Experimental Stress Analysis
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Lecture - 09
Ordinary and Extraordinary Rays

We have started our discussion on transmission photoelasticity in the last class and I mentioned light is used as a sensor in photoelasticity. Then we moved on to find out what is the nature of light. We recall that light is nothing but an electromagnetic disturbance. So you have an electric vector and magnetic vector, which are mutually perpendicular and in phase are to be looked at.

For the purpose of simplified mathematical treatment, we would take the electric vector as the bases to represent the light vector and what we saw the natural light was not convenient to be used as a sensor. Then we said that we need polarization and we also looked at because we use polarization optics, we call the equipment used for photoelasticity as a polariscope. The name indicates that you are using polarization.

You have a plain polariscope, you have a circular polariscope and for you to understand what happens in photoelasticity you need to build up certain background. The first concept is what is polarization. The second concept is what is birefringence. Birefringence is natural to crystals and what we do in photoelasticity is certain polymeric substances become birefringent when they are stressed.

That is the advantage, when the loads are removed, the phenomenon of birefringence no longer exist and in order to understand how do you get the stress feel, you need to understand what is birefringence. So to understand birefringence we look at crystal optics and another important aspect is when you have fringe patterns, you have phenomena of interference.

One of the common example is given to understand interference in the first level course is you go to a pond, take 2 stones and then drop it. What happens? You have spherical waves formed and they interfere. When there is a crust and crust meets, you have constructive interference and when you have the destructive interference where the light is extinguished, the wave is extinguished.

And what happens in photoelasticity is slightly different. Photoelasticity you have relative retardation, which causes the formation of fringes and in the pond when you put 2 pebbles, both the waves are in the same plane and in photoelasticity, you have one wave and the other wave are mutually perpendicular. There is a phase difference between these 2 and where do these 2 waves come from?

That is what we have to understand and a difference from other optical technique is vibration requirements are not that stringent in photoelasticity. That is the greatest advantage and why it is so? All that we will understand when we look at what happens in a crystal and if you look at the polarization, birefringence and also formation of light ellipse, they are interrelated concepts.

You know you have to go back and forth and then try to understand and then get onto solid mechanics aspects and then look at how to relate the optical phenomena to stress information.

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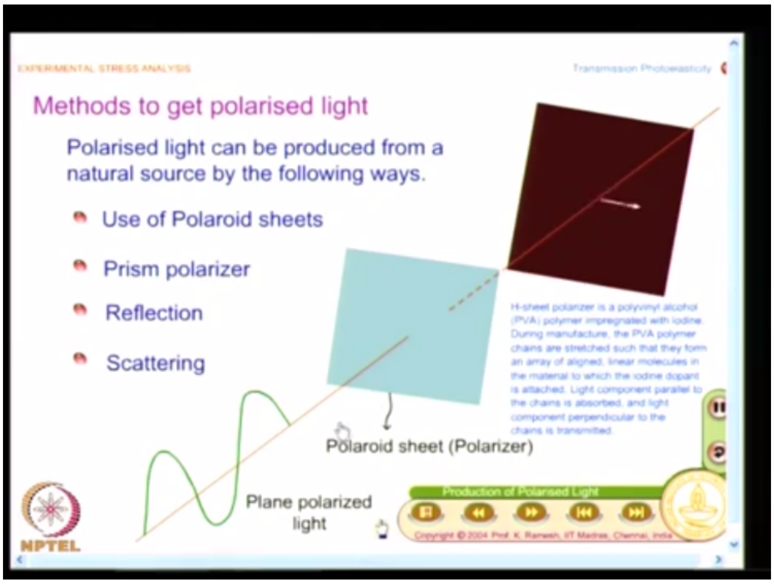

And first look at what is polarization. So I have a natural light, which is so random the magnitude as well as direction keeps on changing and the moment you put a polaroid sheet, you have a plain polarized light coming out after the polaroid sheet and this is only a statement and what I have attempted to show in this course is for any statement I make I try to provide you some kind of an experimental justification.

To a large extent, most of the statements I make I will try to provide you experimental justification and that gives you a certain level of confidence and we have also seen polarization can be affected by polaroid sheets, prism polarizers, reflection or scattering and we said that prism polarizer, the polarization quality is very high, but the field of view is very small.

On the other hand, polaroid sheets you almost get 99.9% of polarization. The greatest advantage is the field of view can be as large as even 1 meter you can do and for the certain wave lengths you know reflection and scattering are ideal and you also know at an appropriate angle called Brewster angle, you have polarization takes place. This is also another method of getting polarized beam of light.

And simplest form of polarization is plane polarized light and once you have plain polarized light, you could get elliptical and circular polarization and what we will now look at is we will have a justification.

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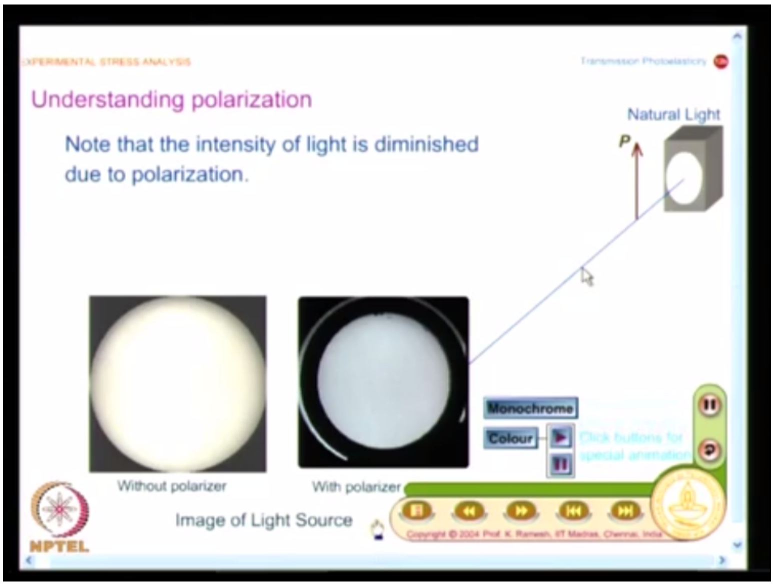

Yes, the light is polarized and that is what we saw in this slide last class. You have understanding polarization and the moment you send a polarized beam of light the amount of light available on the screen is diminished and I show the polarizer simply by a line sketch and this indicates the direction of polarization. So what I have here, I said that by putting the sheet only the vertical component is transmitted.

That was only a statement. Now I have to understand myself, this is indeed so. So how do I get it? I put another element, which also allows light only in one direction, when I keep it exactly perpendicular, the light should be cut off and what I am doing is the second element functions as analyzing the light that is coming out that is impinging on it. Both physically or same, the second one helps in analyzing the light coming on it.

