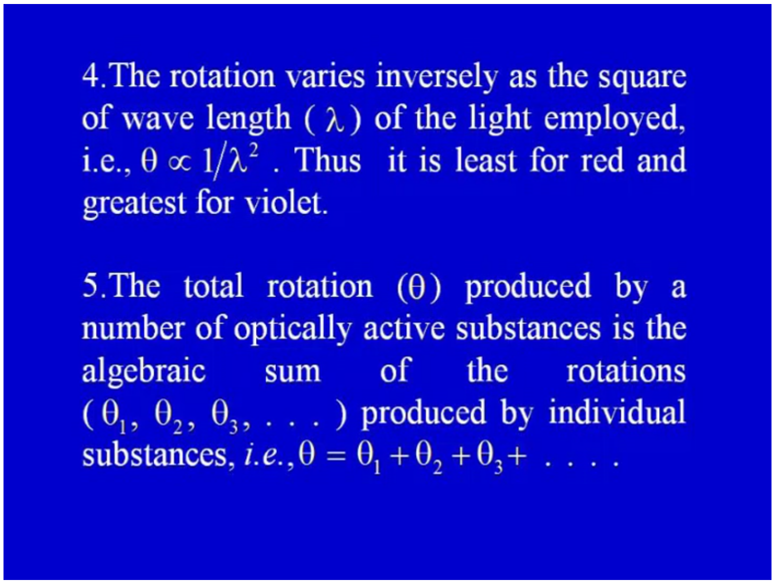

Number 4: The rotation varies inversely as the square of the wavelength lambda, of the light employed. The theta is proportional to 1 upon lambda square. This is the rotational dispersion. Naturally, theta will be least for red in the visible spectrum and greatest for violet. Number 5: The total rotation theta produced by a number of optically active substances is algebraic sum of the rotations theta1, theta2, theta3, produced by individual substances.

Some theta's will be positive, the right handed system; some will be negative, if the system is left handed one.

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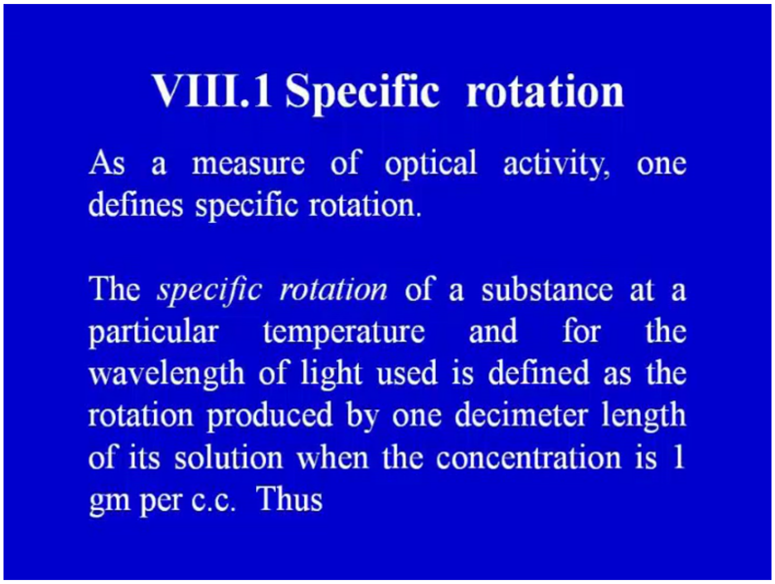

Specific rotation as a major of optical activity one defines specific rotation. The specific rotation of a substance at a particular temperature and for the wavelength of the light used is defined as the rotation produced by 1 decimeter like note, it is not centimeter or meters, 1 decimeter length of its solution when the concentration is 1 gram per cc.

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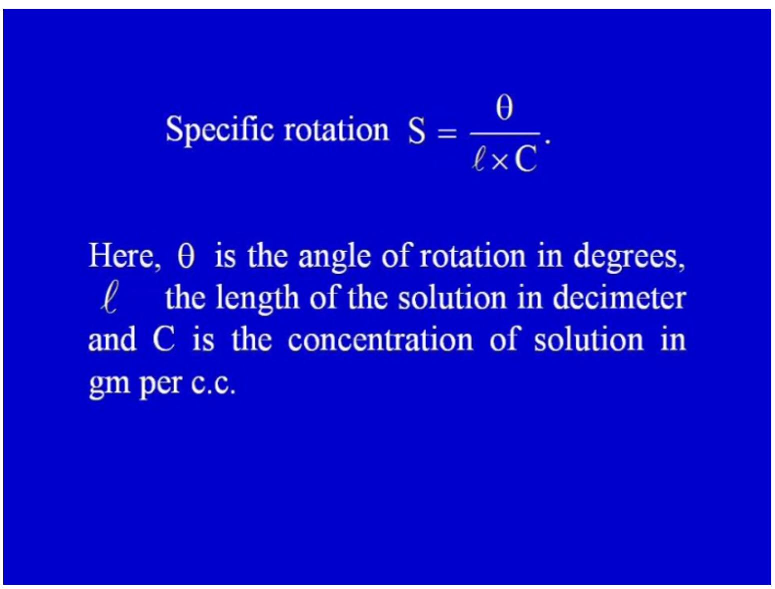

Thus the specific rotation S is given by, theta upon l C theta is the angle of rotation in degrees value, the length of the solution in decimeters and C, the concentration of solution in grams per cc. Let us now come to Fresnel's theory of optical rotation, very interesting theory which explains how the plane of polarization gets rotated, when a plane polarized beam passes through adopting reactive substance.

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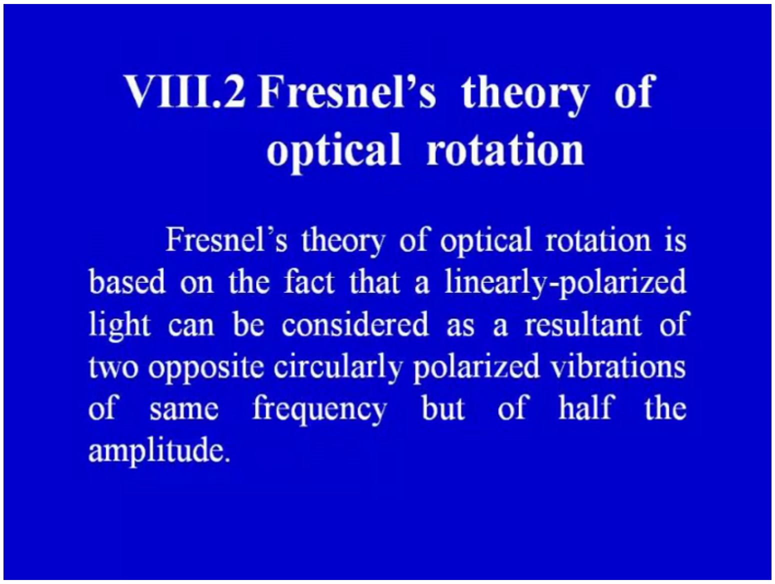

Fresnel's theory of optical rotation is based on the fact that a linearly polarized light can be considered as a resultant of two opposite circularly polarized vibration. Opposite means as a resultant of right circularly and left circularly on the same frequency but of half the amplitude.

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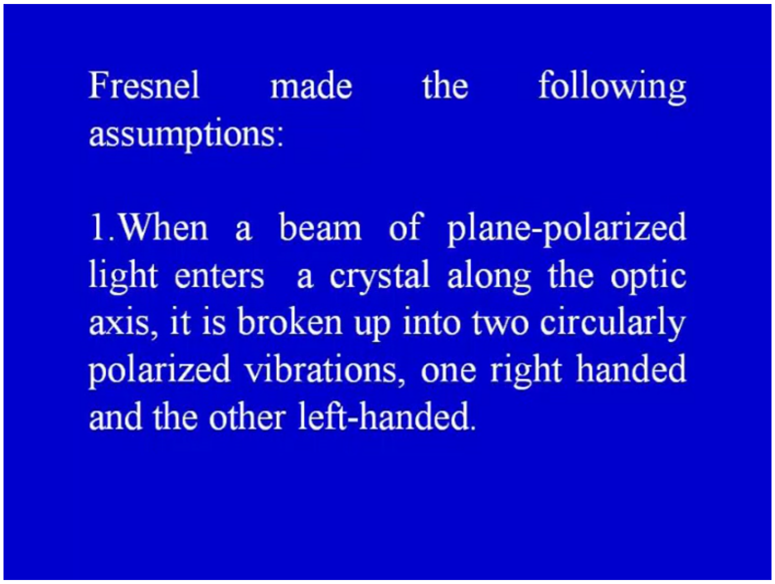

Fresnel made the following basic assumptions: Number 1: When a beam of plane polarized light enters a crystal along the optic axis, remember, here the propagation is along the optic axis. It is broken up into two circularly polarized vibrations as I said, one right handed and the other left handed.

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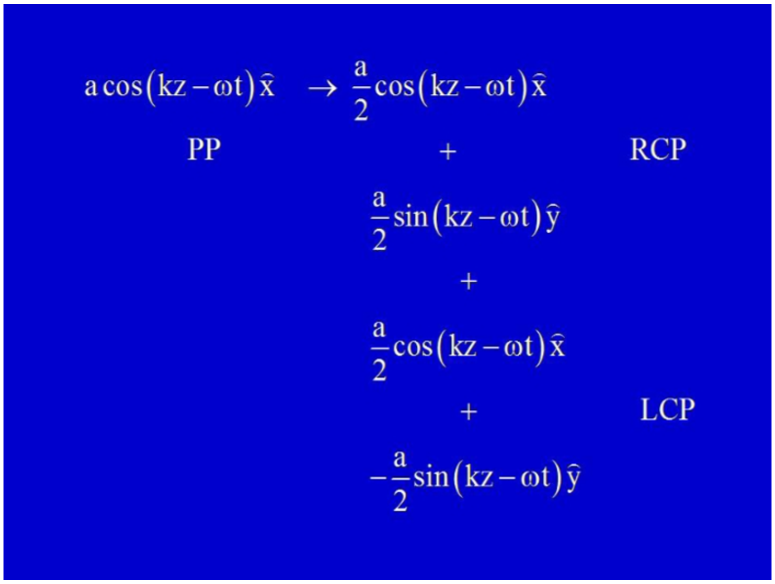

On the left, a cos of kz - Omega t along the x axis, this is the incident plane polarized beam; on the right side, we have now a by 2 times cos of kz - Omega t along the x axis + a by 2 sine of k z - Omega t along the y axis. These two together form the right circularly polarized wave + a by 2 cos of kz - Omega t along the x axis + with the - sign now, a by 2 sine of kz - Omega t along the y axis. These two together, form the left circularly polarized beam. And basically one can consider it as follows:

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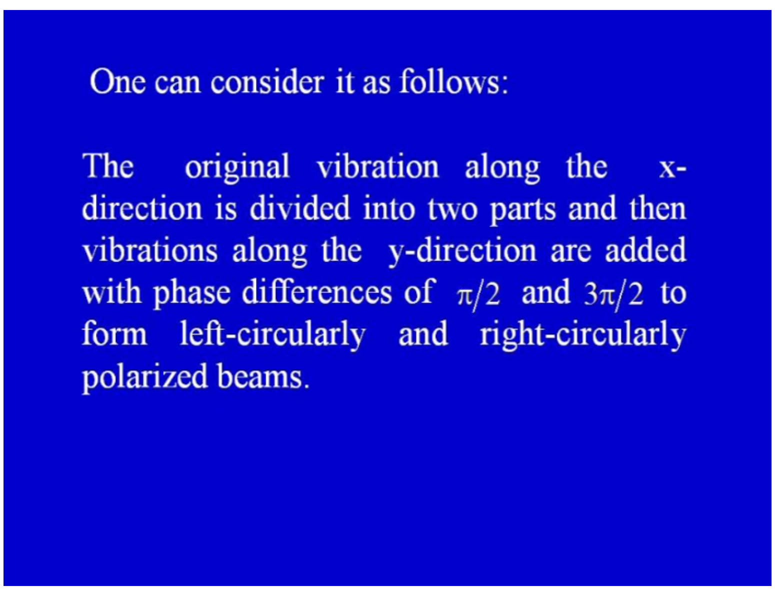

The original vibration along the x direction is divided into two parts and then vibrations along the y direction or added with phase difference of Pi by 2 and 3Pi by 2 to form the left circularly and right circularly polarized beams. The phase difference of Pi by 2 gives the left circularly one circular one and the phase difference of 3Pi by 2 leads to right circularly polarized beam.

