Experimental Stress Analysis

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Module No. # 02

Lecture No. # 13

Light Ellipse, Passage of Light through a Crystal Plate

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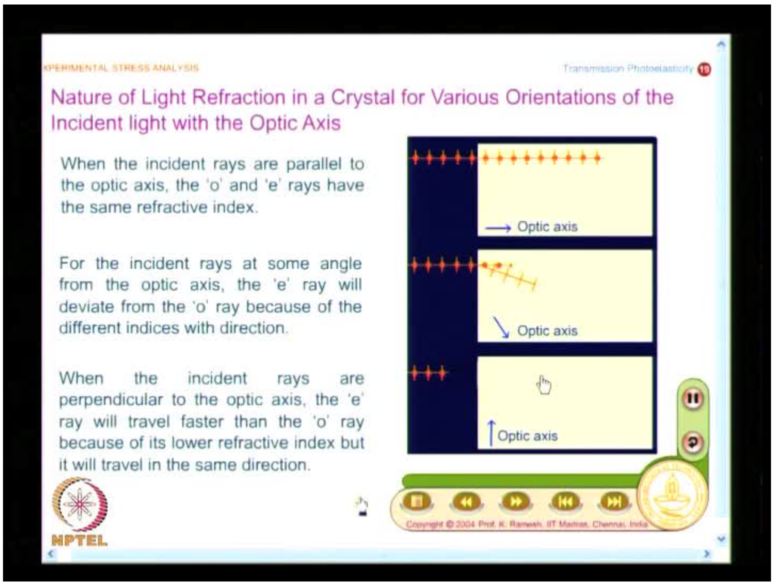

Let us continue our discussion on transmission photoelasticity. And for you to understand photoelasticity, you need to develop concepts related to crystal optics. And in this, one of the very important concepts that we saw in the last class was, when I have a crystal and when I have a light incident on it, I can look at the incident light with respect to the optic axis. In the first case, the incident light is along the optic axis; in the second case, the incident light is at an angle to the optic axis; in the third case, the incident light is perpendicular to the optic axis.

And what I mentioned in the last class, was the third case is particularly attractive to photoelasticity. The second case really brings out, how does one look at two images in a crystal; so the second case helps in understanding what is birefringence. On the other hand, the third case is what is useful from photoelasticity point of view, and the first case is very similar to what happens in an isotropic medium; and in the third case, both the ordinary and extraordinary rays travel in the same direction, but because of different in refractive indices, they travel with different velocities. So, now what I find is for one incident beam, I have two refracted beams; their planes of polarization are mutually perpendicular; they also acquire a retardation within the crystal.

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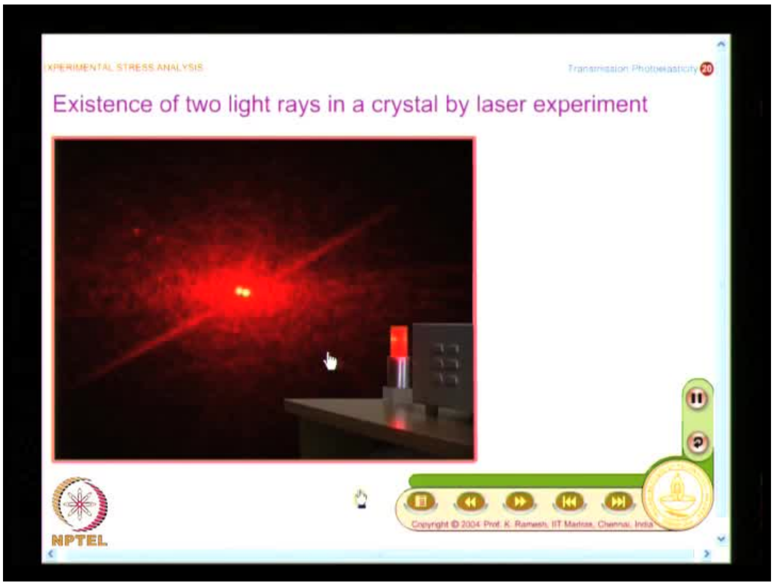

And in order to give you an idea, it is indeed so, we have also rotated a crystal and we saw that one dot becomes two dot, which indicates that the incident light in relation to the optic axis has a role to play. So, now the stage is set for how to analyze this mathematically.

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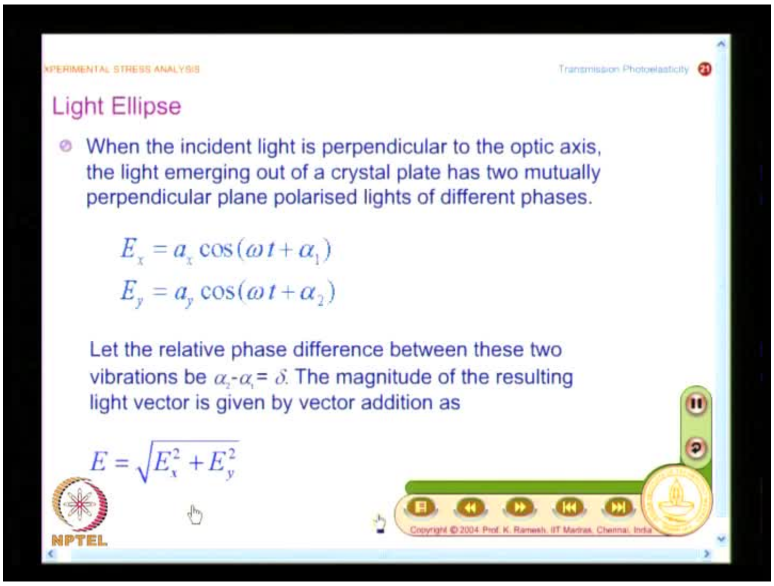

And even before developing the concept, we have labeled this as Light Ellipse. So, you can say that whatever we are go to do, finally we end up with equation for an ellipse. And what you have is, for one incident light I have two refracted beams and they travel with different velocities, and they could be easily represented by a x cos omega t plus alpha 1 and a y cos omega t plus alpha 2. So, what I have is, I essentially have two simple harmonic motions, one in the x direction, one in the y direction, they have different amplitudes a x and a y. And in general, you could also think of a phase, alpha 1 and alpha 2.

See, what you will find is, in photoelasticity literature, more than the absolute phase it is the relative retardation that is very important. So, keeping this idea in mind, we would also go back and recast the equation, that is what we will do later. So, what we will look at is, we will look at relative phase difference between these two vibrations, label that as delta, and delta is nothing but alpha 2 minus alpha 1. So, it is a relative phase difference that is very important.