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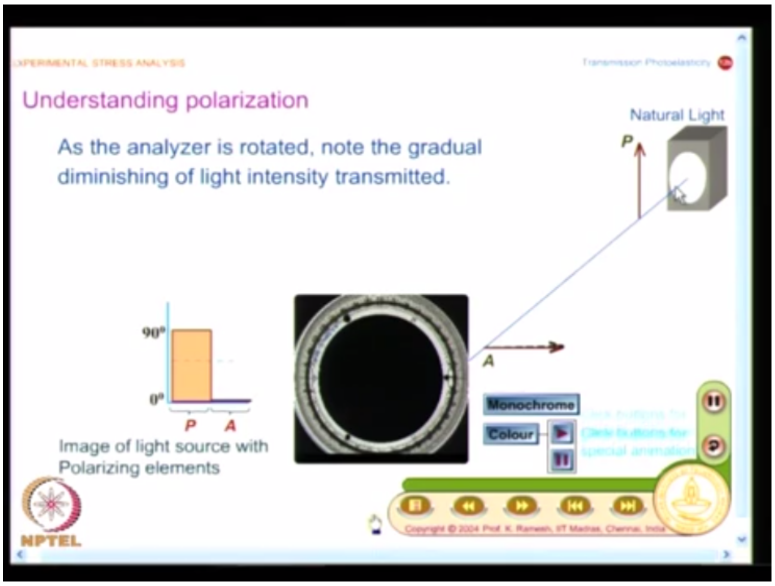

So you call that as analyzer, so what I do here is put an analyzer and I keep rotating it. So when I keep rotating it, I find that light gets diminished and when it becomes perpendicular, you have light is totally extinct and another subtle concept was also introduced while discussing this. I had a natural light, this is a white light source and we also looked at monochrome light source.

What is the difference between the white light source and the monochrome light source? In a white light source, you have play of colors, you have VIBGYOR. There may be with different proportions depending on the light source. So it is a multi-wavelength source and I said for all numerical development, a single wave length is simple and convenient.

Right now, people also have developed methodologies to find out even in a multi wavelength as light source how to interpret data, but for this initial development, we will look at a single wave length and what you saw here was for a multi-wavelength also when the polarizer and analyzer are crossed, the light is extinguished. When I have a monochrome source also the light is completely extinguished and you see black.

And this is a very important aspect that you have to keep in mind because when we go and put the model in between, when I go and put the model in between the polarizer and analyzer, we will also look at qualitatively how a fringe gets formed. We will not get into mathematics; first we will look at purely based on qualitative arguments. What could be the light extinction condition?

And we will find out and logically develop you would see contours of this nature, you would see contours of second nature and so on and so forth. So currently what we are having is we are having only a polarizer and analyzer and we saw that entire field could be dark or the field could be bright.

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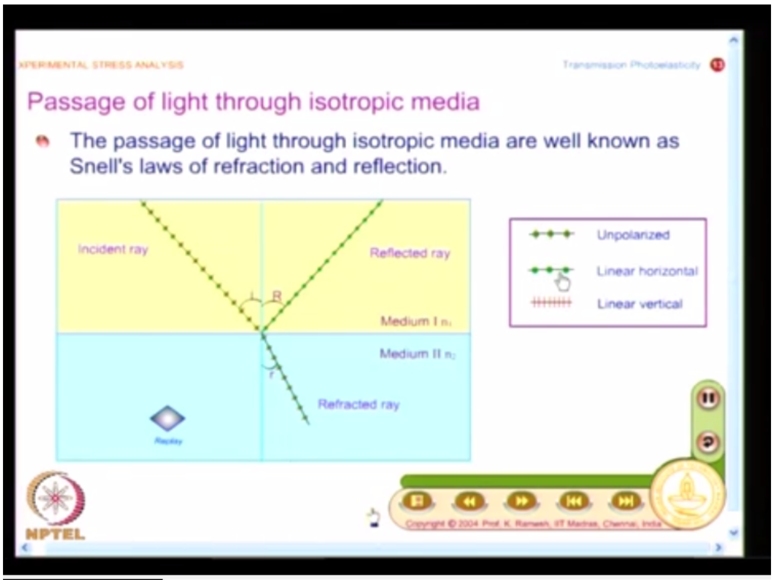

Next, we move on to what happens in a isotropic medium because when we want to go into crystal, it is better that a recapitulate what happens in a isotropic medium first and this all of you have seen in your school physics curriculum, but we will look at the same thing with our interest in mind. We will look at refractive index, but we will look at refractive index with a different perspective.

And we will also look at from the point of view of polarization what happens. So when I take an isotropic media, I have an incident ray and I have medium 1 shown by one color, medium 2 shown by another color. So the light gets refracted, also gets reflected and what you have to note here is the representation of unpolarized light that is nothing, but natural light is shown with a dot and a straight line.

Suppose you have only dots, it is understood as linear polarization in the horizontal direction and if you have only vertical lines, it is linear polarization in the vertical direction and what you see here? I send an unpolarized beam of light and this comes out as unpolarized beam of light. It also gets reflected as unpolarized beam of light. Suppose you adjust the angle of incidence; you may get the reflected ray at a particular angle for a glass it is about 56 degrees.

You will get only a polarized beam of light, so that is called a Brewster angle that we are not getting into. Our interest is to see in an isotropic medium, when I send a natural light, you get natural light getting transmitted within the medium, this is one observation. The other observation is we will define refractive index in terms of velocities of propagation that is very crucial.

From photoelasticity point of view, looking from that perspective is crucial and you know very famously that these are all Snell's law of refraction and reflection.

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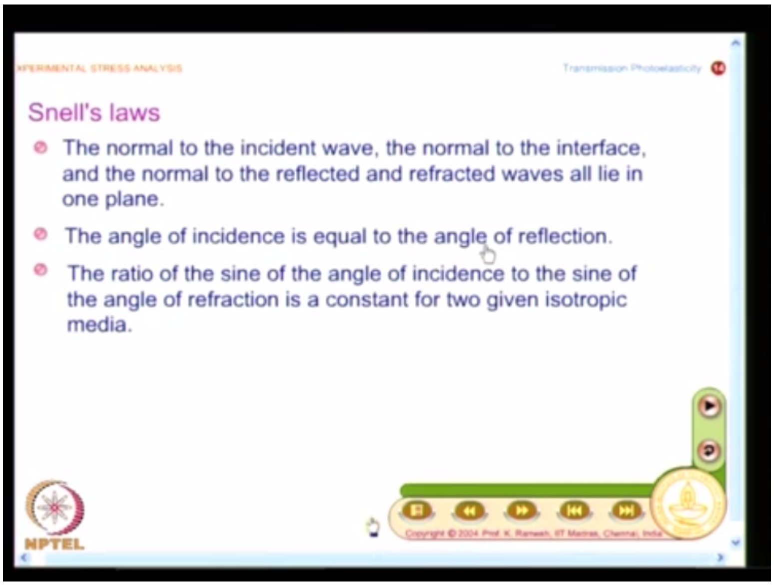

We will just look at those statements. These statements you know already. We are only going to have a relook at that. So what you saw? The normal to the incident wave, the normal to the interface, and the normal to the reflected and refracted waves all lie in one plane. It is a first observation, this you all have understood from your course in physics and the second observation is the angle of incidence=the angle of reflection.