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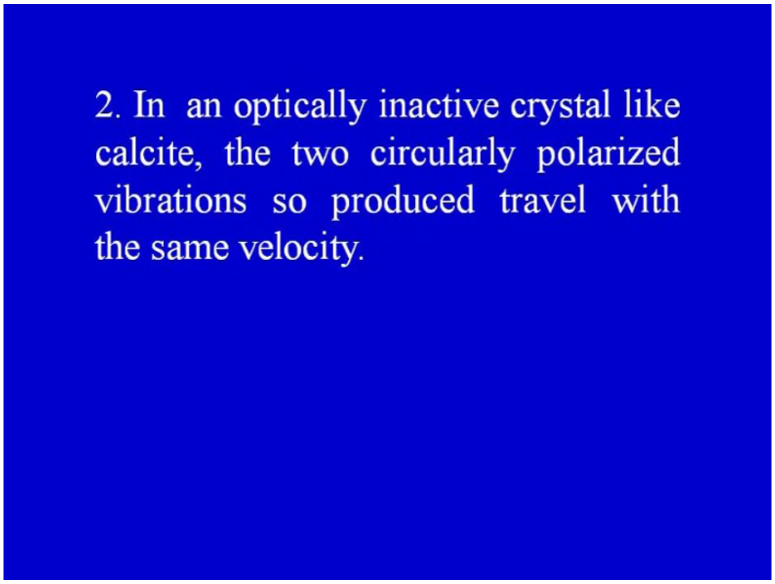

Number 2: In an optically inactive crystal important let us see note it optically inactive, inactive crystals, are those which do not produce any rotation. Calcite is an inactive crystal, a doubly refracting, but optically inactive. The two circularly polarized vibration so produced travel with the same velocity.

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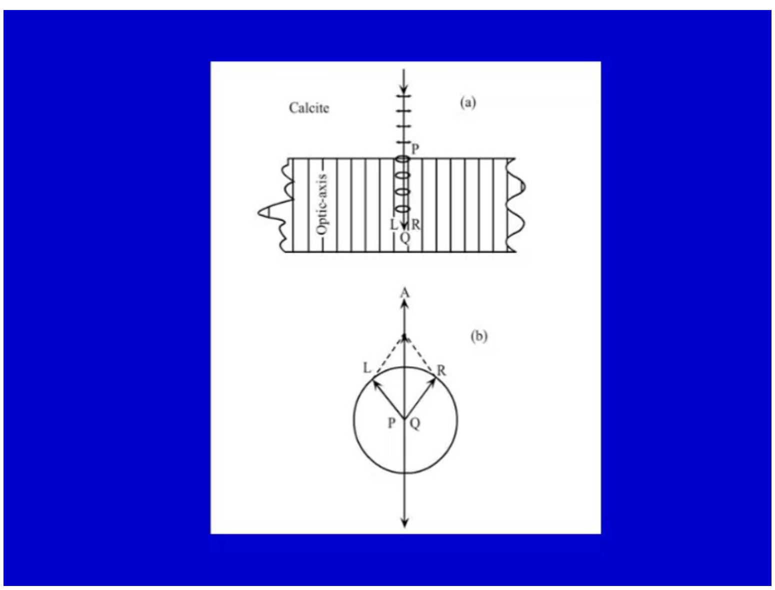

The upper part of the figure shows the propagation of the circularly polarized to beam.

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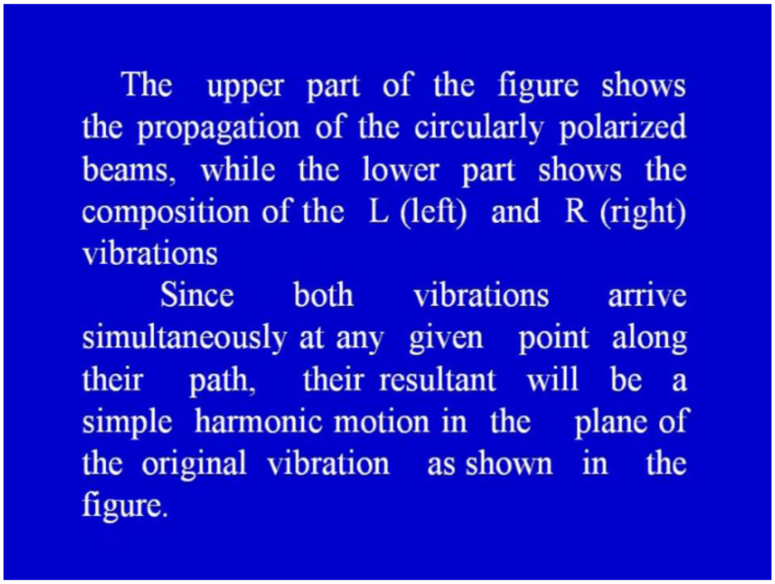

While the lower part shows the composition of the left and right vibrations; since both the vibrations arrive simultaneously at any given point along the path, naturally, they will arrive simultaneously because they are traveling with the same speed. The resultant will be a simple harmonic motion in the plane of the original vibration. No change as shown in the figure.

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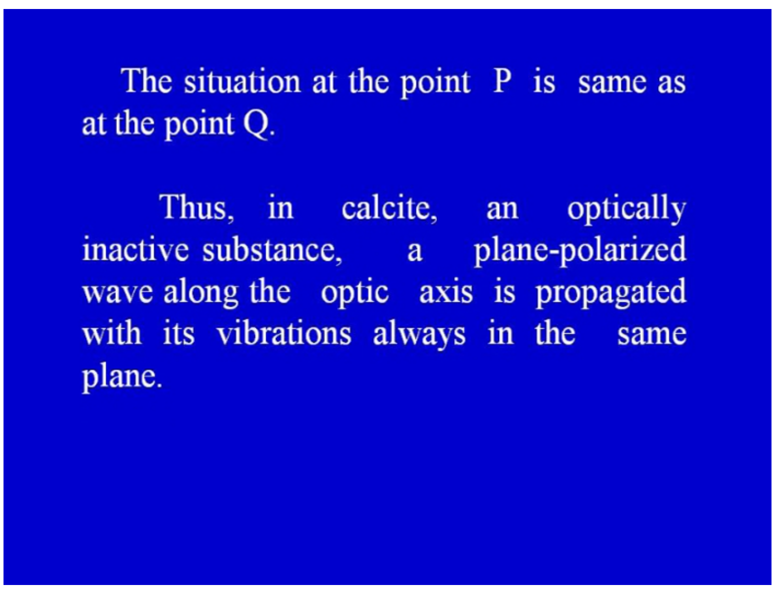

The situation at the point P in the figure is same as at the point Q. Thus, in calcite, which are optically inactive substance a plane polarized wave along the optic axis be propagated with its vibrations always in the same plane no rotation.

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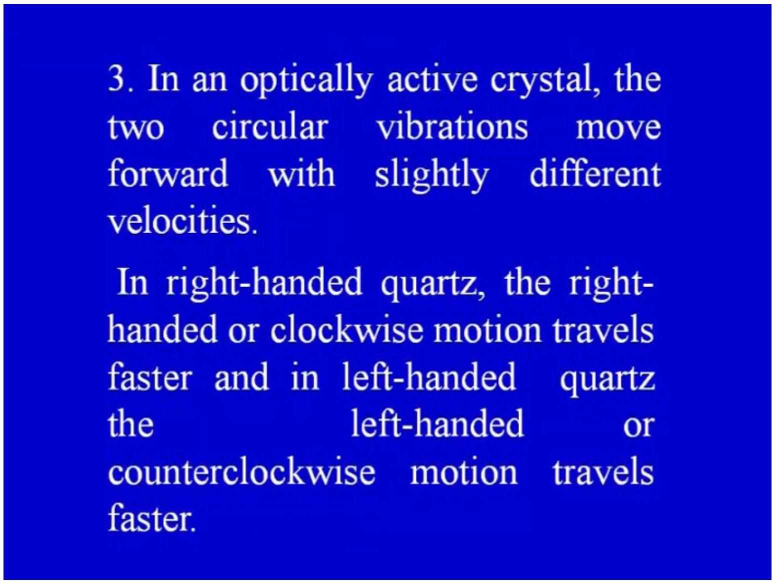

Number 3: In an optically active crystal, the two circular vibrations move forward slightly different velocities in the right handed quartz, the right handed or clockwise motion travels faster and in left handed quartz, the left handed or the counterclockwise motion travels faster. This figure again shows the propagation.

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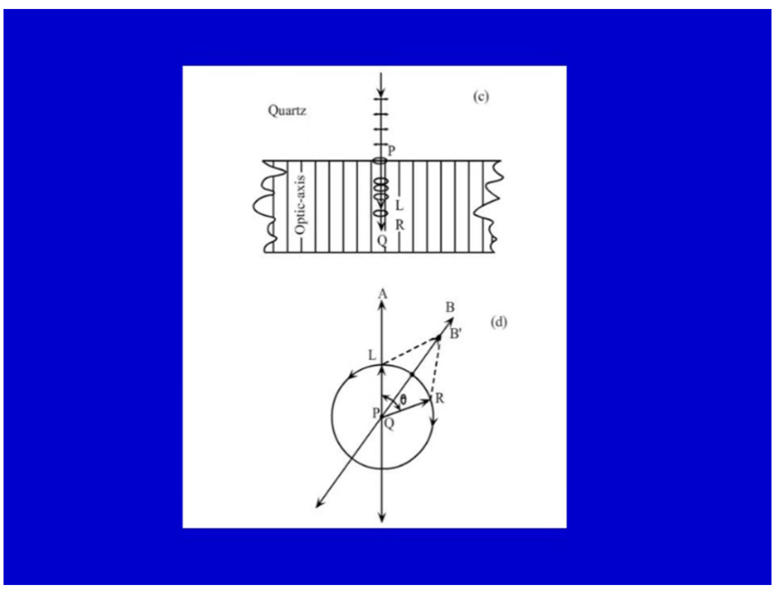

Consider some point PQ in the figure, in a right handed crystal along the path of a plane polarized incident beam.

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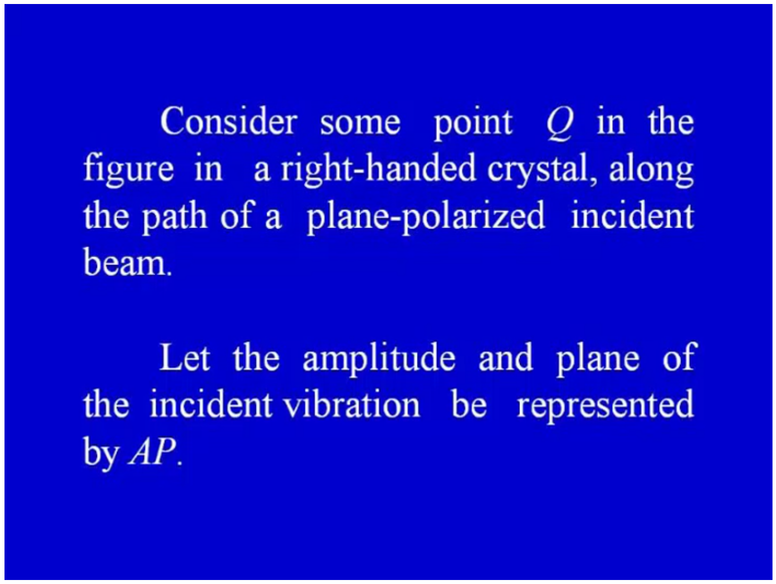

Let the amplitude and the plane of the incident vibration be represented by AP in the figure, the right circular component are, of this vibration arrives at Q first and Lt wave travels on the displacement turns through an angle theta, before the left handed component L arrives. They are arriving at a different instance because their speeds are different. At this instance, the two circular motions are in opposite senses with the same frequency but one is starting at R and the other at L.