So, what I have is, for one incident light I have two refracted beams and they are simple harmonic, planes of vibration are mutually perpendicular, and when I want to find out what is the resultant, the magnitude of the resultant light vector is given by simple vector addition. Suppose, I want to find out what is E at a particular instant of time, I have to simply take the amplitude of this, I have to simply take this square root of it, so I have this as E x squared plus E y squared, I can find out the amplitude. And this I do because they are mutually perpendicular. It is not like, when I go to the pond, drop the two pebbles, both the waves in the same plane. Here, the waves are mutually perpendicular, they travel with different phase. They acquire a phase retardation when it comes out the crystal, when it comes out of the crystal, you see the interaction of this, and what would be the nature of this interaction, the polarization behavior changes. So, that is what we are going to look at.

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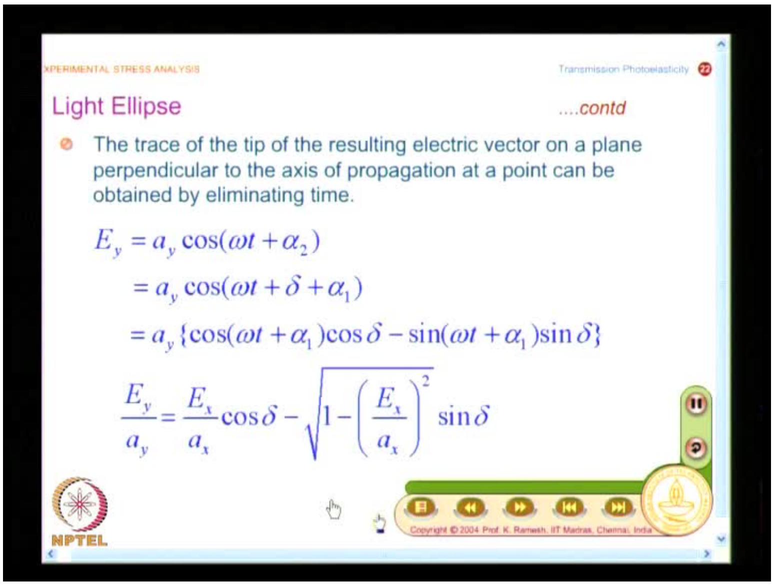

Now, my interest is, what would be the trace of this light that comes out of the crystal plate. So for me to do that, I have to eliminate time. So, what I want is, I want to get that trace of that tip of the resulting electric vector on a plane perpendicular to the axis of propagation, this is my interest, and this can be obtained by eliminating time. And I have already mentioned that for you to carry on with photoelasticity, you need to brush up your trigonometric identities, we will use several of them, even for this development, we will use the trigonometric identity and simplify the set of expressions. I will give you the clue, you have the expression for E y and that has a phase alpha 2. And I said in photoelasticity we are interested only in relative phase difference. So, write that in terms of delta and alpha 1, and you can simplify it. Take two minutes of your time and do it.

I have E y as this, and I would like you to simplify this expression, as simple as that. So, what is the trigonometric identity I can use? Cos a plus b. So, I can have this as cos omega t plus alpha 1, omega t plus alpha 1 I can take it as a, and delta as b. So, cos a plus b you will get it as cos a cos b minus sine a sine b. So, when I do that, I will get this expression. So, what I have is, I have a y cos omega t plus alpha 1 into cos delta minus sine omega t plus alpha 1 into sine delta. And this, I could replace in terms of E x as well as this also I could replace it in terms of capital E x. Now, I will have an expression only consisting of E y, a y, E x, a x and expression involving delta. You could simplify it, can you write in this fashion? It is straight forward, you could do it easily, and when I do that I get the expression like this. So, I have this as E x by a x cos delta minus square root of 1 minus E x by a x whole squared into sine delta.

And what I could do is, I could segregate the terms, and finally write what is the expression that would give you the trace of the tip of the resulting electric vector. So, what I have done is, I have just taken this expression, replaced alpha 2 in terms of delta plus alpha 1, used trigonometric identity and got this expression, then replaced this terms involving time by E x by a x, and now I have the final expression, and this could be further simplified. Can you do that simplification? Do that simplification, because if we do the simplification right in the class, when you revise the notes, whatever you have learnt becomes very simple, it is a very simple exercise and let us see what we get.

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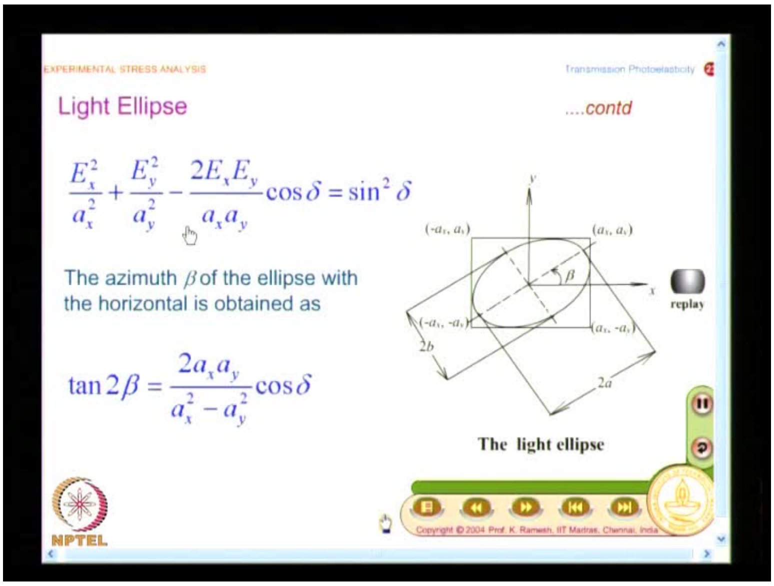

So, I am want to get an expression like this. What I have is E x squared by a x squared plus E y squared by a y squared minus 2 E x E y divided by a x a y cos delta equal to sine squared delta. And this is the generic expression of an ellipse. Suppose, delta becomes pi by 2, what happens to this expression, you have this becomes 1 and this terms goes to 0 and this is your famous equation of ellipse. You have x squared by a squared plus y squared by b squared equal to 1, that you all know, that is the equation of an ellipse. And what you have here is, this is an equation of an ellipse at some arbitrary angle. And that is what you have here, I have this as the light ellipse, and this light ellipse, the major and minor axis are shown here, and this is orientated at an angle beta, and this is governed by a generic expression like this. And I have the amplitudes marked, and you can also find out the expression for a as well as b, in terms of these quantities. That is not our focus, so we will not really determine that, but would definitely find out what is the expression for beta. And we will directly take that result from what is available in the literature, we will not derive it, and what I have here is the azimuth beta of the ellipse with the horizontal is obtained as, given as, tan 2 beta, and that is given in terms of the amplitudes 2 a x a y divided by a x squared minus a y squared into cos delta.

And this is a very important learning, what you have is, when I have two simple harmonic motion, which travel perpendicularly, and they have a phase difference when it is comes out, and they interact, and you essentially get an ellipse. And what you have is, you have two expressions, one expression gives the equation of the ellipse, the other expression gives you the orientation of the ellipse, and this is called the azimuth. And if I calculate a and b, if I have b by a, I also get the ellipticity. In fact, if you go to optics literature, there is a quite a good measurement approach is available, where they call it as ellipsometry. They find out the ellipticity, they find out the azimuth they also find out the handedness of ellipse. So, what you find here is, if I add two simple harmonic motions which are mutually perpendicular with the phase difference, if I add them, in general I get the interaction as trace of an ellipse, this is very important photoelasticity.