So angle i=R that is the symbol that we have used. Then what you have the ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant and it depends on the given isotropic media. So you have only a relative refractive index. So if you want to go to absolute refractive index, 1 medium should be (()) (13:28). So we will see both and you all know sine a/sine r is the refractive index.

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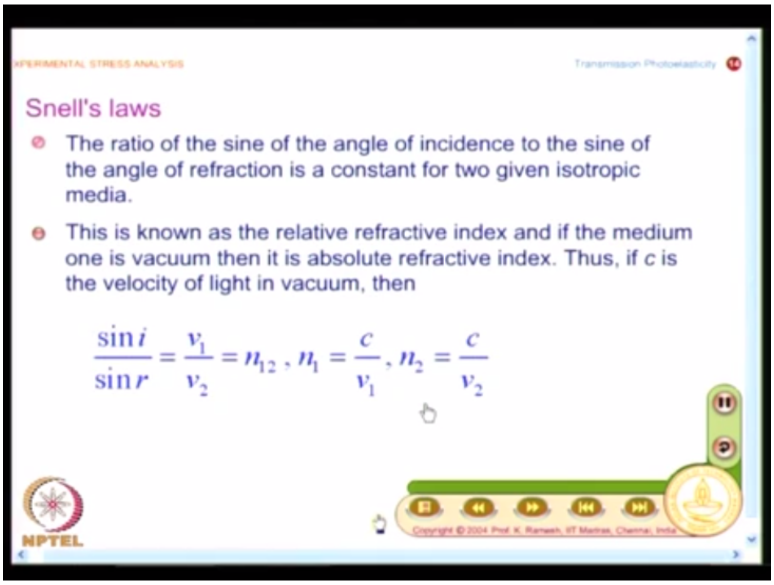

That is also known from your earlier course. So what you have, you have a concept of relative refractive index and also have a concept of absolute refractive index and you know sin i/sin r and if the medium is air, you will call this as relative refractive index and you have a symbol small n is used and you should not confuse this with your direction cosines, that is also we use n1, n2 and n3 and here it denotes the refractive index.

And what we look at especially here is I see the sin i/sin r as ratio of velocities v1 and v2. So what does this say? When I look at this as ratio of velocity, what do you infer from this? We all know the velocity of light in vacuum is c and when it travels in different medium, there is a slight change in the velocity and what we will look at later, we are going to have some kind of a phase difference, which is being initiated into the wave.

Because of the stress information and you need to have some phase difference developed and what you find here is when I have these 2 velocities as v1 and v2, when the refractive index is different the velocities are different in the media. So I have a relative refractive index, which is given as v1/v2 and absolute refractive index for the medium 1 is given as c/v1 and for the medium 2 it is given as c/v2.

And what I have here is for 1 incident ray, I have 1 refracted ray and this totally changes when I go to crystals and you know in photoelasticity, you also call this as common path interferometer so they are less stringent in vibration, isolation requirement that will be understood when you look at crystal optics.

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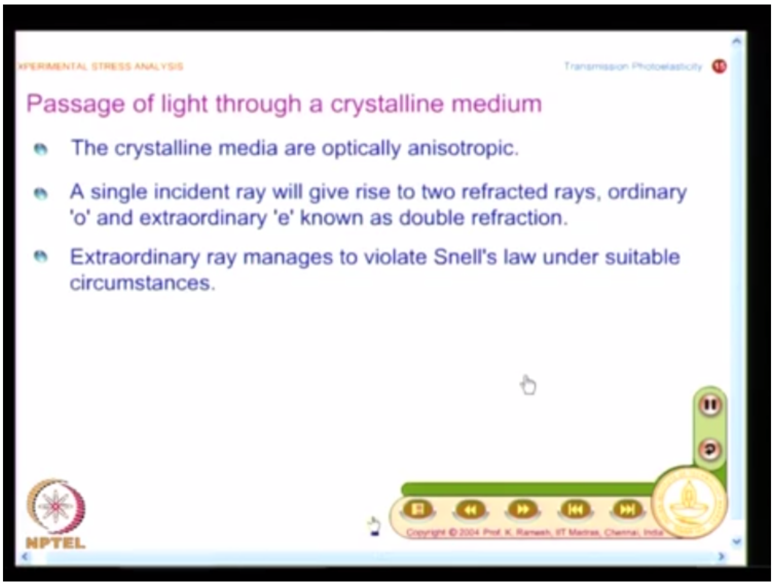

And what you have here? What happens when light passes through a crystalline media? First observation is the crystalline media are optically anisotropic. So how do you define isotropy? If the property is same along all directions, then you call that as isotropic. If the properties of function of direction, then it is anisotropy. So the first observation is crystalline media or optically anisotropic.

Because it is optically anisotropic, you also have another interesting thing happening a single incident ray will give rise to 2 refracted ways and they are also named in a conventional sense. You know you have one ray which is called ordinary ray labeled as o, another ray is called extraordinary and this happens because of double refraction. So when you say why do you label it as extraordinary even in our common life?

You know somebody is extraordinary you should have some special qualities okay and sometimes you also say somebody does not follow rules, he is an extraordinary person. So what you find here is the ordinary ray faithfully follows Snell’s law, under suitable conditions extraordinary ray violates Snell’s law. That is why we read Snell’s law first, so one ray same as what you see in an isotropic media.

In addition, you have another ray, which violates this law and this violation is useful to us. This is useful to us in photoelasticity and we exploit it. That is the advantage. So you have for a single incident ray, 2 refracted rays ordinary and extraordinary. First, we will have a look at the ray diagram and then as I mentioned, I will provide you an experimental justification for all these concepts.