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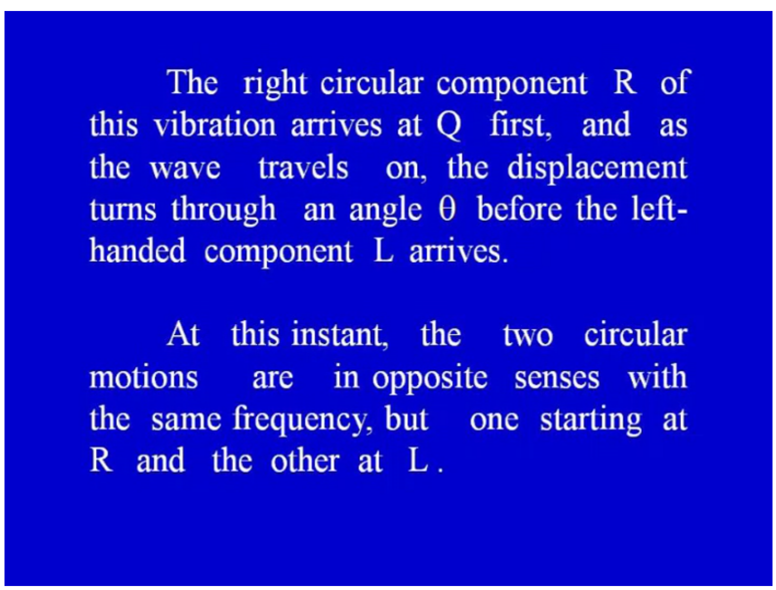

The result is that the point B prime vibrates, along the fixed line BQ with the same amplitude and frequency as the original vibration AP. And this represents the vibration form of the light at

Q. Thus in traveling from the crystal face at P, to the point Q the plane of vibration has got rotated through an angle theta by 2.

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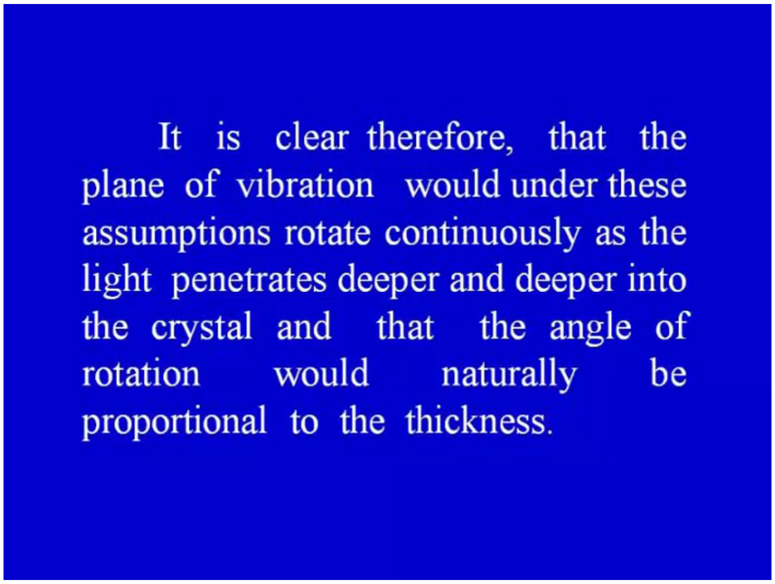

It is clear therefore that the plane of vibration would under these assumptions rotate continuously as the light penetrates deeper and deeper into the crystal and that the angle of rotation will naturally be proportional to the distance travelled that is proportional to the thickness of the active material. Number 4: Now, in order to experimentally show just an experimental verification of this idea that an incident plane polarized beam gets broken up into two circular polarizations: left circular and right circular.

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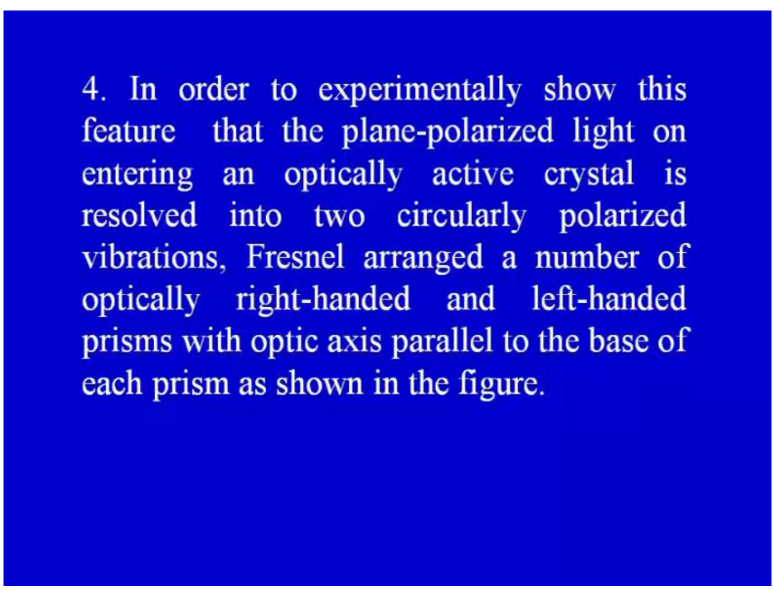

So, just to show it experimentally, during the day plane polarized light on entering an optically active crystal is resolved into two circularly polar vibrations. Fresnel arranged a number of optically right handed and left handed prisms with optic axis parallel to the base of each prism as shown in the figure.

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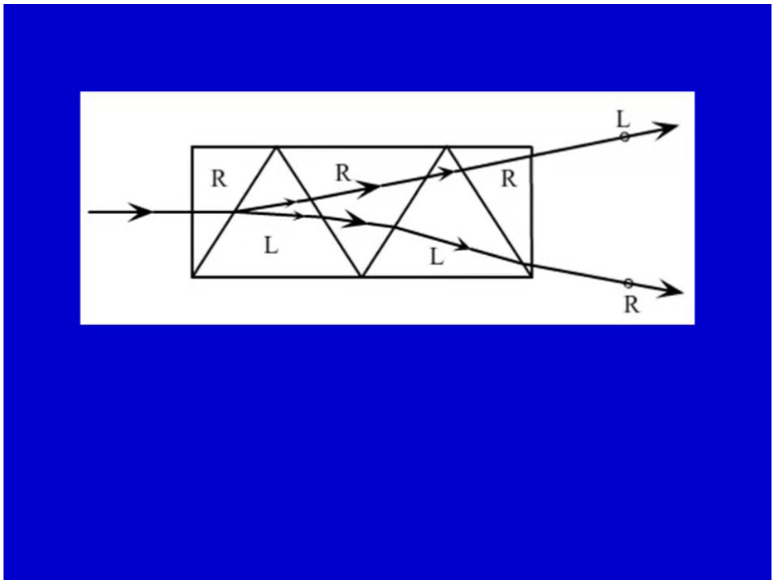

Alternate arrangement of right-left, right-left like this and the plane polarized incident beam.

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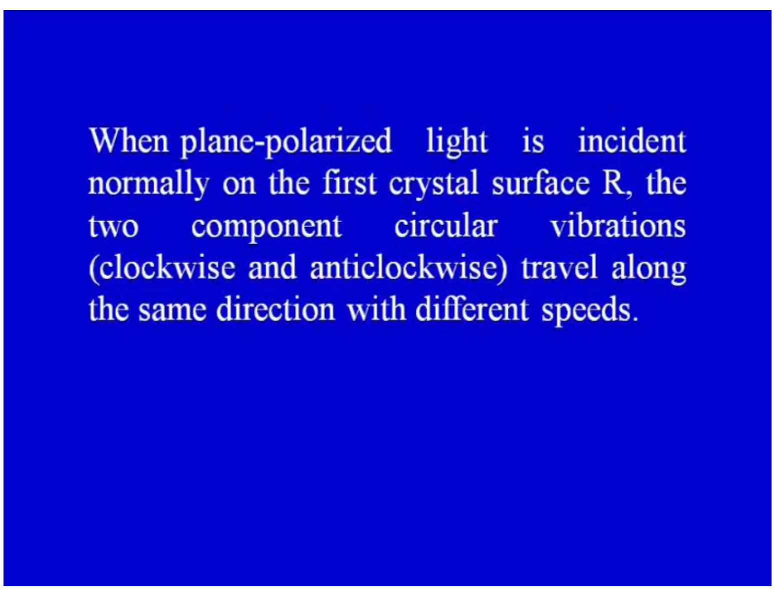

When plane polar light incident normally on the first crystal surface R, the two components, two components circular vibrations clockwise and anti-clockwise, travel along the same direction with different speeds.

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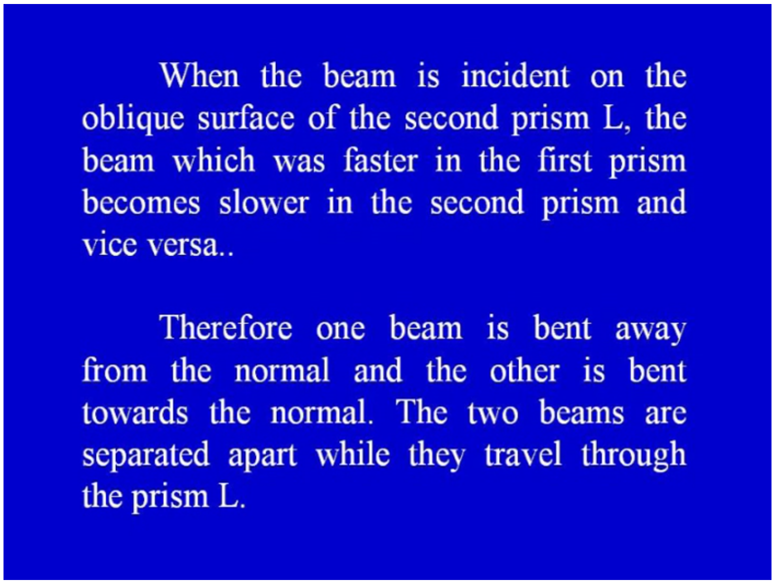

When the beam is incident on the oblique surface of the second program prism L, the beam which was faster in the first prism, becomes slower in the second prism and vice versa. Therefore one beam is bent away from the normal and the other beam is bent towards the normal. The two beams are separated apart while the two travel through the prism L.

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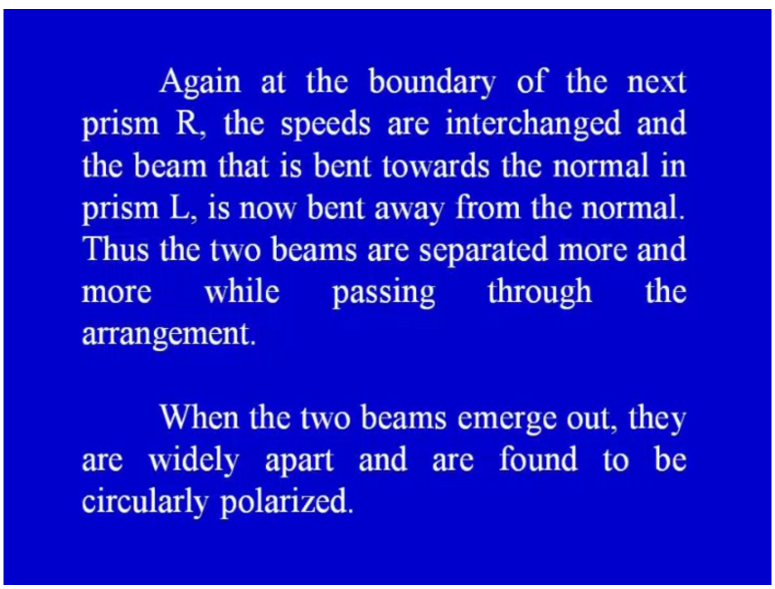

Again at the boundary of the next prism R, the speeds are interchanged and the beam that has been towards the normal in prism L is now bent away from the normal and thus the two beams are separated more and more while passing through the arrangement. When the two beams emerge out, they are widely apart and are found to be circularly polarized which can be experimentally checked.

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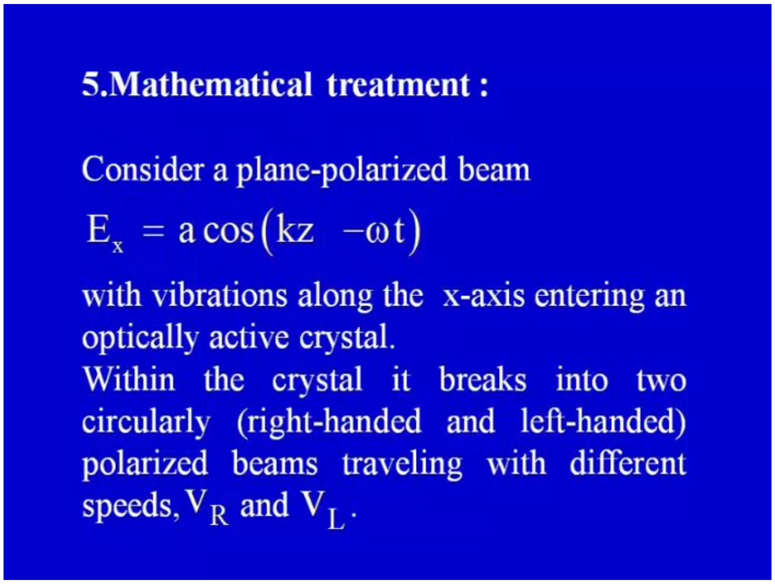

Let us go through a mathematical treatment of this analysis to make the things a little more precise. Consider a plane polarized beam E x =a cos of kz - Omega t, the vibrations along the x axis entering an optically active crystal, propagation is along the z axis. This A is the amplitude of the plane polarized beam. Within the crystal it breaks into two circularly as we pointed out earlier, right handed left handed circularly polarized beams, traveling with different speed. That is important traveling with different speeds, VR on the right handed and VL on the left handed.