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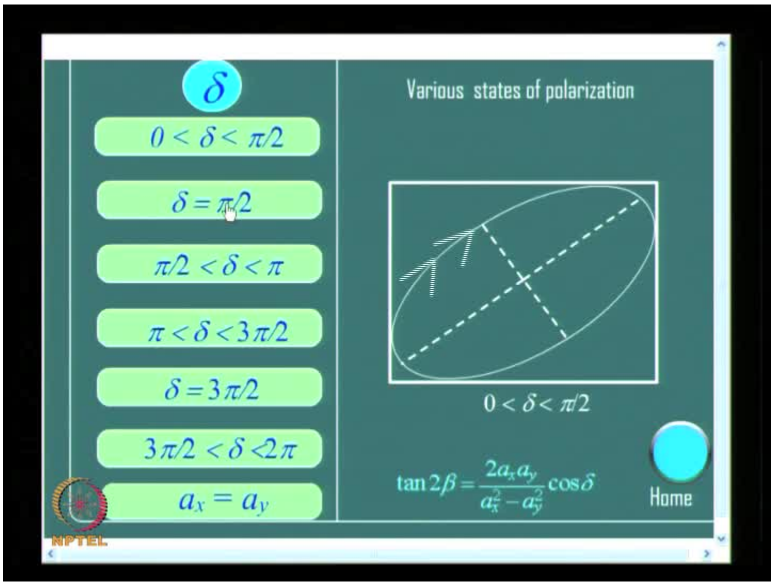

We would also see this little further. And what my interest is, when I changed delta, what happens. For various values of delta, what way you will get the state of polarization. We have already seen when delta equal to 0, what happens. When I have delta equal to 0, I have two vibrations and they will give you a plane polarized light, where is the ellipse comes, ellipse is not come there, delta equal to pi by 2, then you had equation of a simple ellipse, whose axis coincide with the x and y direction.

And what we are looking here is, we want find out in the range 0 to pi by 2, when delta lies, it is not 0 or not pi by 2, it is within this range how do you have is, you have an ellipse like this. I want you to make a sketch, you will have sketch for all of these cases, and also note down that this is rotating in a clock wise direction.

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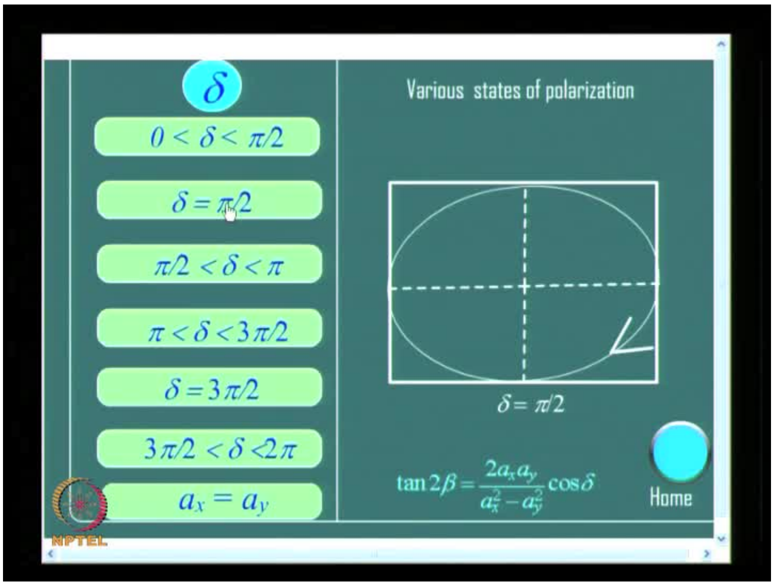

So, if delta is between 0 to pi by 2, their resulting trace of the light would be an ellipse orientated with this orientation, and it will have handedness indicated in this fashion. And suppose I got delta equal to pi by 2, which we have already looked at it, we will see pictorially. So, when delta equal to pi by 2, the major and minor axis of the ellipse coincide with the reference direction x and y. This is a very important result, this is very useful result in photoelasticity. The vibration along the major and minor axis having a phase difference of pi by 2, that is very important information you have. So, if the vibration is, we having a phase difference of pi by 2, then those axis form the axis of the ellipse.

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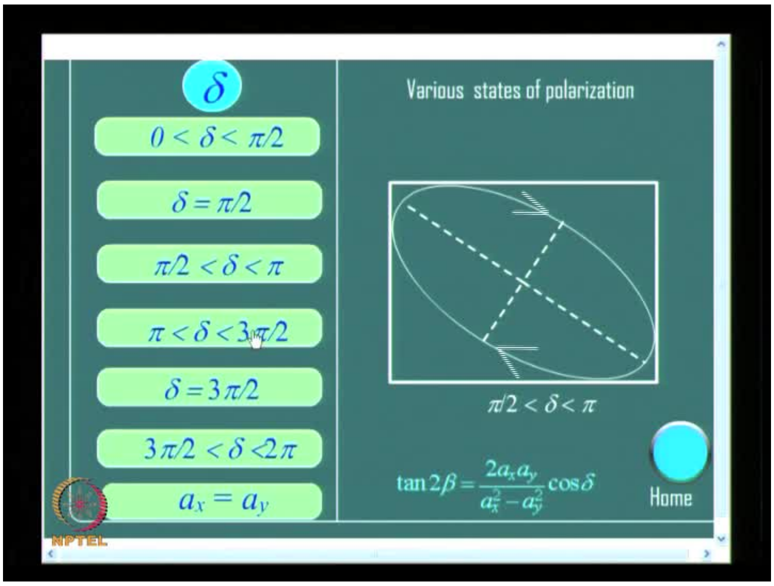

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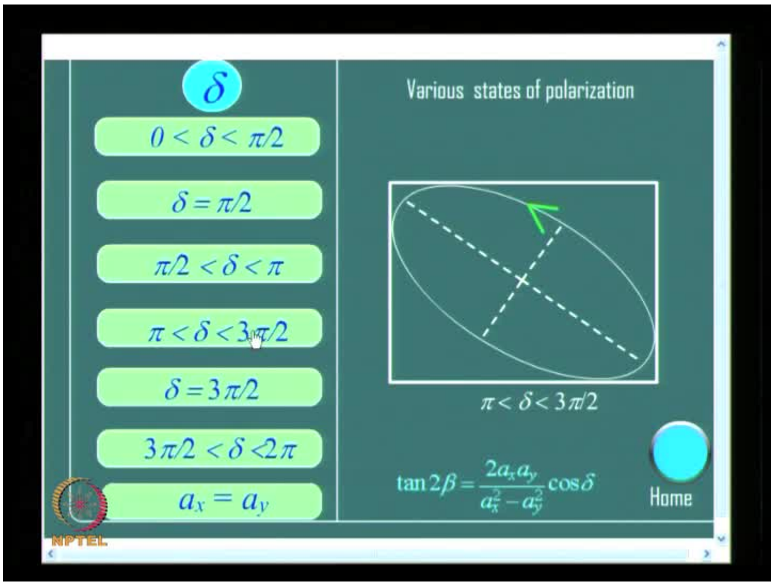

And what happens when I have the range goes to pi by 2 to pi. The orientation changes and you have the handedness still remains, the handedness is still clockwise. And when you complete this picture, you will have a nice picture, nice set of pictures that you will have. If I go to the range pi to 3 pi by 2, you will find the handedness also changes. So, that is what I have, the handedness changes, orientation remains same, but the handedness changes.