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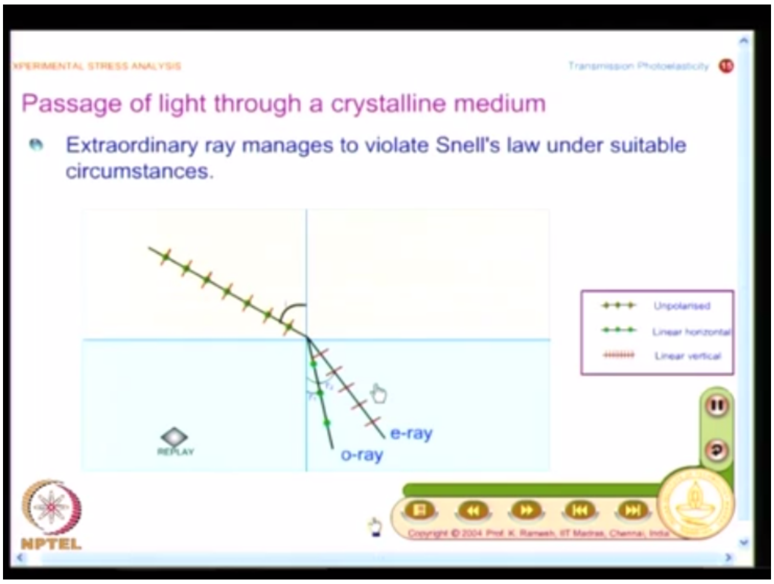

We will just look at the ray diagram and what happens here. So I have medium one and medium 2 now is crystal. It is not an isotropic media, medium 2 is a crystal and you draw the diagram, make a neat sketch of it, take your time and I can replay how the rays come. So I have a ray which impinges on this. Carefully look at how the incident ray is drawn and how the refracted rays are drawn.

First observation is for 1 incident ray; I have 2 refracted rays. I have 1 labeled as ordinary ray, another is labeled as extraordinary ray and if you look at how do these rays are depicted? Can you tell me the difference between the incident ray and the refracted rays? The incident ray is unpolarized, but within the medium because the medium does not end here, medium ends only here.

Within the medium, I find the rays are polarized. That is represented by only straight lines in this and only dots in this and the planes of polarization are mutually perpendicular. You know this is a very pertinent and important observation that you should keep in mind. So I have 2 simple harmonic motions, which are mutually perpendicular. The planes of polarization are mutually perpendicular and in this case you see them as 2 different rays.

In photoelasticity, we will develop it and see that they will travel in the same direction and they will have planes of polarization mutually perpendicular and when I have this angle changed, I have r2 and r1 what do you infer? You will say refractive index is different, that is not what is sufficient for me and I go to photoelasticity, what I will have to look at? I look at refractive index as different velocities.

So that gives you the information. See when you look at holography what happens light impinges on the model. If you are looking at meteorology application because of the 3-dimensional shape, the debts are different. So you have a light which impinges and comes back, so there is a phase difference. So you need to have some form of phase difference and that is not what happens in photoelasticity.

Photoelasticity, it penetrates the model and it gets modified within the model, it acquires a phase difference. All that you can understand, so what you find here is the model behaves like a crystal. The moment you have a crystal, a generic understanding is for 1 incident ray, I have 2 refracted beams, which are travelling at different velocities. Our interest is not just r1 and r2 are different we do not want to look at it that way.

That is why we introduced definition of refractive index more in terms of velocities. So you have for 1 incident ray, there are 2 refracted beams. First observation is they move with different velocities. Their planes of vibration are mutually perpendicular but in this case they travel in different directions. They travel in different directions. So that is not going to be convenient photoelasticity point of view but this is used.

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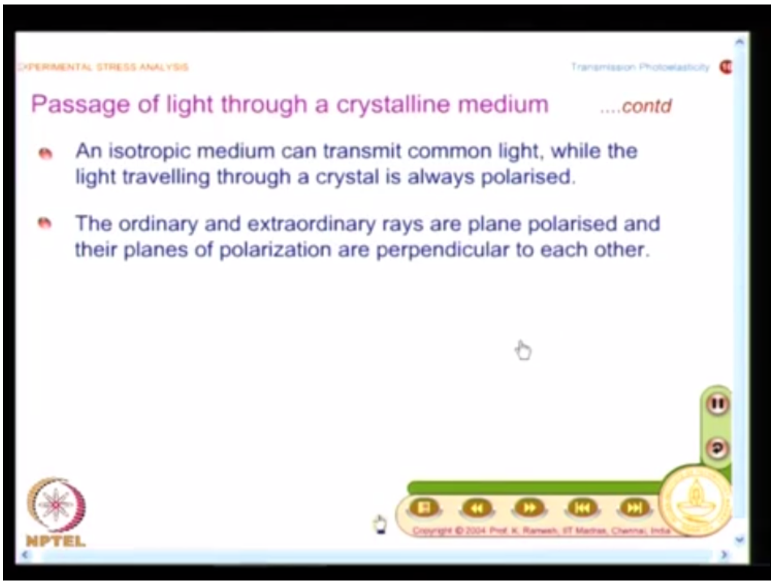

And we summarize these points. The first point is an isotropic medium can transmit common light, which is nothing but natural light. So an unpolarized beam will go as unpolarized beam while the light traveling through a crystal is always polarized. This is a very key and important point. So within a crystal whatever the light that travels through, it is polarized. A crystal cannot sustain unpolarized light.

And what happens in photoelasticity, the model behaves like a crystal when it is stressed. So that is the reason why we are able to look at modification of the light as a function of stress because a natural crystal will always have birefringence. We are also going to look at wave plates, they are all natural crystals. You will have 2 vibrations and we will use it in an advantageous way.

So a crystal can transmit light, within the crystal it is always polarized. So first and foremost observation that you make and we have seen very clearly the ordinary and extraordinary rays are plane polarized and their planes of polarization are perpendicular to each other and this is again only a statement. You are only taking the statement because I am a teacher and you are listening to it.

If you are a true student, you will have to question is it really so? I have to do an experiment, you provide an opportunity to do the experiment and let me get convinced myself yes there are 2 beams in and they are also polarized and their planes of polarization is mutually perpendicular, do not you think that knowledge you should get because you are learning science.

You are not learning other pseudoscience. Here we need for proof for every statement we make. That is what we will look at.