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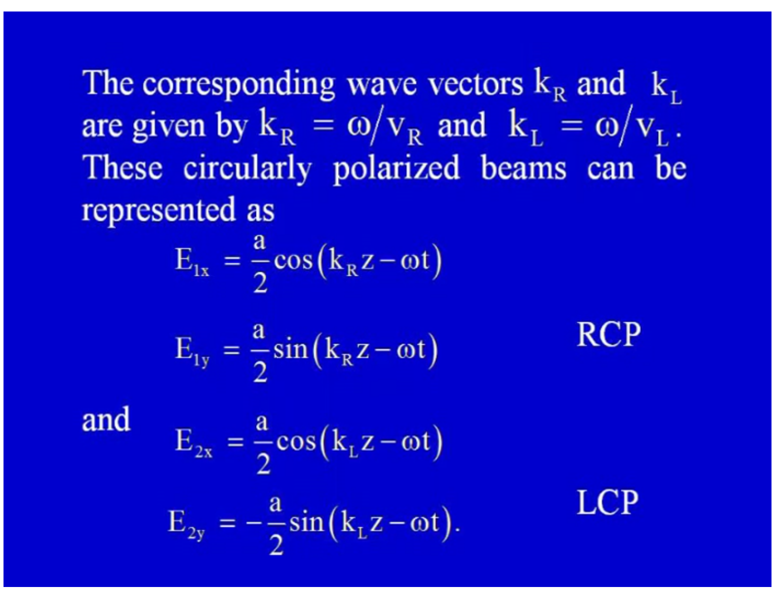

The corresponding wave vectors kR and k L are given by kR = Omega upon VR kL = Omega upon VL. These circularly polarized beams can be represented as E for the first beam E1x is =a by 2 cos of k R z - Omega t and E 1 y =a by 2 sine of k R z - Omega t together forming the right circularly polarized and E2 x =a by 2 cos of kLz - Omega t and E2y is =- note the - sign a by 2 sine of kLz at - Omega t forming the left circularly polarized.

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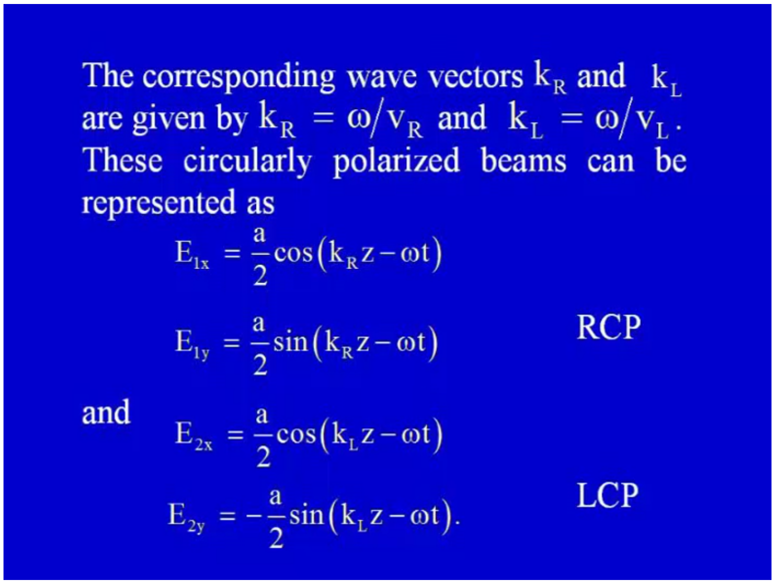

You see at the entry point, if you put z is =0 and add them all the total is just a cos Omega t. That is the incident plane polarized P. Now, the superposition of the above which is in the crystal, optically active crystal leads to along the x direction Ex =E1x + E2x, along the x component of the two beams E1x + E2x which is =a by 2 cos of k Rz - Omega t + a by 2 cos of kLz - Omega t. And that leads to a times cos of kL + kR by 2 times z - Omega t and cos of kL - kR by 2 times z along the y direction.

Ey is =E1y + E2y is =a by 2 sine of kRz - Omega t - remember this is the - sign now a by 2 sine of kLz - Omega t this gives a cos of kL + kR by 2 z - Omega t into sine of kL - kR by 2z.

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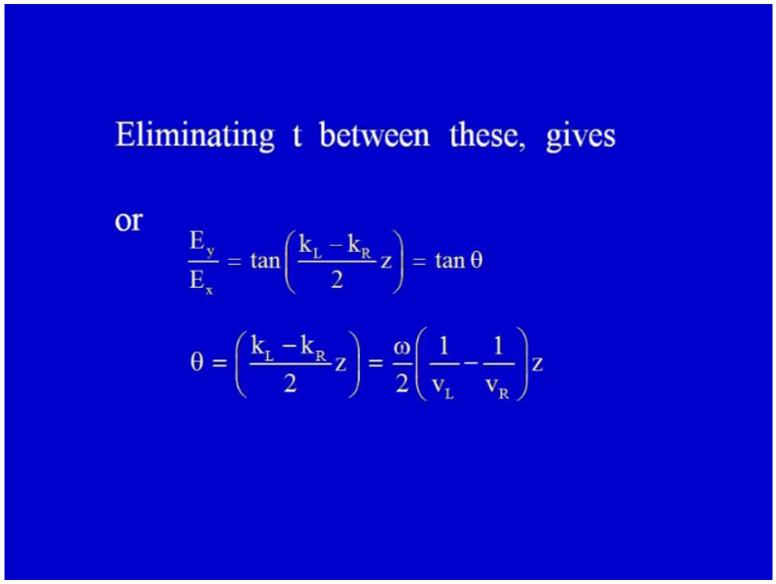

You can very easily eliminate t between these, just by dividing Ey by Ex. If we do that, we get, Ey by Ex is tangent of kL - kR times z. Let us call it tan theta where theta is kL - kR by 2 times z or Omega by 2 into 1 by VL - 1 by VR times z.

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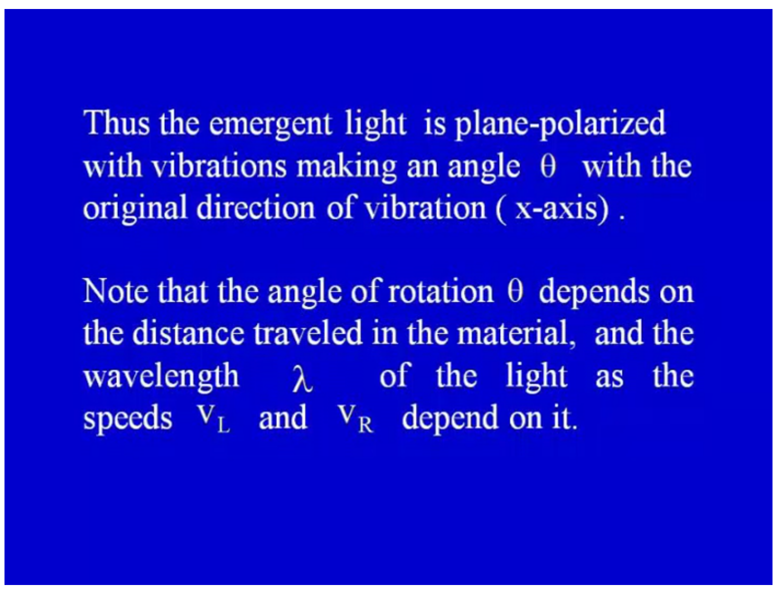

Thus the emergent light is plane polarized again with vibrations making an angle theta with the original direction of vibration the, which was x axis. So the original direction of vibration was the x axis along the x axis the emergent light now makes an angle theta with the x axis. It has got rotated and the angle of rotation theta depends on the distance travelled in the material, as it should be naturally. And the wavelength lambda of light as the speeds VL and VR, they depend on it.

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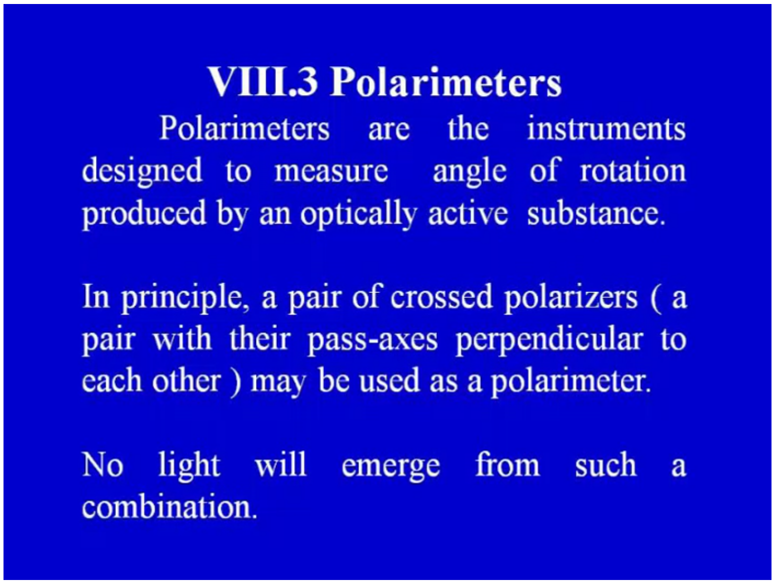

Let us now consider the polar polarimeters which are the instruments used to measure the angle through which the plane of polarization gets rotated when the light beam, by a plane polarized light beam passes to an optically active substance. So, these are the instruments to measure the angle of rotation. In principle, a pair of crossed polarizers pair with their pass axes perpendicular to each other may be used as a polarimeter in a very simple way.

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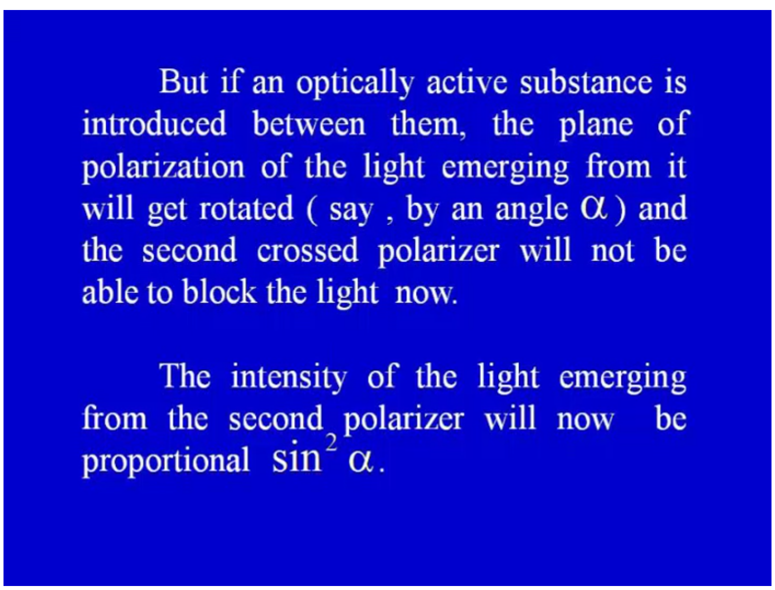

If we have a pair of crossed polarizers, no light will emerge from such a combination just the Malus Law. Now if an optically active substance is introduced between these two crossed polarizers, the plane of polarization of the light emerging from the first polarizer, will get rotated now, when it passes through the optically active substance. Suppose, it gets rotated by an angle alpha and the second polarizer now will not be able to block the light.

The intensity of the light emerging from the second polarizer will now be proportional to sine square alpha just the Malus Law. This is cos square of 90 - alpha.