So what you find here is, for different values of delta, you see different forms of elliptically polarized light. So, you can look at it the other way, when I look at the light ellipse, it is possible for me to find out, what would be the value of delta that would have caused this, our interest is the reverse. But in order to understand the cos of delta, we look at for various values of delta, how does the light characteristic changes, that is what we are look at.

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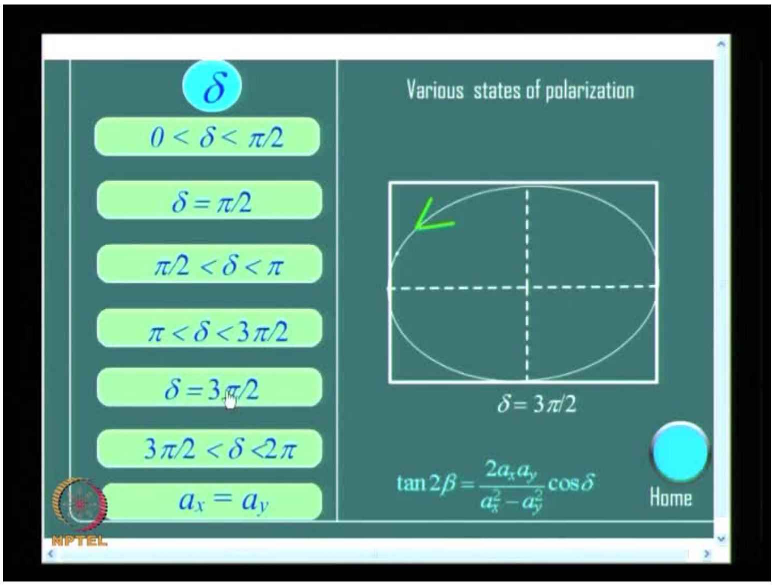

And when I have delta equal to 3 pi by 2, pi by 2 and 3 pi by 2 share a commonality, you will have the axis coincide with the reference axis. But the handedness changes, when it was pi by 2, the handedness was clockwise, and when it is 3 pi by 2, the handedness is anticlockwise. And what you need to appreciate here is, in conventional photoelasticity, people never bothered about the handedness, it was not really affecting the results. The moment digital photoelasticity came, where they used CCD cameras as electronic eye and they wanted to automate the procedure in order to minimize the error sources, change of handedness helped in minimizing the error due to quarter wave plate. So, though in conventional photoelasticity handedness does not play a significant role, it does play an important role when you come to the domain of digital photoelasticity. So, it is better to know, the handedness has it’s importance.

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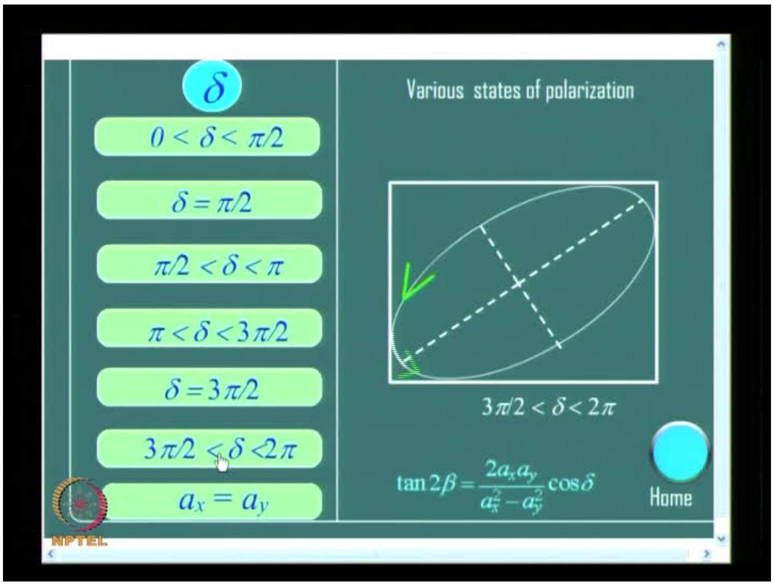

And when I go to the range 3 pi by 2 to 2 pi, I have the ellipse orientated in this fashion, and this is anticlockwise. So, you have three cases where you have anticlockwise, we have three cases where you have clockwise. And when delta equal to 0 or delta equal to pi or delta equal to 2 pi, you will have plane polarized light coming out as plane polarized light, except the case which is slightly different is when you have delta equal to pi. When delta equal to pi, it will be rotated by some angle. But the state of polarization will remain still plane, but it will get rotated by some angle.

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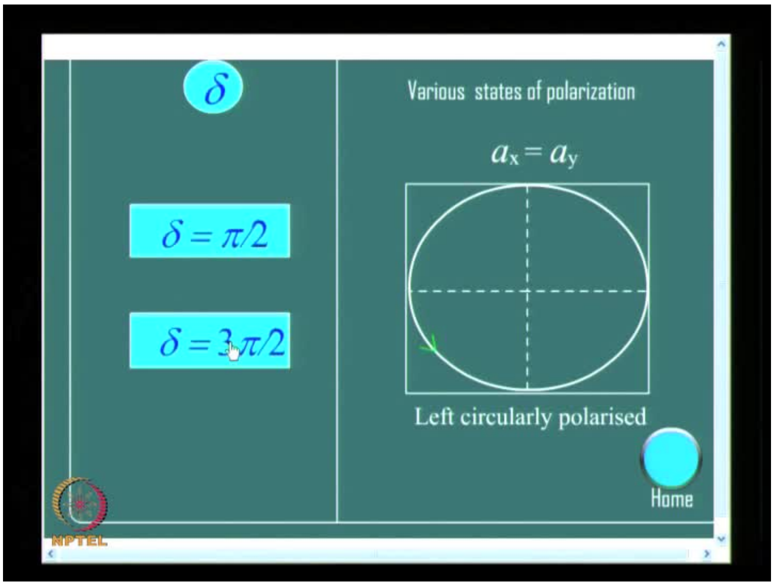

And now, we come to another important aspect, what happens to this expression when a x equal to a y. So, it becomes undefined. When tan 2 beta becomes infinity, 1 by 0 you have, so it becomes undefined. And when the amplitudes are equal, you have essentially a circularly polarized light. Because there is no specific axis, you have only circularly polarized light that comes out of the model. And this is a very important state of polarization we want, because I said that you have a plane polarized scope, you have a circular polarized scope. In a plane polarized scope, you impinge a plane polarized light, in a circular polarized scope, you impinge a circularly polarized light. So, I need to generate a circularly polarized light and make it hit on the model and this gives a via media. So, I have a crystal plate in between, a plane polarized light can be converted into a circularly polarized light.