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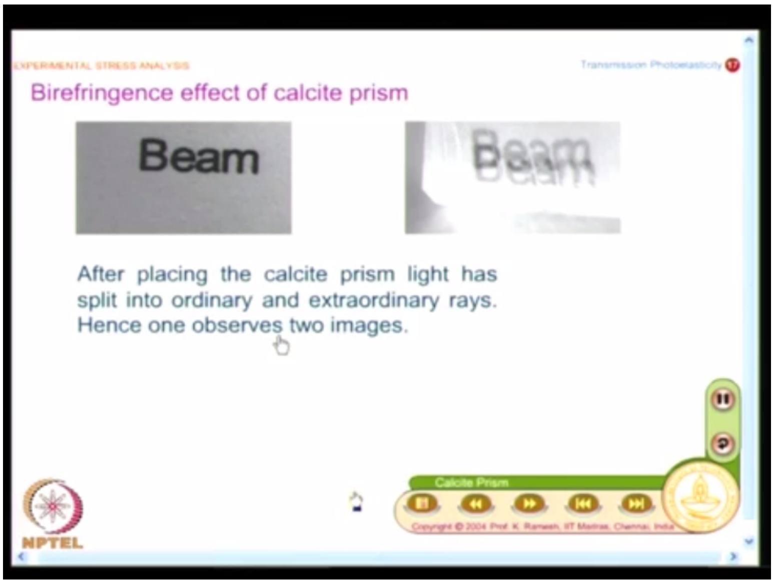

We will look at in the next slide. I again come back to the letter beam, so I have an image of the word beam written on a paper and you view it normally. Then what I do? I go and put a crystal on top of it. This is in normal light you view it. The moment I put a crystal, I clearly see 2 sets of the word beam appearing and we have seen within the crystal, you have an ordinary and extraordinary rays.

You have 2 rays are being seen and you see 2 images. I also made one more statement that this ordinary and extraordinary rays are polarized and we have already looked at what is polarization. If there is a light beam is polarized, I can always analyze it by a polarizer, keep on rotating it, when the light is cut off, I will say that the original light was polarized. So I can do that analysis by taking a polaroid sheet.

And here we have also seen that the ordinary and extraordinary rays are polarized in perpendicular direction. So that means what I want is suppose I take a polaroid sheet, place it on this image and rotate it appropriately, what I should anticipate? At particular orientation, one of the images should not be seen, only 1 image should be seen, at another orientation I should see the other image.

Because if we have understood what is polarization, we also understand that polarization can be analyzed and you take a polaroid sheet and then move over it. I should be able to get that; we will just perform that.

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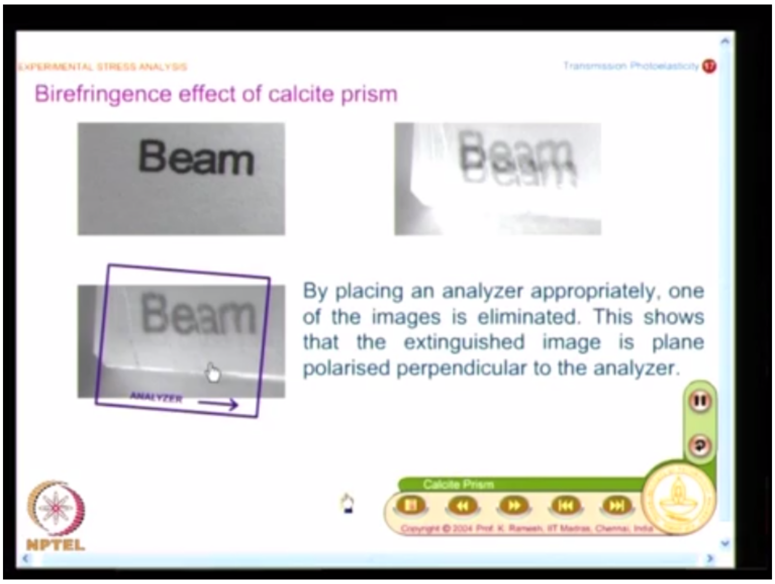

So what I will do is I am going to put a polaroid sheet on top of it and the intermediate process is not shown, final process is shown here. So I have analyzer and I oriented in this direction, what do I see? I see only one of the images what I saw as 2 in the earlier case. So this goes to prove 2 things, you find these rays are polarized that is why I am able to cut off one image.

The other image vibration is perpendicular to this, so that image is cut off because it will allow only one component of light. So what you see here is in the first case, you see when I put a crystal, I see 2 images, so this indicates for a single incident ray, you have 2 refracted beams and I have shown by putting a polarizer because it analyzes the light it is named as analyzer.

And when I place it appropriately, one of the images is eliminated, this shows that the extinguished image is plane polarized perpendicular to the analyzer. You can interpret in any way, you can look at this image and then discuss it and suppose I keep this analyzer perpendicular to this, what I should see? I should see the other image. Let us put it, rotate it and then keep it, let us see what happens.

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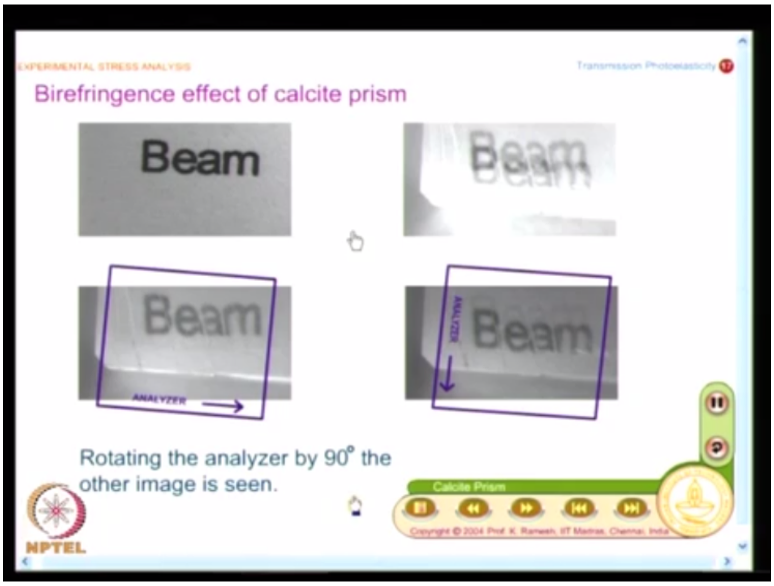

This is exactly so, so you could see here, I have 2 images seen, and you could also see, there is a slight shift. The shift is same as like what you see here. This is the image on the top and this is the image of the bottom. So I could filter out from this one of the images by employing an analyzer. So this shows that the beams are polarized.