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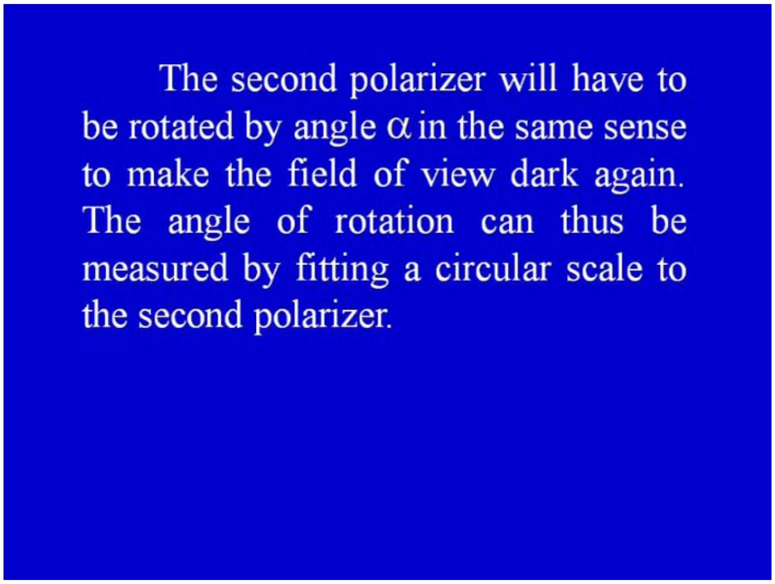

The second polarizer now will have to be rotated by an angle alpha in the same sense to make the field of view dark again. The angle of rotation can just be measured by fitting a circular scale to the second polarizer. So, we have got a polarimeter to be able to measure the angle of rotation.

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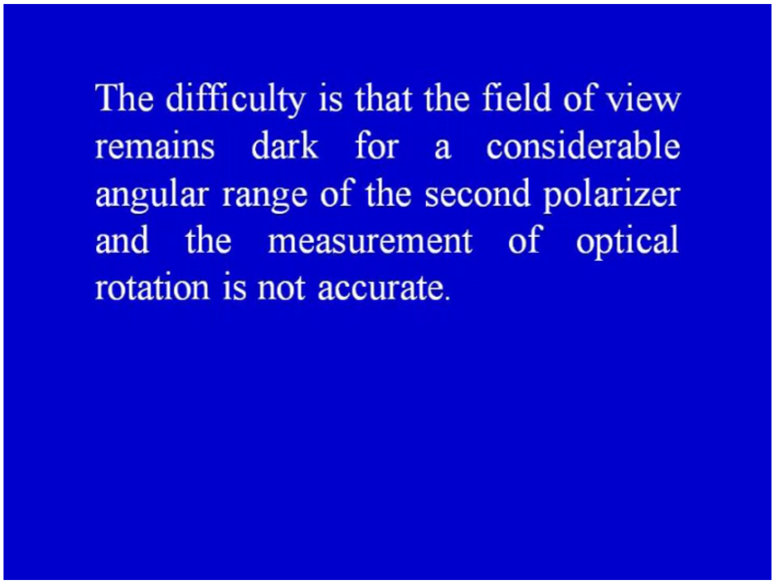

The difficulty is that in actual practice, the field of view remains dark for a considerable angular range of the second polarizer. The range is quite a bit + - 10 degrees, some kind be, even more. And the measurement of optical rotation is not accurate.

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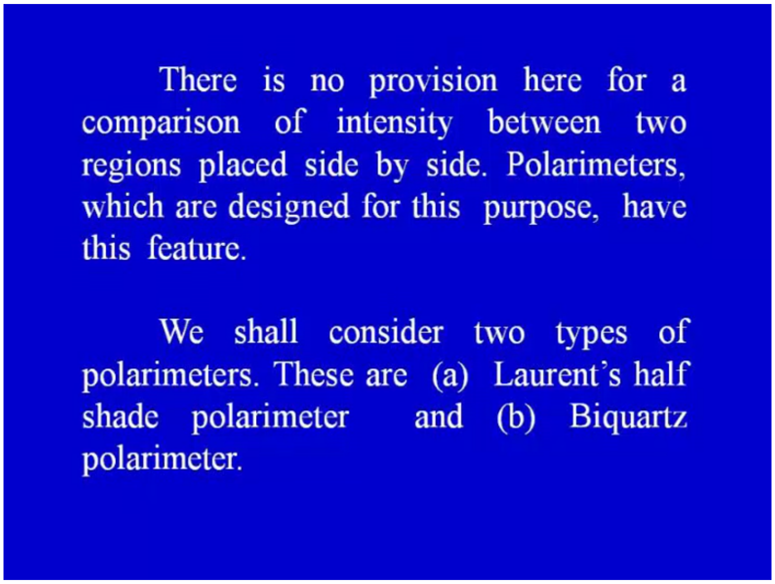

There is no provision here for a comparison of intensity between say two regions placed side by side. Polarimeters are designed for this purpose. To measure the angle, they have these features. We shall consider two types of polarimeters. These are Laurent's half shade polarimeter and the second one, the Biquartz polarimeter. That is the first one.

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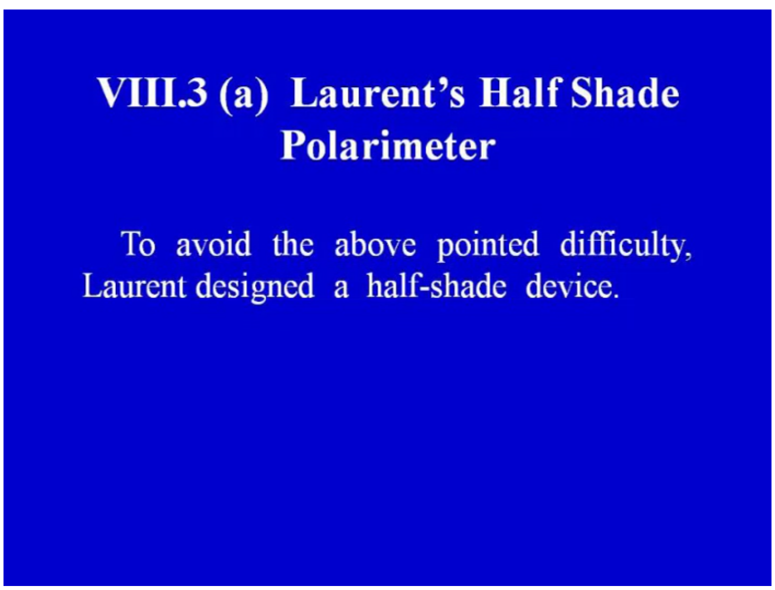

Now, to avoid the ever pointed difficulties problem of getting darkness over a considerable range Laurent designed a half shade device.

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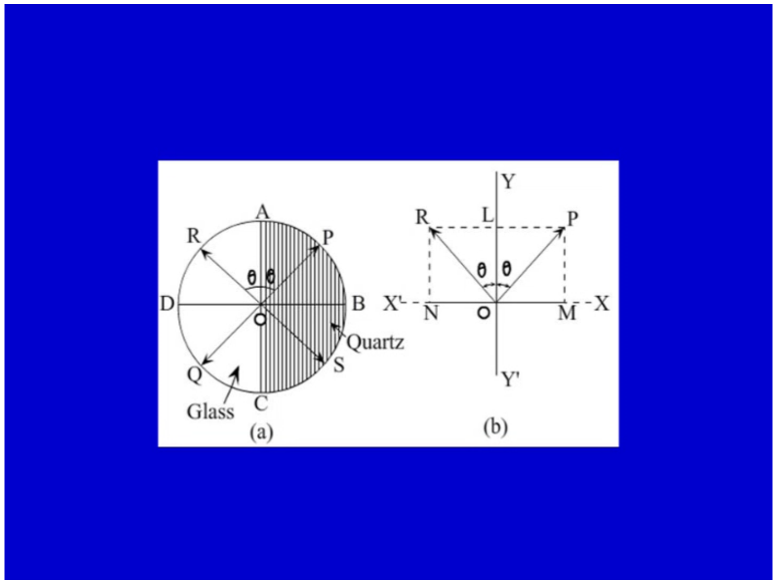

This device consists of a semicircular half wave plate ABC of quartz cut parallel to the optic axis as shown.

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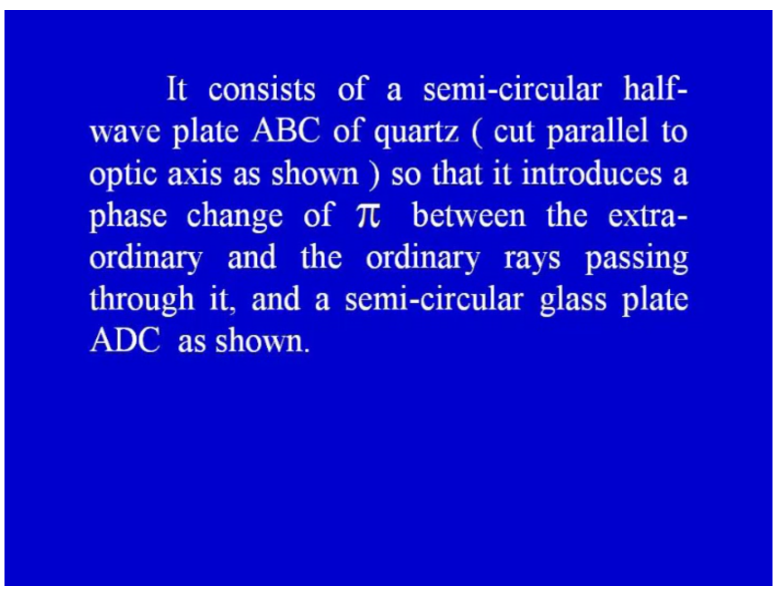

It is just a half wave plate. Remember, half wave plates are cut parallel to the optic axis, light passes through them normally and ultimately, on emergence a path difference of lambda by 2 or a phase difference of Pi is introduced. So, it says this is a half wave plate introduces the phase change of Pi between the extraordinary and the ordinary rays passing through it. To it we join a semicircular glass plate ADC as shown. So, the half of the semicircular portion is parts and the other half is a glass plate.

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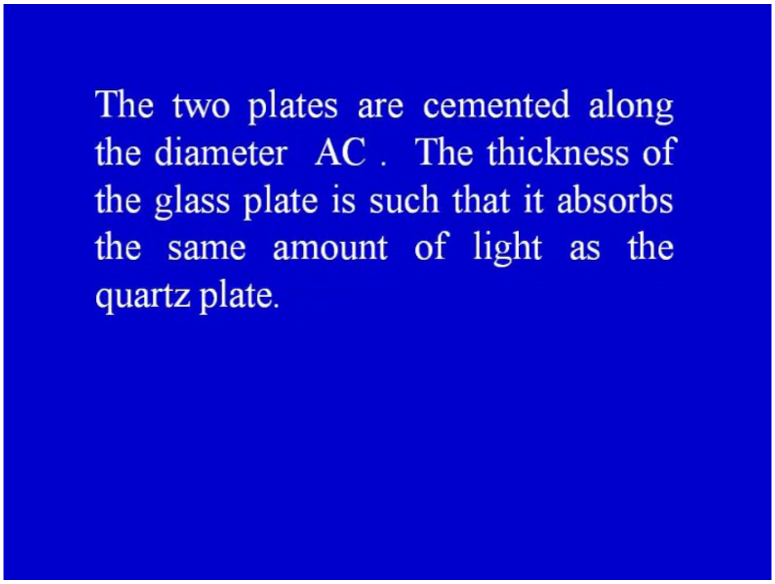

The two plates are cemented along the diameter AC. The thickness of the glass plate is such that it absorbs the same amount of light as the quartz plate. The idea is that any extraneous loss of light is same in both the parts.

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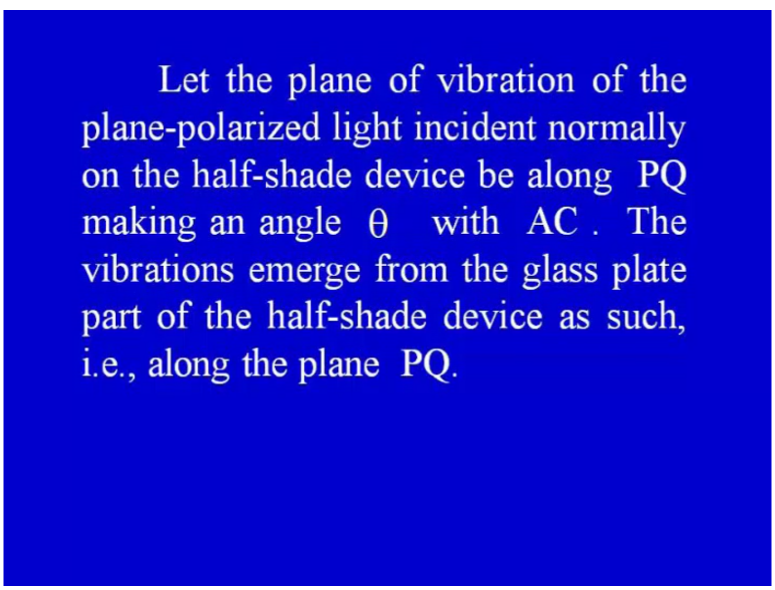

Now, let the plane a vibration of the plane polarized light incident normally on the half shade device be along PQ making an angle theta with AC. The vibrations emerge from the glass plate part of the half shade device; as such no change along the plane PQ.