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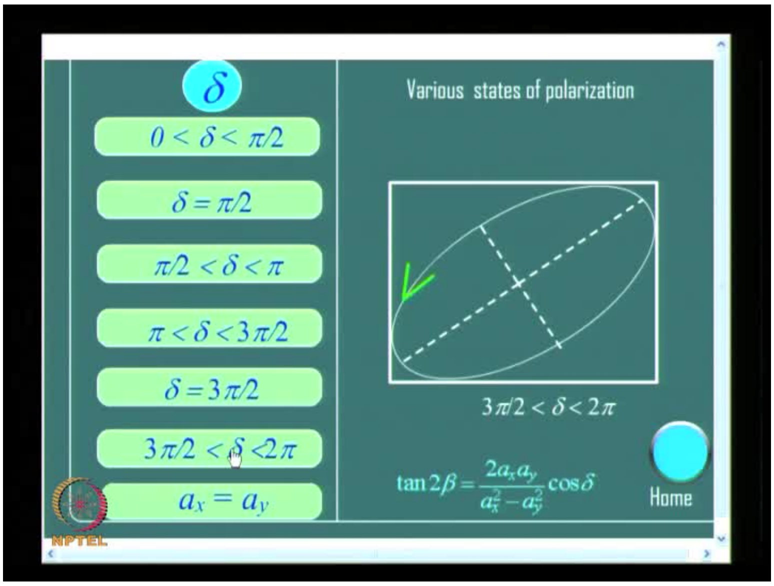

And what you have here, when delta equal to pi by 2, the handedness is clockwise, when delta equal to 3 pi by 2, the handedness is anticlockwise. So, handedness tells you what is the value of delta. So, in ellipsometry, they measure the ellipticity, they measure the azimuth, they also measure the handedness. So by knowing this, you can fix delta. Our idea is to find out delta by optical measurement. I said, light is a sensor and light gets modified within the model because of the sources applied, and you get exit light, which is in general elliptically polarized. If I analyze what is a light coming out, I can fix what is the delta, that is what you have learnt it now. We will also look at it in a slightly elaborate way, when you look at what is retardation plate. As far as this discussion goes, what you find is, when I have two simple harmonic motions, which are mutually perpendicular, which have a phase difference for different values of phase difference, I get different states of polarization as the exist light.

So, this gives you a hope to use light as a sensor. Because essentially, I will find out what happens to the exit light, with the exit light I will go back to find out what was the delta that has caused. Now, we will relate delta to sigma 1 minus sigma 2 later, that is how we will merge physics and stress analysis. But before we get into that, we need to know little more about what happens, suppose I take a crystal plate, that we will see now.

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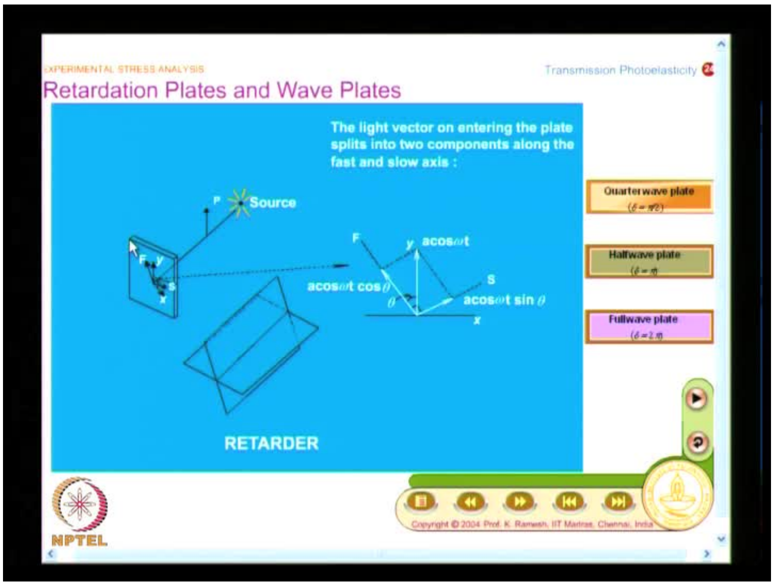

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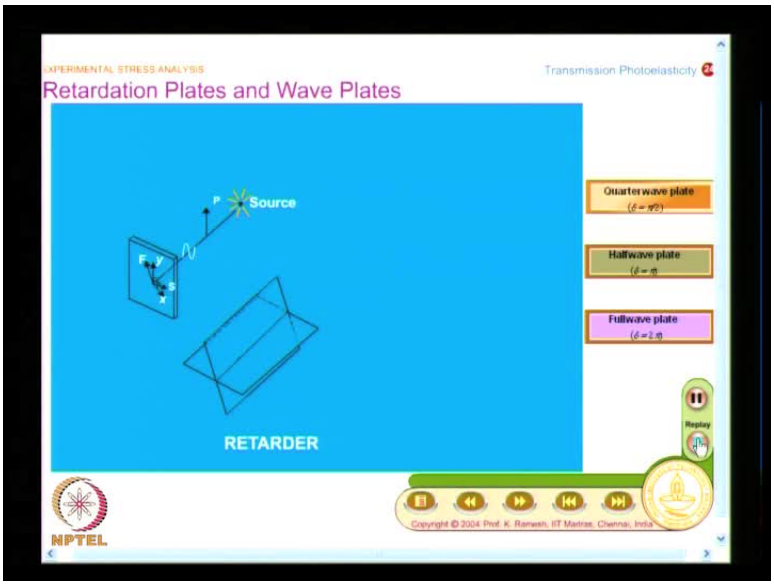

I will just take a crystal plate and you have to observe it very carefully, we will do this two-three times. So, what I have here is, you keep your note book horizontal and draw this sketch, and we will see part by part and then explain, and what we are going to discuss is retardation plates and wave plates. So, what I have here is, I have a crystal plate, it is not loaded, it is a natural crystal and I have this in a form of a plate. And what I have is, I have a light source and I have put a polarizer. Now, you must be familiar and we will just see what happens. So, what you have here is, I have a natural source of light, after the polarizer I have a plane polarized light impinges on the model.

So, what you have is, I have a plane polarized light, because I want to use light as a sensor, so I should know the input light characteristic. Input light is simply a plane polarized light. And when it hits the model, when it hits the crystal plate, it is not the model, model also behave likes a crystal when it is loaded, and here we are looking at in general what happens to the crystal plate. And what do you anticipate? You anticipate for one incident light there will be two refracted beams, because that is what the whole of the crystal optics tells you. For one incident beam, I will have two refracted beams, and these two refracted beams are plane polarized, and their planes of polarization mutually perpendicular. Let us see this, that is what is shown in the animation, you carefully watch.