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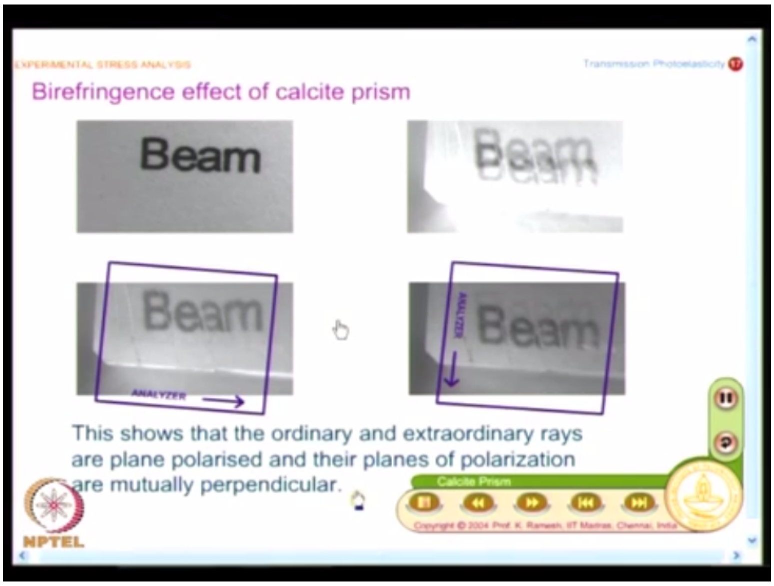

And because I get these 2 images when I keep them at mutually perpendicular positions of the analyzer, we also have established that these 2 beams are polarized in mutually perpendicular direction so that is what is summarized here. The ordinary and extraordinary rays are plane polarized. How do you establish they are plane polarized? I just use an analyzer, which would only cut off light perpendicular to it.

So that shows when I extinguish one image, the plane of polarization is perpendicular to it. So we indirectly show that it is a plane polarized beam of light and because I keep these 2 perpendicular to each other, I also understand the planes of polarization of ordinary and extraordinary rays are mutually perpendicular. You know this helps in understanding photoelasticity.

But in photoelasticity, we do not want to see 2 images. We want to see it in a particularly different fashion. We will also bring in the concept of optic axis. We will look at the incident ray in relation to the optic axis and we will find out one of these combination is advantageous for photoelasticity that is what we will learn today.

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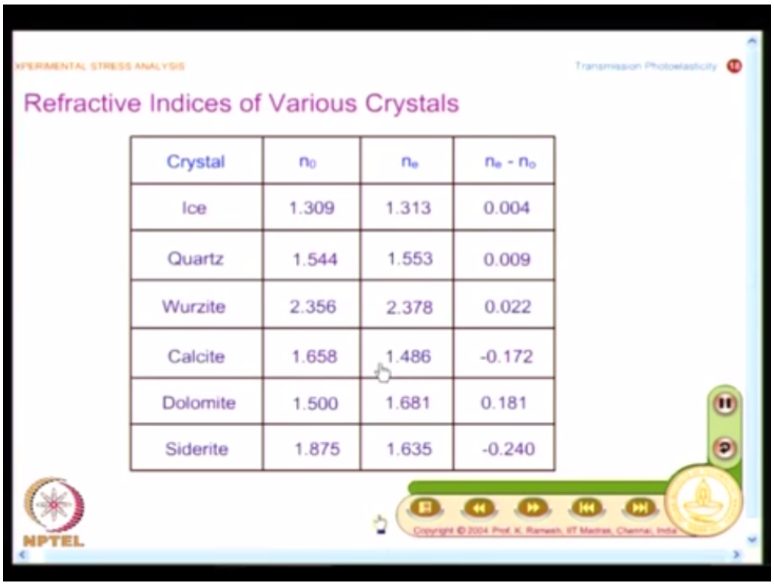

And what you have here is I said that when you have a natural crystal, it has 2 refracted beams, ordinary and extraordinary ray and you also have tables available, which give you the ordinary ray refractive index and the extraordinary ray refractive index and this is written for a large list. You write it for ice, you write it for calcite. These 2 are sufficient. So that gives you an indication that you have 2 refracted beams, which has different refractive indices.

And what is important in photoelasticity? We look at these different refractive indices more from the point of view of velocities. We are not interested this is 1.6 and that is 1.4, we are only interested that these 2 waves will travel with different velocities. That is the key point that is why we define, we looked at the definition of refractive index, not only as sin a/sin r but also as ratios of velocities.

So in a crystal you have this naturally happening and the crystal behavior is introduced because of the stresses, we are in a position to relate stresses to optical behavior that is the crux of photoelasticity.

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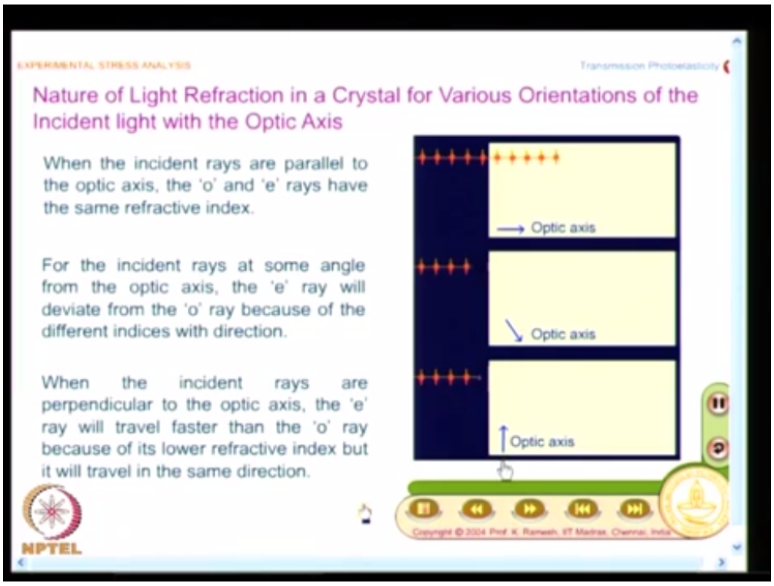

And now what we will have to look at is what is the direction of incident of light, which is suitable for photoelastic analysis and when you take a crystal, you have what is known as optic axis. I have a crystal here and I have a ray of light impinging on it and how is this ray shown? This is an unpolarized beam, you have a dot and a straight line and if this direction is parallel to optic axis what do I find?

What does this diagram show? I have the ray traveling as such like in an isotropic medium. In an isotropic medium, you will have the unpolarized beam transmitted as unpolarized beam. There is no specialty about crystal behavior here. So what you find here is when the incident rays are parallel to the optic axis, the ordinary and extraordinary rays have the same refractive index.

Now we will look at another case. We will have this axis impinging at a different direction. For convenience, I have shown that I have cut the crystal in a manner that optic axis is at an arbitrary position like this and what I have here, I have an incident ray and I have 2 refracted beams and the animation is also very carefully shown. What does this show? One ray travels faster than the other and you find this is polarized, this is also polarized.

And the planes of polarization is mutually perpendicular. You know this is nice to illustrate that I see 2 images and you see 2 images without any hallucinations. You are not on the power of intoxicants to see 2 images. Then also you see 2 images and you are alert in a morning class, you are very bright and you see 2 images, you see 2 images because of a physical phenomenon not because of hallucinations.