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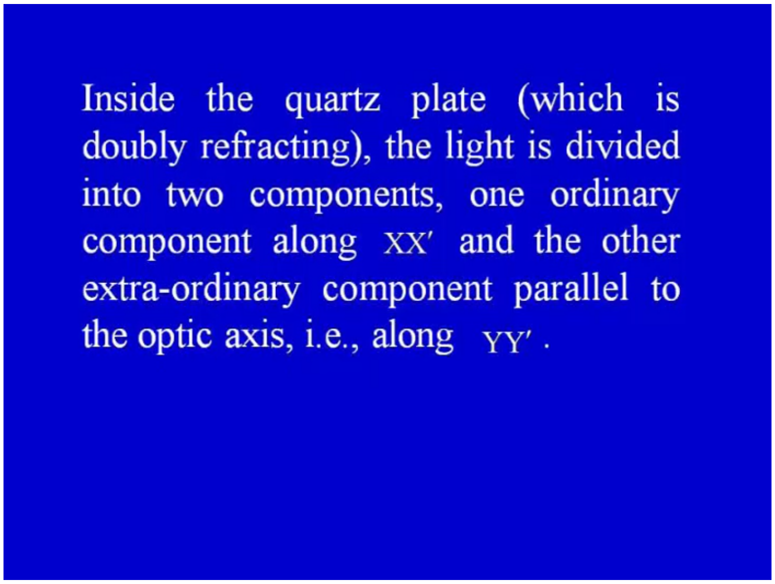

Inside the quartz plate which is doubly refracting, the light is divided into two components as we know, one ordinary component X, X prime and the other extraordinary component parallel to the optic axis along Y,Y prime.

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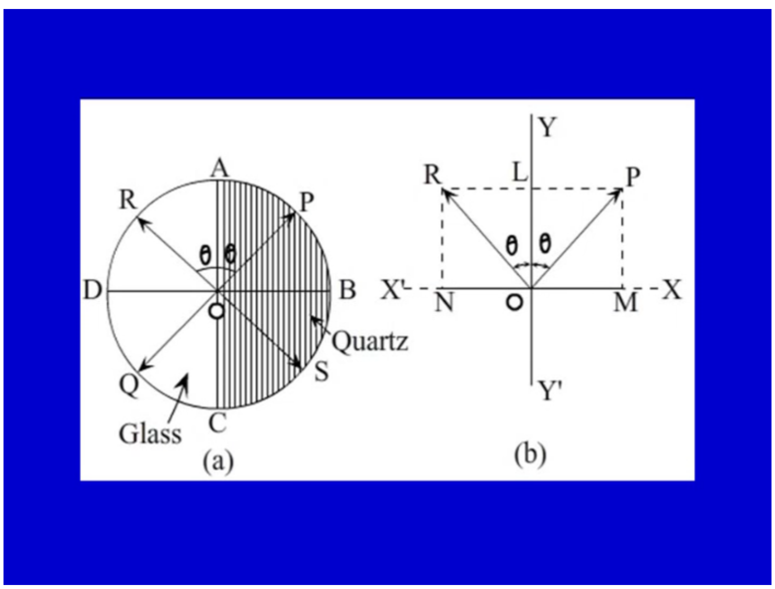

The two components travel along the same direction through separation but with different velocities. The ordinary component moves with greater velocity than the extraordinary component.

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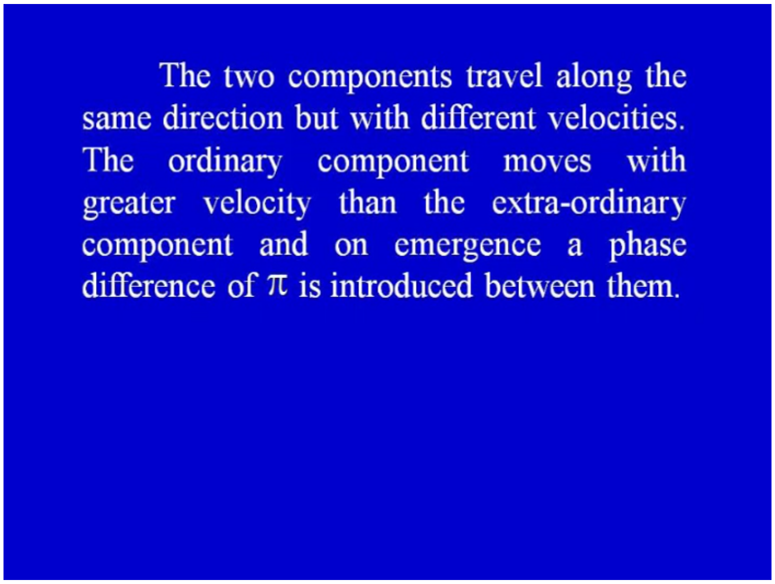

And on emergence, a phase difference of Pi is introduced between them.

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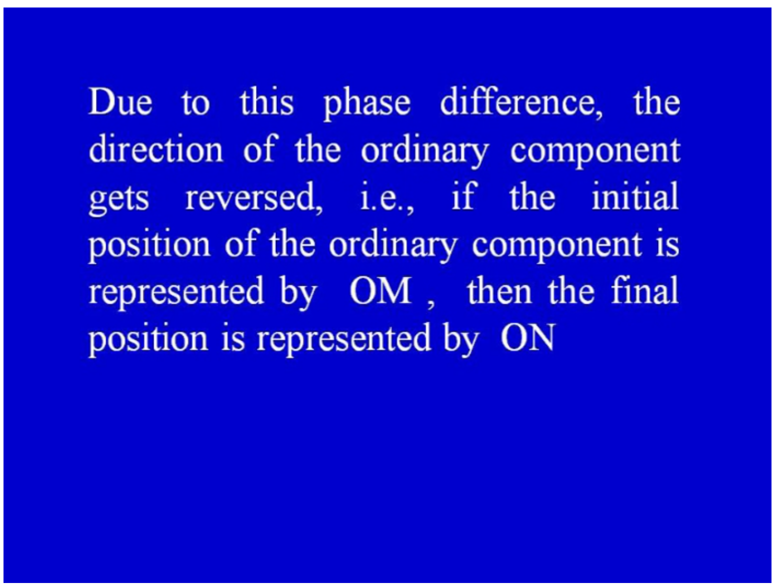

Due to this phase difference the direction of the ordinary component gets reversed. If the initial position of the ordinary component is represented by OM, then the final position is represented by ON. Now, on emergence the resultant of the extraordinary OL and ordinary component ON will be OR making an angle theta with the y axis.

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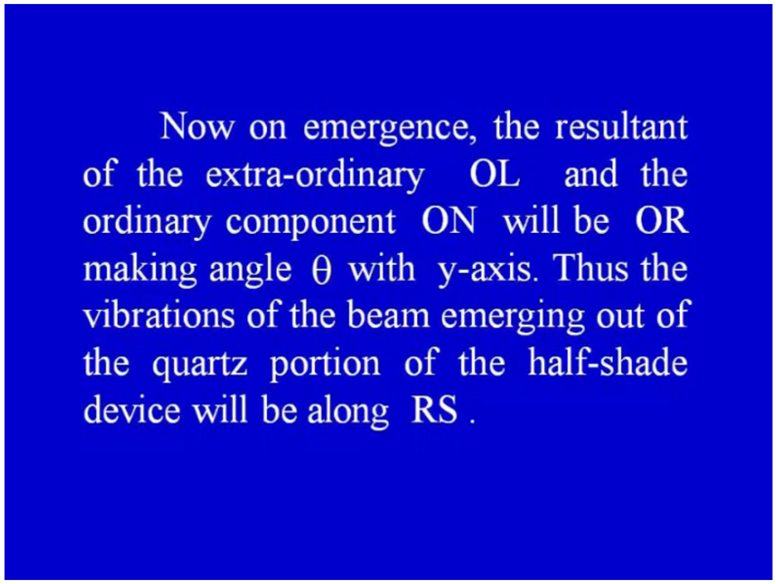

The vibrations of the beam emerging out of the quartz portion of the half shade device will be along RS. That is the change.

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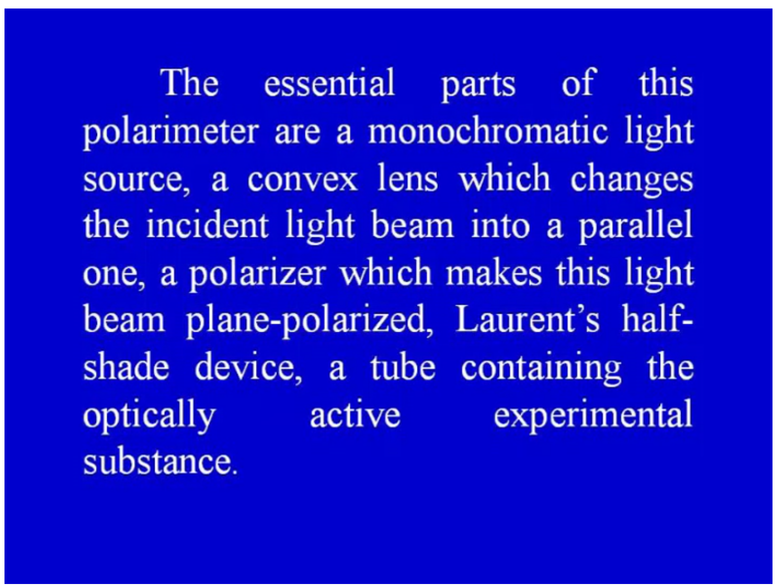

The essential parts of this polarimeter are a monochromatic light source, a convex lens which changes the incident light beam into a parallel one. A polarization which makes this light plane polarized then, the Laurent's half shade device and then a tube containing the optically active experimental substance.

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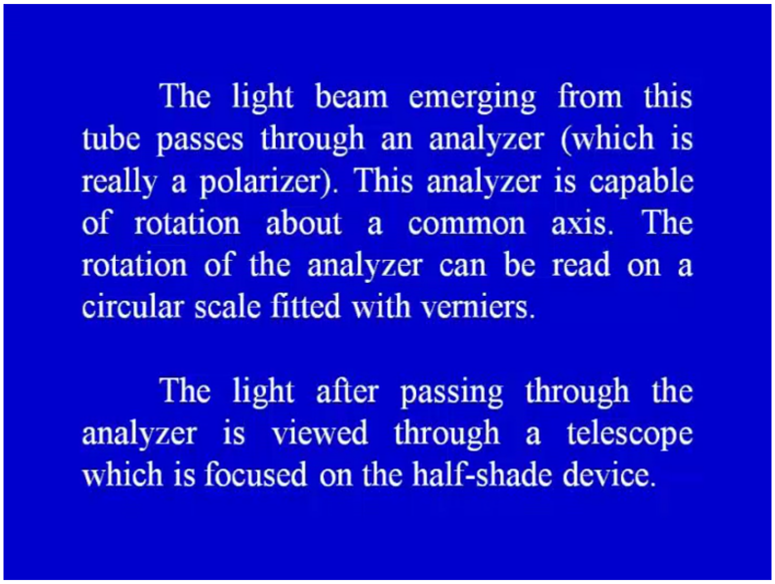

The light beam emerging from this cube passes through an analyzer. This analyzer is capable of rotation about a common axis. The rotation of the analyzer can be read on a circular scale fitted with verniers. The light after passing through the analyzer is viewed through a telescope which is focused on the half shade device. If the pass direction of the analyzing polarizer which is capable of being rotated and if it is fitted with the circular.