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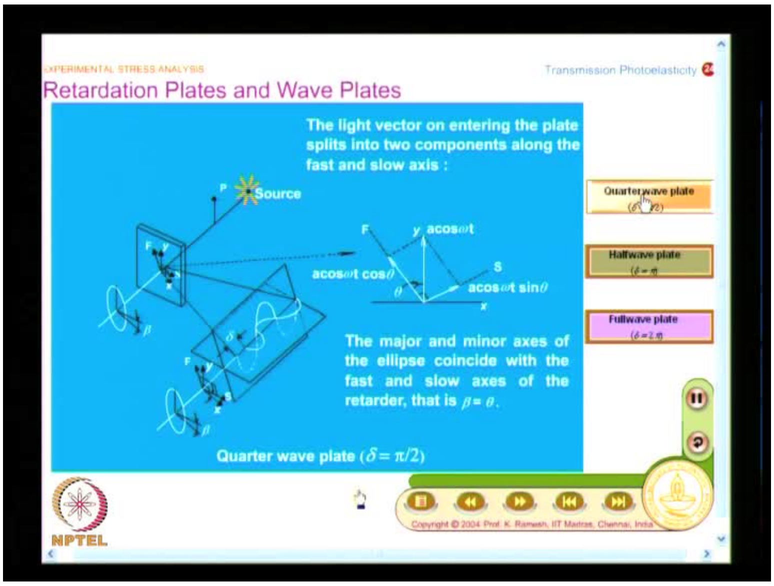

So, what I, what happens is the light vector on entering the plate splits into two components along the fast and slow axis. So, you have to understand, I am bring in two new terminologies, fast and slow axis. The reason for this labeling would become clear, when we look at what happens. So, what we saw is, I have a natural source of light which become plane polarized, hits the model and then on the front surfaces it splits into two components. Let us see the two components. Is the idea clear? I send a vibration, a cos omega t, this will become two rays within the model, within the crystal plate. And you have a, depending on the orientation, you have one of this amplitude is longer, another amplitude is smaller, so amplitude is plate.

And this is nothing but they are, the planes of vibration is in this direction, planes of vibration is in this direction and they are perpendicular. So, for one beam within the model, I will have two rays. And what you have here is, if you watch it very carefully, whatever is the thickness is expanded as two planes, I have one plane coinciding with the fast axis, another plane coinciding with the slow axis. And let us see what happens.

So, what happens is, you know that when light enters the crystal, it splits into two rays, and because it is perpendicular to the optic axis, they travel in the same direction. But the plane of vibration is mutually perpendicular, you have one plane like this, you have another plane like this, and you have a wave travels like this. And what has happened? This wave has travelled past the other wave, that is what is shown in the sketch. So, this has traversed the thickness of the plate faster than the other wave. So, I call this axis has fast axis. And this wave has taken little more time and it has acquired a retardation delta within the plate. I will repeat the animation, then you will understand. So, what you find here is, I have a natural source, I put a polarizer definitely, and I know what kind of light that impinges on the crystal plate, and this splits into two rays when it enters the model. Depending on the angle theta, you will have the amplitude as a cos omega t cos theta a cos theta into a cos omega t, that is the expression for the light vector, and you will have this as a sine theta cos omega t, and within the model which is shown in an expanded fashion, I have this like this.

Make a neat sketch of this. And what do you anticipate? I have two simple harmonic motion, which are mutually perpendicular, which has acquired a phase difference. When they come out of the crystal plate, how will it appear. We have just now seen mathematical expression. It will appear like an ellipse, that is why we develop the mathematics. If I have two simple harmonic motion which are mutually perpendicular, if they have a phase difference, depending on the difference in phase, you will see lights different states of polarization.

And let us see that. So, I will have a light ellipse coming out of the model. I use model and crystal plate interchangeably, please pardon me. And model behaves like a crystal plate when stressed, in a crystal plate it is naturally having birefringence, that is only difference. So, what I have here is, when I have a normal light source, I have a polarizer, I put a crystal plate, in general I will have a light ellipse. And how this light ellipse has come about? I know that within the crystal plate I have two rays traveling, one plane of vibration is in this plane, another in the plane perpendicular to it, they acquire a phase difference delta. And we just now has seen, if I have two simple harmonic motions with the phase difference which are mutually perpendicular, I get essentially an ellipse. If you understand this, the whole of photoelasticity is mastered. And what we will do is, we will see the animation again, I will stop at intermediate stages, and you can verify your drawing as well as improve your understanding.

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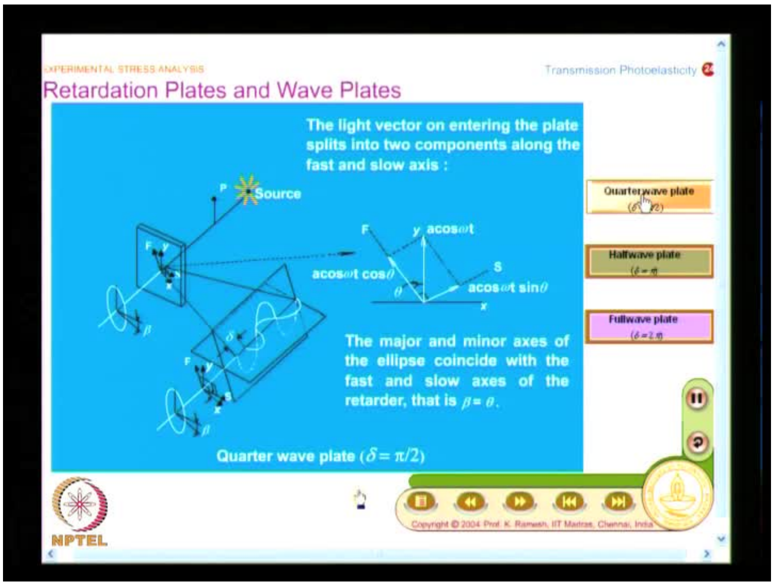

So, what this shows is, I have a source of light, I have a plane polarizer, after the plane polarizer, I have a plane polarized light, hits the crystal plate. As soon as it touches the front surface, it splits into two components. Because within the crystal you will have two refracted beams, you are not going to have only one refracted ray. And these two refracted rays will have different amplitude, which are shown, which is depicted by the angle theta.