So what I find here is when the incident rays at some angle from optic axis, the extraordinary ray will deviate from the ordinary ray because of the different indices with direction because we have already seen crystal is optically anisotropic and that is dictated by the incident ray in relation to the optic axis direction. If it is same as optic axis direction, then it behaves like an optically isotropic medium.

If it is at an angle, you see 2 refracted beams, which travel with different velocities and the planes of vibration is mutually perpendicular. Even this is not useful in photoelasticity neither this is useful in photoelasticity. This is only to understand that within a crystal, you have double refraction, you see 2 images and so on and so forth and what you will have to look at in photoelasticity is the incident ray is perpendicular to the optic axis.

Then what happens? When it is perpendicular to the optic axis, both the ordinary and extraordinary rays travel in the same direction but within the crystal what will they do? They will acquire phase retardation because they have different refractive indices and we have emphasized that we look at in photoelasticity different refractive indices more from the point of view of velocity of propagation.

And here you have the magic, so within the crystal, the 2 waves acquire a case retardation. In fact, if you understand this aspect photoelasticity is mastered. This is all you require for photoelasticity. There are many things you can understand from this slide and what is summarized here? When the incident rays are perpendicular to the optic axis, the extraordinary ray will travel faster than the ordinary ray.

Because of its lower refractive index or it will travel in the same direction. It will travel in the same direction, this is very, very important and you have already seen from a solid mechanics point of view photoelasticity provides difference in principal stresses and I also mentioned in one of the earlier classes that refractive index is a tensor of Rank 2 and stresses also a tensor of Rank 2, so whatever happens to refractive index I can match it on stress tensor.

And here what I am showing, for a single incident ray in general you have 2 refracted beams but when it is perpendicular to the optic axis, they travel in the same direction and acquire a phase retardation so this is what happens in photoelasticity. The phase retardation is not because of depth change. It is because of the way the material behaves like a crystal. Crystal behavior is perceived as n1 and n2 at the point of interest.

And this n1 and n2 could be related to what sigma 1 and sigma 2. If you have crystal, at every point n1, n2 is same. If you have this as a stressed model, n1, n2 also changes from point to point, n1, n2 does not remain same at every point. In a crystal plate, n1, n2 remains same. In a stressed model, n1, n2 is dictated by the stresses applied. This is observation number 1. Other observation is I also said photoelasticity gives you direction of principal stress.

Where does this come? This comes from the optic axis and it is perpendicular to it and we are looking at only planar problems. So now you understand how optics is related to stresses in a very simplified fashion okay. Here again, I will say you can say sir you have shown me that 2 refracted beams, but you have not shown me when I rotate the crystal, I have only 1 beam, this I can show by a demonstration.

In photoelasticity, 1 beam travels faster and another beam trails behind it that I can show only in photoelasticity. If I perform a separate experiment where I rotate the crystal, when I send a beam of light, by rotating the crystal what I should see? For different orientation, I should see different things. At particular orientation, you will see only 1 beam coming out. At a different orientation, you will have 2 beams coming out.

That is what you have to anticipate. I have also said experimentalist, anticipate the result before performing an experiment. In many cases, your anticipation may match with observation. In some cases, anticipation does not match with observation and that is where the scope for research. Why it does not match? What have you missed? And then you learn and then go deeper into the subject.

So this is what I said. In this course with the powerful multimedia presentation, I would bring in experiments that we have conducted in the lab which is recorded. Most of these experiments are done in digital photo mechanics lab at IIT Madras. Some of these experiments are specially commissioned for this book. Many of my students have participated.

My thanks to all of them and you will see that experiment because what I want to emphasize here is you learn the theory, you do not take it because a teacher says, you also observe, you observe, re-convince yourself, this is indeed so, it is not friction.

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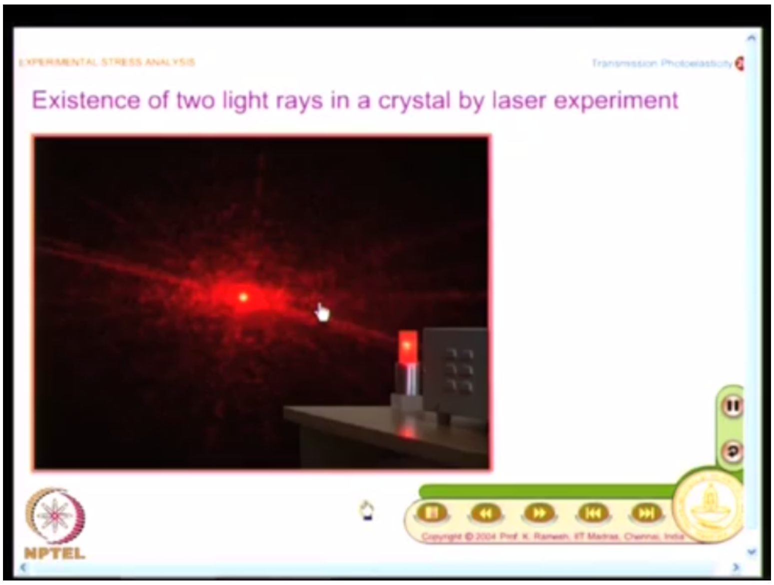

I will see the experiment so what I have here is I have this crystal is moving. Crystal is getting rotated. I have laser beam and I will replay this okay. What you have to see this is, I have a bright spot here and what you have to look for is when I rotate the crystal, you will see 2 dots and merge into 1 dot. See when the light is coming out of the crystal then they will interfere.

Suppose I have the light ray which is parallel to the optic axis or perpendicular to the optic axis, both will appear as 1 dot only. Only when I go to photoelasticity I can show fringes. In fact, if you recall in the last class I showed 2 plates. When I applied load, I saw beautiful patters. Why do I see beautiful patterns? Instead of black background I saw beautiful patterns, we will reason it out.

So that shows that light travels with different velocities. I cannot show that in this animation. In this animation, you have to look for 1 dot and 2 dots. That will convince the optic axis has an influence on the behavior of the crystal. The incident light in relation to the optic axis behaves differently. So I will replay it and I will also have a magnified picture.