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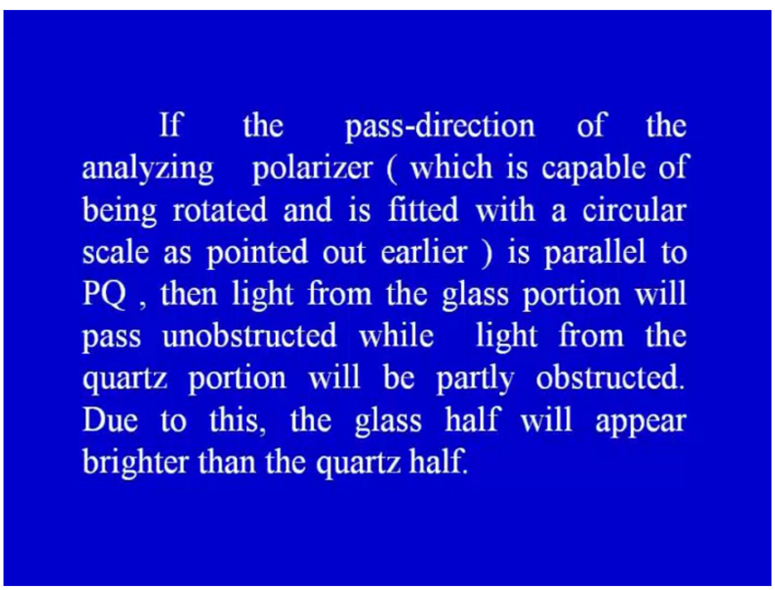

So, when the past direction is parallel to PQ then light from the glass portion will pass unobstructed while the light from the quartz portion will be partly obstructed. And due to this, the last half will appear brighter than the quartz half.

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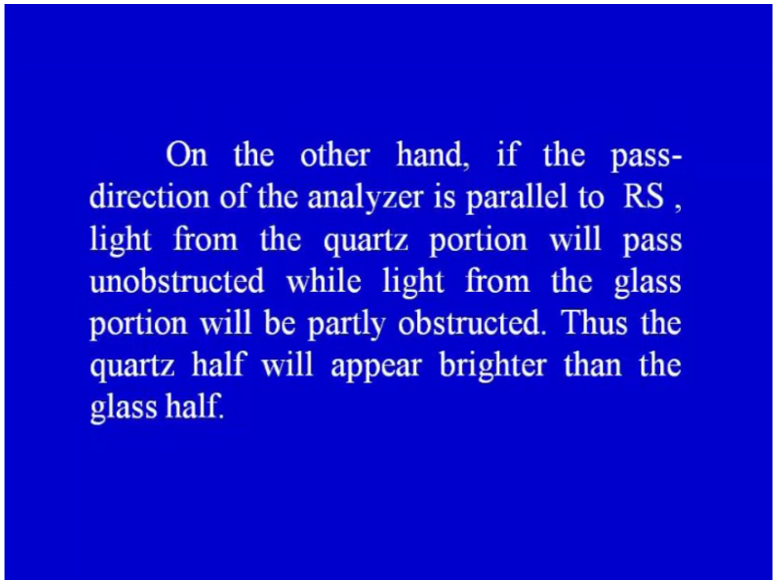

On the other hand, if the pass direction of the analyzer is parallel to RS, light from the quartz portion will pass unobstructed. But the light from the glass portion will be partly obstructed. Thus the quartz half will appear brighter than the glass half. If however, the past direction of the analyzer is parallel to AC, y axis it equally inclined to the two planes polarized lights.

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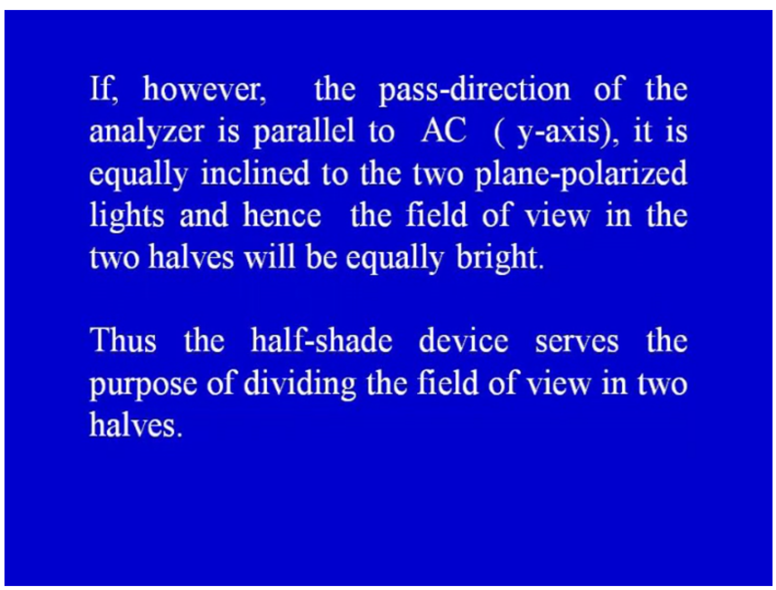

And hence the field of view, in the two halves, will be equally bright because the half shade device serves the purpose of dividing the field of view in 2 halves. And a little change in the direction of the pass direction of the analyzer, makes one half brighter other half darker; measurements can be done in much more accurate way.

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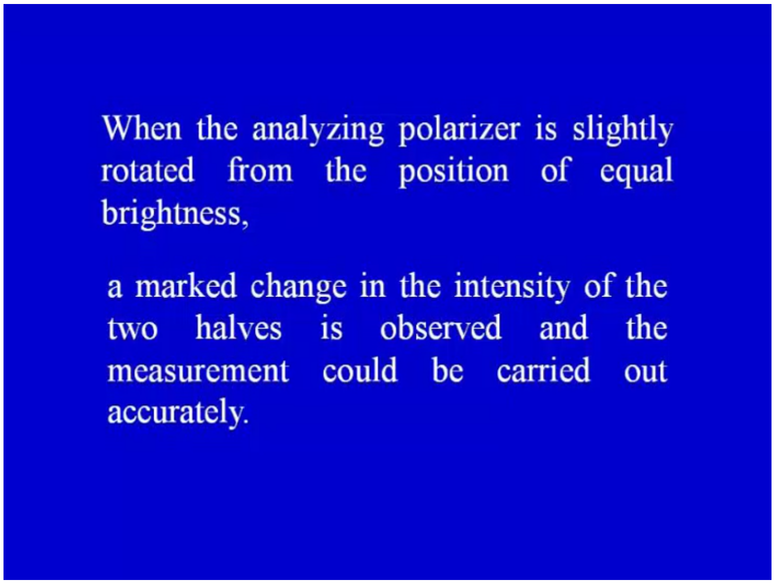

So, when analyzing polarizer is slightly rotated from the position of equal brightness, as I said, a marked change in the intensity of the two halves is observed and the measurement could be carried out with much more accuracy.

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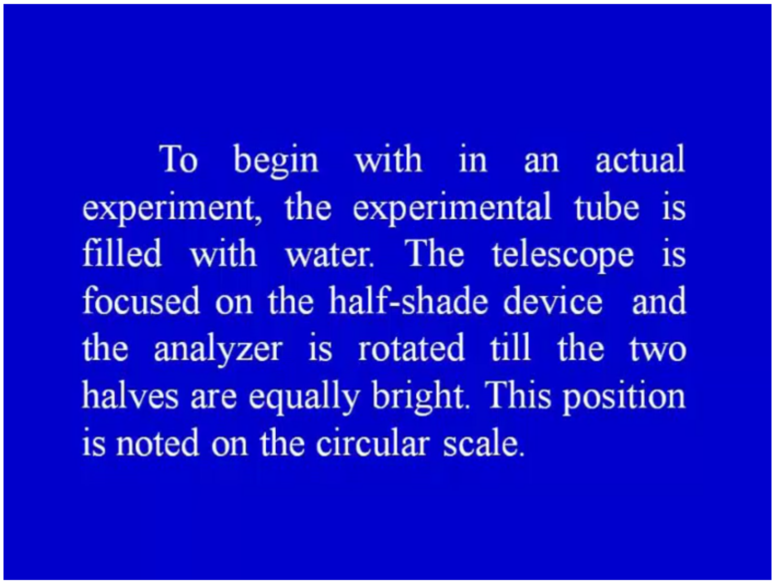

In the experiment to begin with, the experimental tube is filled with water; the telescope is focused on the half shade device. And analyzer is rotated till the 2 halves are equally bright. This position is noted on the circular scale.

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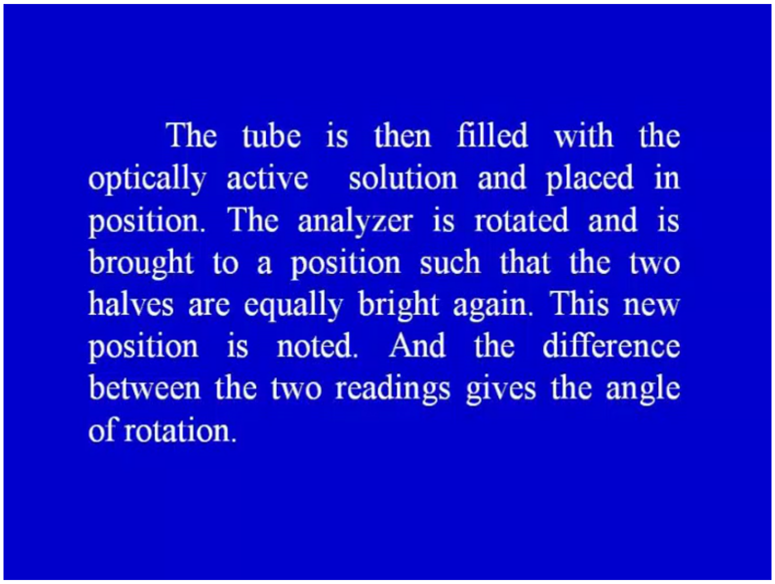

The tube is then filled with the optically active solution and placed in position. The analyzer is rotated and it brought to a position such that the two halves are equally bright again. This new position is noted and the difference between the two regions gives the angle of rotation, pretty accurately.

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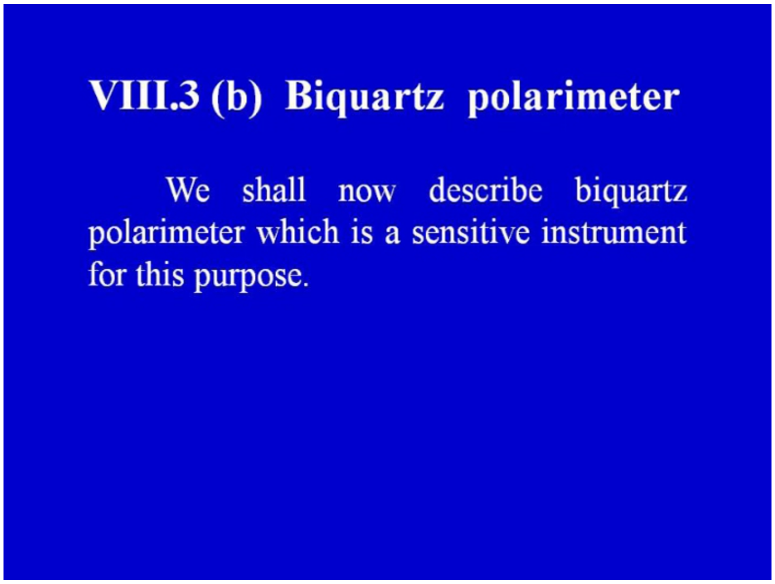

Now we come to Biquartz polarimeter. This is a little more sensitive than the Laurent's half shade plate. Here a monochromatic light is not used rather than we use a white light; maybe a mercury lamp.

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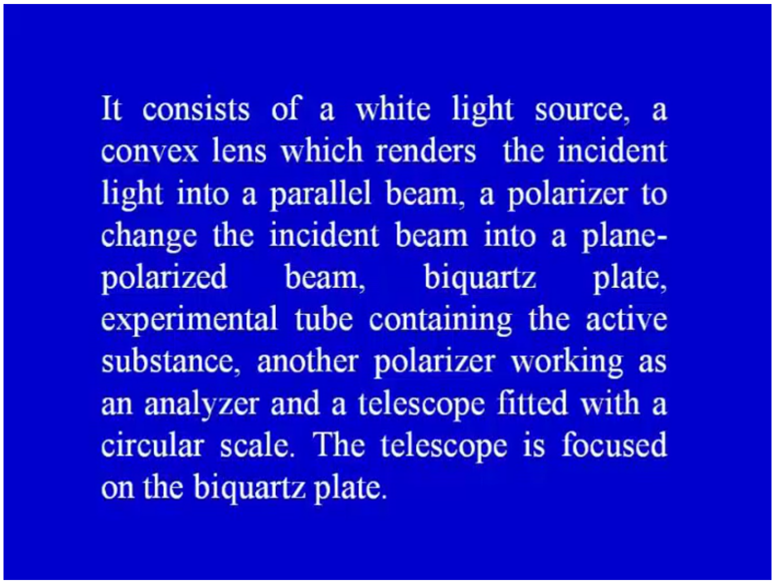

It consists of a white light source, a convex lens as before, which renders the light into a parallel beam, the polarizer changes the incident beam into a plane polarized beam, then a biquartz plate, then the experimental tube containing the active substance and a polarizer working as an analyzer as before. And a telescope fitted with a circular scale. The telescope is focused on the biquartz plate.