So, when you look at a crystal, crystal will always have a fast axis and slow axis, which are mutually perpendicular. And you may have to perform an experiment to find out these axis, their labels F and S are again arbitrary, appearing we do not know whether it is a fast axis or a slow axis. You can label it as fast axis and carry on, but once you do this, you must match your optical arrangement to the actual physical polarized scope. And again in conventional photoelasticity, whether it is a fast or slow axis did not play a significant role. The moment you come to the digital photoelasticity, whether at the point of interest, the axis could be label the fast or slow had an effect in digital photoelasticity. And that is very important, you had ambiguity and these ambiguous zones need to be corrected. So, it is better know, it is an arbitrary label. And how to do it? You have to do an extra step, you have to do some kind of calibration to establish this, without calibration you cannot do it. And with this, you can really go back and see which way you can relate this to stress analysis. Even without looking at what others have done it, with the information you have gathered, you can really find out, we have also looked at photoelasticity gives a sigma 1 minus sigma 2, and then it gives you orientation of theta, you have answers for that in this slide. One answer is, when I look at fast and slow , they could be thinking of coincide with the sigma 1 and sigma 2 direction, and this is what your theta. So, if you find out the theta, you get the principles of direction.

And we are talking about delta, that is acquired within the crystal plate, and this delta, whatever the delta you have acquire is nothing but sigma 1 minus sigma 2. In a crystal plate, the fast and slow axis are same at every point in the whole crystal plate. In an actual model, the fast and slow axis change from point to point depending on the state of stress, as simple as that. And you have a very nice animation here, this animation gives you what happens pictorially within the model, and what you see when the light comes out. And when the light comes out, you have this as an elliptically polarized beam of light.

And now what I am going to do is, I am not going to stop in between, I am going to redo this animation, you just watch. Whatever the concept that I have developed, you will understand. So, is the idea clear? I have a natural light source, you have plane polarized beam of light, when it hits the front surface, it splits into two components, within the thickness of the crystal plate it acquires a retardation. Why it acquires a retardation? Because it has different refractive indices and we have looked at the refractive index as ratio of velocities, that is why we said, we always want to look at as ratio of velocities, because we want to feel that one wave will travel faster than the another, I have ordinary and extraordinary rays that travel with different velocities.

And when they come out, you have this as elliptically polarized beam of light. Suppose, I go and adjust the thickness of the plate, and then ensure that I have delta equal to pi by 2, it is one quarter of a wave, so I call that as a quarter wave plate. So, what happens here, this beta will coincide with theta, whatever I have shown this as beta, it will coincide with theta. The major and minor axis of the ellipse coincide with the fast and slow axis of the retarder.

So, what you get is, you get beta equal to theta. You write only this statement, you do not have to redraw this complete figure, what you learnt here is the major and minor axis of the ellipse coincide with the fast and slow axis of the retarder. So, if I have a quarter wave plate, when I send the beam of light, because the fast and slow axis themselves became the axes of the right ellipse that comes out of it. In general, it is an ellipse, in particular cases, it can be plane polarized or it could be circularly polarized, depending on how do I manipulate the amplitudes. How do I manipulate the amplitude? I can orient this theta in such a way that I make it 0, I make theta 0, the fast axis coincide with the plane of incident light. What happens? Only a plane polarized light will pass through, on the other hand, when I have this angle as 45 degrees, I will have this as amplitude same, when the amplitude is same, I will have a circularly polarized light. In fact, if I have a polarizer and a quarter wave plate, I can get light ellipse of any azimuth, any ellipticity. You have complete control. How do I control the azimuth? I simply rotate the quarter wave plate axis, because that determines, because the quarter wave plate slow and fast axis acts like major and minor axis of the light ellipse, so that I can control. And if I control the relative orientation between the quarter wave plate axis and the polarizer axis, I can control the ellipticity. So, I can have light of all characteristic generated with combination of polarizer and a quarter wave plate.

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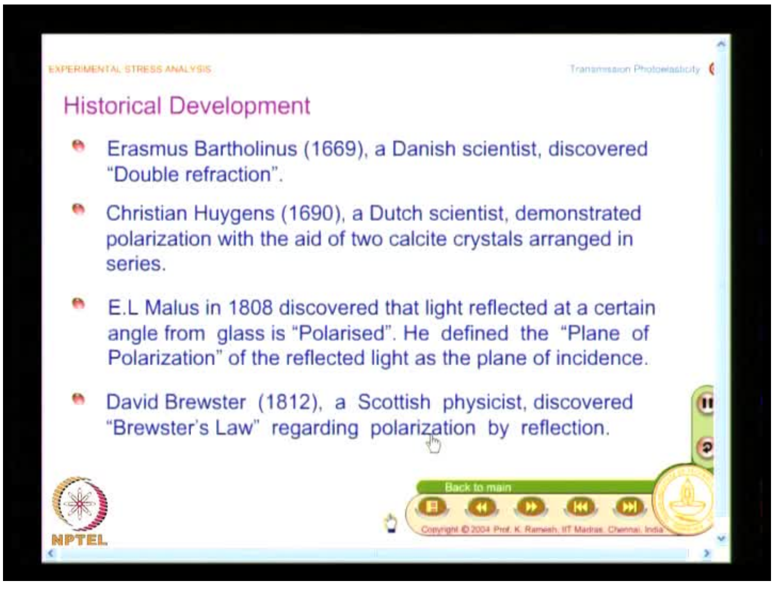

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And what is fundamental here? Fundamental to our photoelasticity is I should get plane polarized beam of light. And it is worthwhile to go back to the literature and find out how we can look at it. There is a large body of literature available and as a very nice development, starting from 1669. See, we do all this quickly, you have this double refraction was found out in 1669, double refraction is the first concept. Then you have, in 1690 Huygens, a Dutch scientist, demonstrated polarization with the aid of two calcite crystals arranged in series.

Then what you have, then you have Malus in 1808, observed that light reflected at a certain angle from glass is polarized. And he defined the plane of polarization of the reflected light as the plane of incidence, that is the definition he has used. And it was Brewster who developed this Brewster's law. So what you find is, double refraction is crucial, that is how crystal behave. And even for this understanding, it took almost hundred and fifty years, it is not so simple, we see that very quickly now. So, you have to have a concept of double refraction, then they understood what is polarization, then Malus found out that light reflected at a certain angle gets polarized, and it was Brewster who formulated this as a law, it is in his honor that the law is given. And we also know that Brewster found out temporary birefringerence, then photoelasticity got developed.

So, if you look at, we want a plane polarized beam of light, and if you look at these names, they are the celebrated people in the field of physics, and you have for each one of them, you have laws associated with them, and Huygens principles is very famous wave optics.