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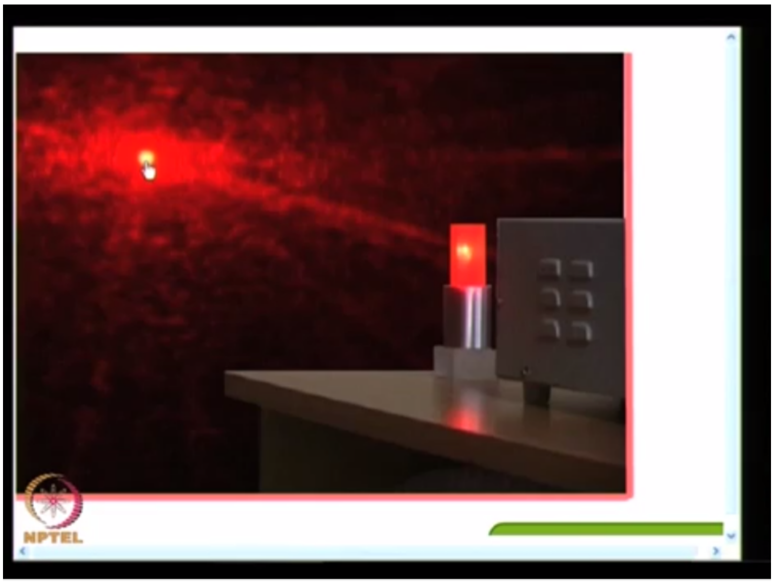

So you could see 2 dots and then that merges into 1 and what I will do is I will have to go and once this is observed, you can repeat it again and then see. You see that this crystal is rotated, I have 1 dot becoming 2 dots. Have you all seen it? Have you been able to observe it? That is the key point and once you understand this, there is joy in doing photoelasticity because you know the in and outs of what happens within the model.

Now we have to get into mathematics. See what you have here is, in normal interferometer both waves travel in the same direction. So if you go and look at books, you might have done when you learnt simple harmonic motion, wave addition you might have done in one of your mathematics courses without knowing where this would be applied. See that is how many courses structured.

You will do a course in mathematics separately then you do a course in engineering, very rarely you find teacher bridges these 2 and show what you learnt there is what you apply it here because while you learn a course in mathematics, you would have found out if I have waves travel in the same direction, if there is a phase difference how do you add them. You can add them.

Suppose I have waves traveling mutually perpendicular and they acquire a phase difference, how do you add them? You have to add it very carefully. You cannot do the same addition law like what you have done it when the waves are travelling in the same plane. When they are mutually perpendicular, the mathematics is slightly different and we have been saying that we have elliptical polarization.

Elliptical polarization can be thought to have as a circular polarization in one limiting case and another limiting case a plane polarization and where does all this comes from? This all comes from your addition of 2 simple harmonic vibrations, which are mutually perpendicular. That is what we need in photoelasticity and I have convincingly shown you have indeed 2 rays, which move with planes of polarization perpendicular to each other.

And we have already seen that this can be written as cos omega t or sin omega t. So you have 2 simple harmonic motion, which all mutually perpendicular and I have also shown that they acquire a phase difference. All that you know, now you can do the mathematics with little more physical understanding. Why this is needed and how it is exploited? So that is what we will have a brief look at it.

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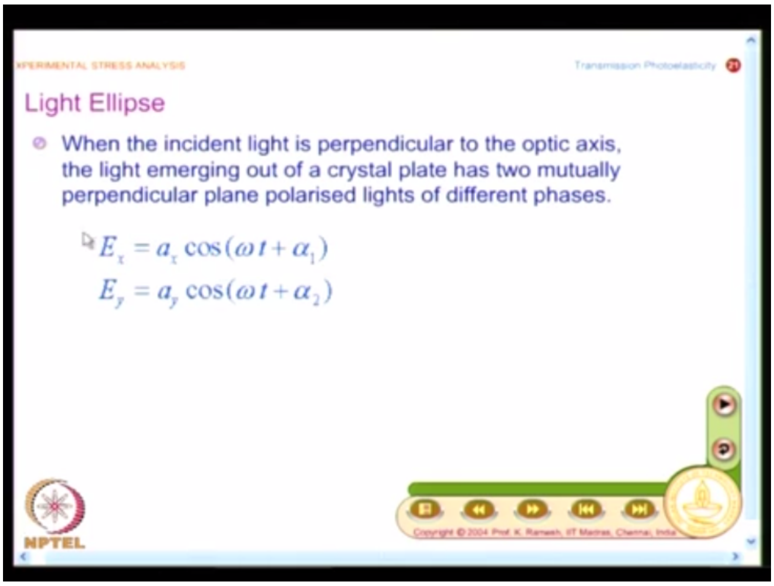

We will continue it in the next class, but this is what we will have a look at it. When the incident light is perpendicular to the optic axis, the light emerging out of a crystal plate has 2 mutually perpendicular plane polarized lights of different phases. This is what you have to understand. They have different phases is very important and you represent the light waves like this.

So I have 2 beams of light, one is given in the x direction, you call it as ax cos omega t+alpha 1 and you call the other wave as Ey=ay cos omega t+alpha 2. So this has one amplitude, this has another amplitude, amplitudes are not same, we are taking a very generic situation. We keep the amplitudes different and we also have some absolute phase. Whenever you generate a presentation, will also have an absolute phase.

Alpha 1 can be 0 in a particular case and you represent the second wave as omega t+alpha 2, but what is important in photoelasticity. We are not interested in absolute phase. So we will only look for difference in phase because within the model you have difference in phase is acquired between the 2 waves because of the optical behavior and this optical behavior is induced by stresses.

So it is fundamentally different from other interferometric techniques. Here you have 2 waves which are mutually perpendicular acquire phase retardation within the model and this phase retardation is caused by the stresses introduced. So this you will have to understand, this is subtle and because 1 ray becomes 2 whatever happens to the 1 ray will happen to both the rays.

So vibration isolation is not a stringent requirement. So that is how it comes. It is beautiful, it is a very nice marriage between physics and stress analysis. If you look at photoelasticity that is why people enjoy and also to enthuse you. God was so kind he gave you nicely colored fringe patterns that you saw only in photoelasticity. You call that as isochromatics beautifully, iso means constant, chromo means color.

So you see contours of constant color and this I will see in a white light. So in this class what we focused was for photoelasticity, you need to understand there are 2 beams, which travel within the model and they acquire phase retardation and these 2 beams are plane polarized and their planes of polarization are mutually perpendicular and this comes from an understanding of crystal optics.

Because a crystal by its very nature behaves like this whereas in photoelasticity the model temporarily behaves like a crystal when loads are applied. When loads are removed, the crystal behavior is different and this will see we will develop it in the future classes and you will also appreciate because if you have this understanding, you can go and develop newer philosophies in data acquisition.

That is how research develops. There are 2 aspects, 1 is how to use the technique. How to use the technique may be having in few steps? A technician requires only that much information. An engineer should know what goes behind the technique and that is what you learn in this course. So with this background, I anticipate that you come out with innovative methods and it helps you to develop your concepts better and maybe come and develop a new experimental technique. Thank you.