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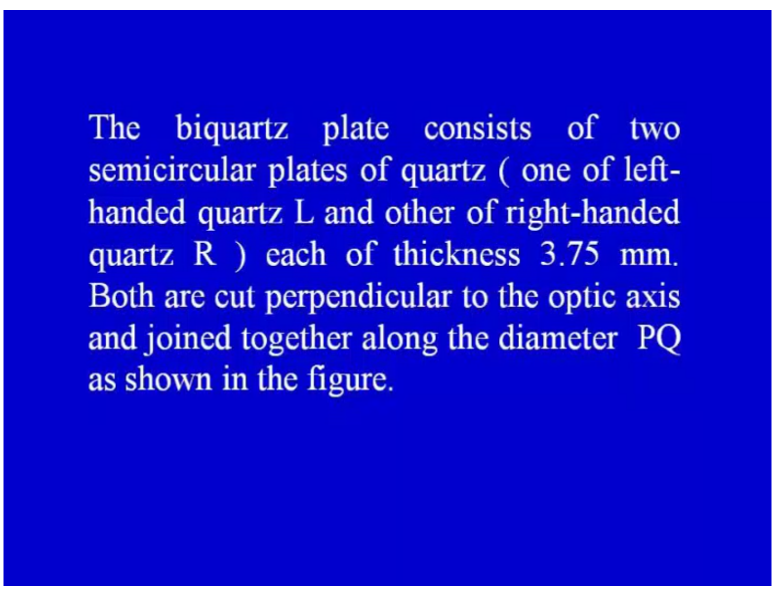

Now the essential pieces the biquartz plate. It consists of two semicircular plates of quartz: One of left handed quartz L and other of right handed quartz R, each of thickness about 3.75

millimeters. Both are cut perpendicular to the optic axis. This means the propagation here is along the optic axis now. They are joined together along the diameter PQ as shown in the figure.

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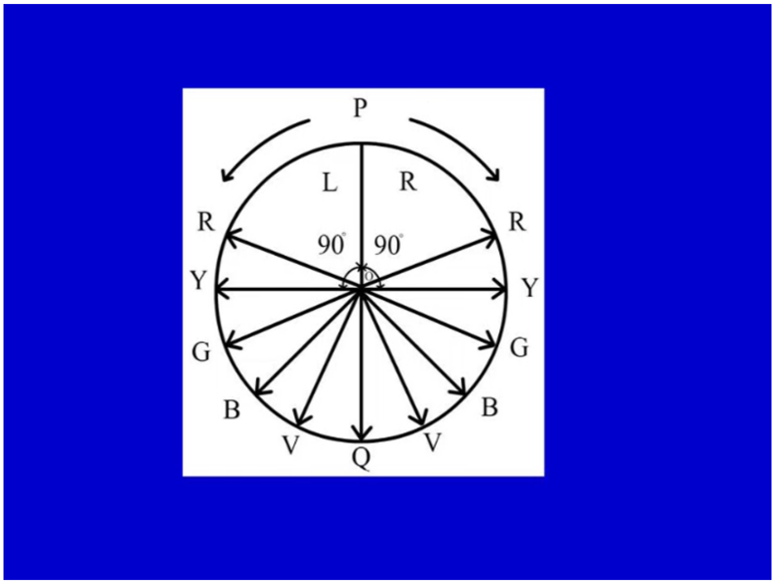

L for the left handed quartz and R for the right handed quartz joined along the diameter PQ.

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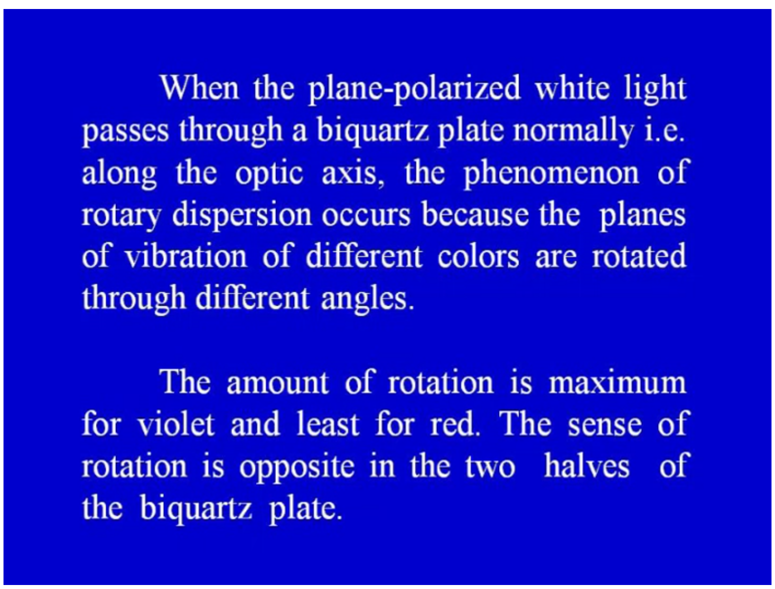

When the plane polarized white light passes through a biquartz plate normally, along the optic axis the phenomena of rotary dispersion occurs because the planes of vibrations of different colors are rotated through different angles. Remember, we have seen that the amount of rotation is proportional to 1 upon lambda Square. And rotation will be in one sense for the left handed portion and other direction for the right handed portion. The amount of rotation is maximum for violet which has the minimum wavelength and least for red.

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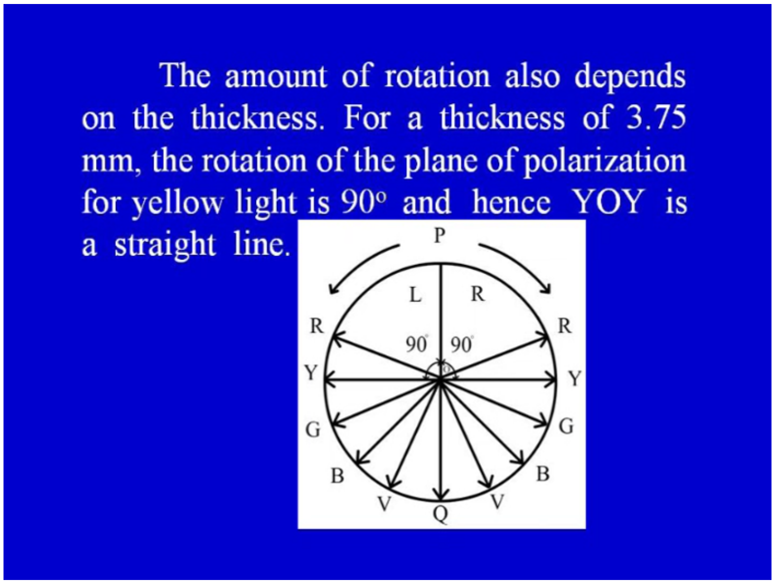

The sense of rotation is opposite in the two halves. The amount of rotation also depends on the thickness. For a thickness of 3.75 millimeters, the rotation of the plane of polarization for yellow light is about 90 degrees. And hence YOY is a straight line.

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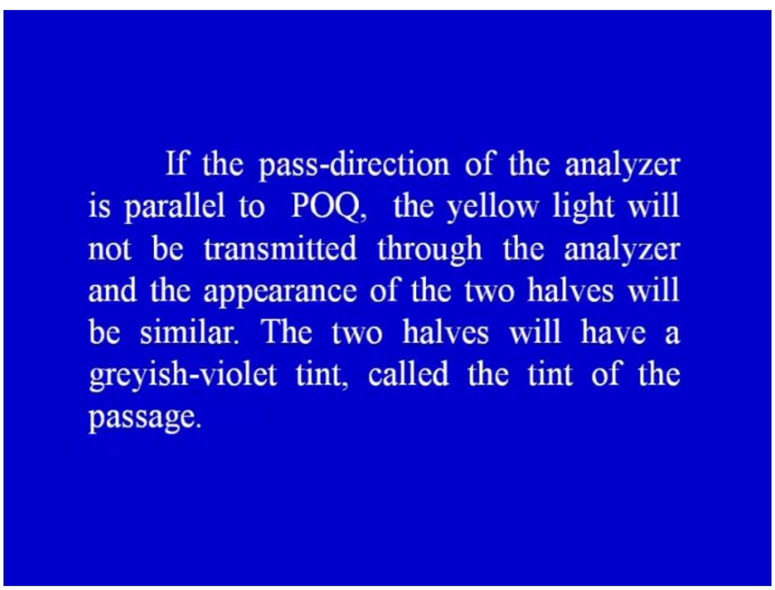

If the pass direction of the analyzer is parallel to POQ, the yellow light will not be transmitted through the analyzer, Malus Law. And the appearance of two halves will be similar. The two halves will have a grayish violet tint called the tint of the passage. When the analyzer is rotated to one side from this position, one half of the field of view appears blue, while the other half appears red.

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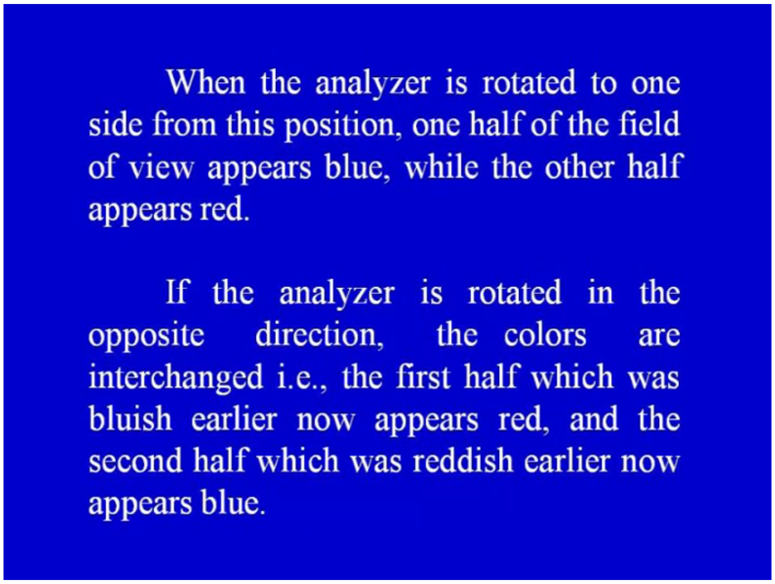

When the analyzer is rotated in the opposite direction, the colors are interchange the first half which was bluish earlier now appears red. And the second half which was reddish earlier now appears blue.

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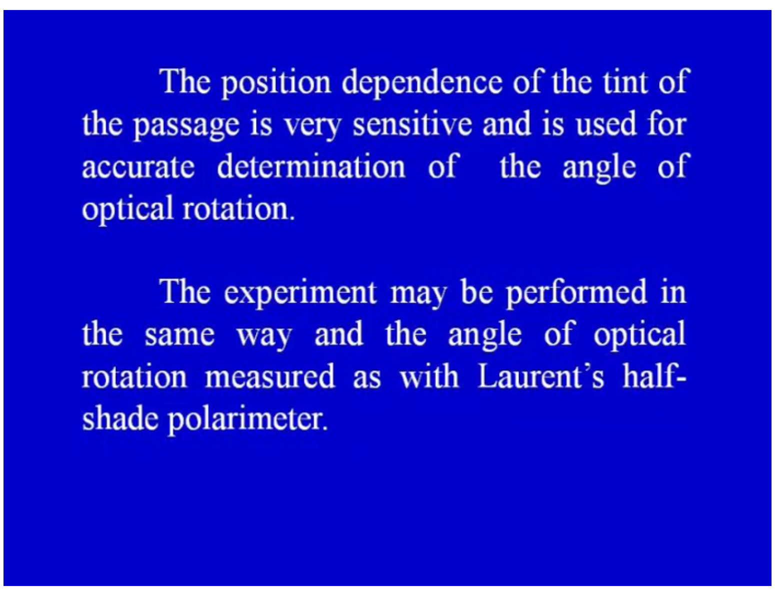

The position dependence of the tint of passage is very sensitive and is used for accurate determination of the angle of optical rotation. The experiment we were born in the same way and the angle of optical rotation measured as with Laurent's half shade polarimeter. And with this, we have come to the end of this lecture. Actually we have come to the end of this lecture series of five lectures. We have almost covered all aspects which need be covered in a series on polarizations. I hope you have enjoyed these lectures. Thank you very much for watching and listening.