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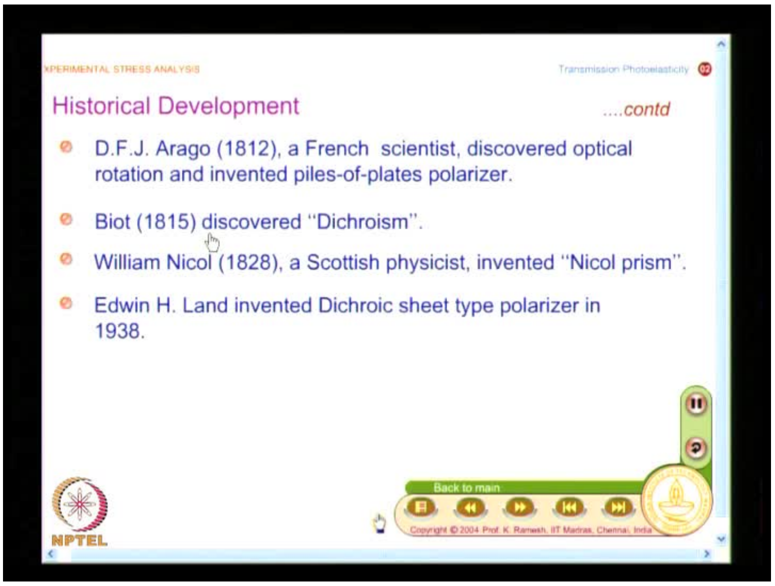

And then what happened, then what all development that took place. You also had Arago in 1812, he invented optical rotation, that you will understand when you look at half wave plate, it behaves like a rotator, and he invented piles of plates polarizer, he invented a new form of getting a polarized beam of light. And Biot in 1815, discovered Dichroism, this is important from the point of view of the polarized sheet that we have. We have a polarized sheet and I have simply said, in polarized sheet, if you put a polarized sheet, the natural light becomes polarized. How it function as a polarizer? You have to understand, that understanding is better. Because we are going to use polarized sheet in and out in photoelasticity So, it operates on the principle of Dichroism. So, you have to understand what is Dichroism. And once you talk of polarization optics, you cannot forget Nicol, you have the Nicol prism, that is also another form of getting the polarized beam of light. I have already mentioned that, you get very high quality polarized beam of light when you use the prism, but the field of view is limited. And it was land who invented Dichroric sheet type polarizer in 1938. Dichroism was observed in 1815, and it became available as a commercial product, for us to use in photoelasticity only in 1938.

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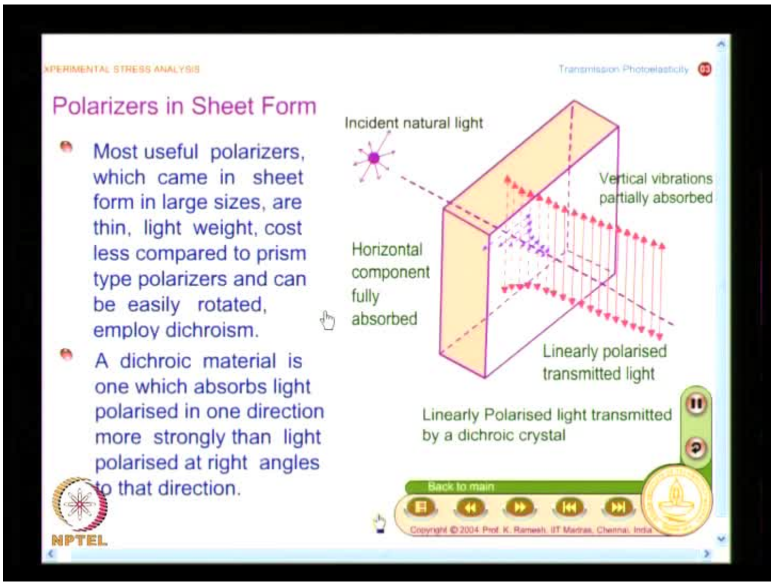

So any physics, it takes a long time for it to become as a technology, there must be need for it, people should know where to use it. They observed the physics, but this has to be translated into technology. And we have also seen, it is only around 1930s, photoelasticity become popular. So, when photoelasticity become popular, they also felt you need larger and larger field of view. So, that prompted people to look for alternatives. And this is what you have to understand, most useful polarizers, which came in sheet form in large sizes, are thin, light weight, they cost less compared to prism type polarizers and can be easily rotated. This advantage, because when I want to analysis light, I want to rotate the polarizer, if I have crystal, I need to have some kind of holding arrangement and do, it becomes difficult, and they all have the characteristic call Dichroism. And what is Dichroism? A dichroic material is one which absorbs light polarized in one direction more strongly than light polarized at right angles to that direction. That is why I am taking up now, we have look at crystal optics, in crystal optics we found for one incident ray, you have two refracted beams, and these two refracted beams travel with different velocities in a crystal at appropriate orientation, we have seen. But in a dichroic material, one of these rays is absorbed, so that helps you. And we have seen that, these are light with different planes of polarization, they are mutually perpendicular, they are plane polarized. And that is what is depicted in the figure, it is a complex figure, you see the horizontal component as it travels within the crystal it gets absorbed, the vertical component go undiminished, whether I incident a natural light or polarized beam of light within the crystal, you will have only polarized beam of light.

And what you fine in a dichroic material is, one of the vibration is completely absorbed within the thickness. So, it allows only one light to pass through. So, I have this plane polarized, horizontal component is fully absorbed, vertical vibrations partially absorbed. So, I get linearly polarized transmitted light. That is a useful information, I have a dichroic material, that is a useful information. You make a neat sketch of this. And for your benefit I can show the animation again.

So, what I have here is, the horizontal components gets absorbed, the animation is not shown simultaneously for vertical and horizontal, it is only emphasized for the horizontal, the horizontal component gets absorbed over the thickness of the sheet.

So, what you have here is, the most useful polarizers employ Dichroism. And what is the meaning of Dichroism? A dichroic material is one which absorbs light polarized in one direction more strongly than light polarized at right angles to that direction. So, that is what you see here. This horizontal component is absorbed, vertical component is allowed to pass through.

And we will continue our discussion further in the next class. And what we have seen today was, we have looked at, for a crystal you have for a single incident beam of light you have two refracted beams, they travel in the same direction, when the incident light is perpendicular to the optics axis of the crystal. And these two ways travel in this same direction but with the different velocities. Two simple harmonic motions with different phases, when they interact, they give that trace of light as an ellipse. And by changing the retardation delta, you get different forms of light ellipse. So, by looking at light ellipse, you can go back and find out what delta that has caused. That is the main focus of this lecture.

And we also looked at, that in a crystal plate, what really happens when I impinge a plane polarized beam of light. We are seen one light travels faster in one plane, we labeled that plane as fast axis, we also labeled another axis, which is perpendicular to this as slow axis. And I mentioned that these two are arbitrary classifications and you how to do some kind of calibration to fix, this is the fast and slow axis, and we also indirectly saw this fast and slow axes could be related to sigma one and sigma two directions.

And we are already seen your famous expression tan to theta equal to 2 power x by divided by sigma x minus sigma y is ambiguous. So, if you ought to resolve that ambiguity, you need auxiliary information, like more circle, or go for a Eigen value Eigen vector type of recasting the mathematics to fix the direction. A similar exercise you may also have to do, when you do an experiment.

And finally, what we saw was, in order to use light as a sensor, it is not good sending a natural light, I must have the complete control on incident light. And one of the simplest incident light in photoelasticity is the plane polarized light, and we saw how we get a plane polarized beam of light. The sheet polarizers are essentially dichroic in nature, we will continued discussion further, we will spend few more minutes on this dichroic sheet polarizers, then we move on to other aspects of photoelasticity, we will also develop the stress optic law in the next class. Thank you.