WAVE OPTICS
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Lecture - 21: Newton's Ring

Welcome, student to the wave optics course. So, today we have lecture number 21 and today we will study an important phenomenon called Newton's ring. So, let me start with a recap of what we had in the last class. So, today we have lecture number 21. So, before going to study Newton's ring let me remind you of the process that we developed in the last class. If we have a film and if light falls on this film there are two surfaces, suppose the ray is coming from air, with the refractive index na and nf is the refractive index of the film and then we again have air. So the structure light is falling like this and then here it goes inside the film following Snell's law and then again reflected back, hits this surface, and then comes out like this. The reflected ray from the first surface is also reflected like this is the light ray geometry that we have but ray 1 and ray 2, can interfere and form a bright or a dark region because of this mutual interaction or interference of this A ray 1 and 2. Now we quantify in the last class that if this thickness is t, this angle of refraction is theta t and the refractive index is nf, then the path difference between ray 1 and 2 is delta is equal to 2nf then t and cos of theta t. That is the amount of the path difference that one can calculate and we propose one of the calculations. There are many other ways one can find out the path difference and the procedure we used is to directly calculate. We have drawn a perpendicular if this is my point A If this is point B, this is C and D, the path difference, the optical path difference through, I mean, if I write down in terms of these lines, delta was nf multiplied by AB plus BC and then minus na multiplied by AD. So, that is the amount of path difference we calculated and after doing all the calculations we find that the delta is simply 2 of nf then t, the thickness of this film, and cos theta t, where theta t is a refracted angle of this ray.

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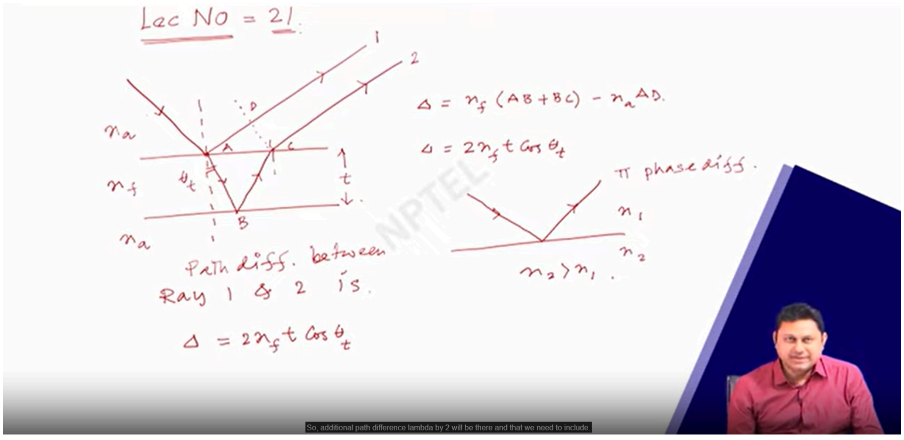
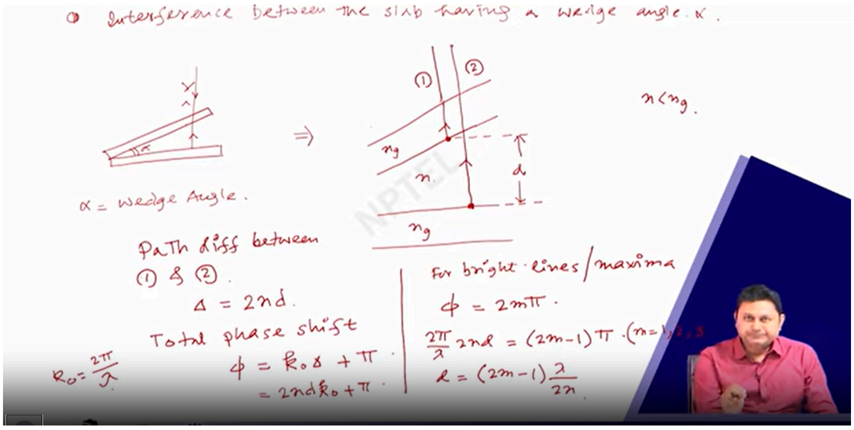


Also, one thing we mentioned is that when the ray is coming from a rarer medium and reflected from reflected through a denser medium in the interface of rarer medium and denser medium like n1 and n2 this reflected ray will have a pi phase difference. This reflected ray incurs a pi phase difference because of the fact that n2 is greater than n1. So during calculating the condition for maxima due to the interference of ray 1 and 2 or minima, you should also take into account this pi phase difference, which leads to a path difference of lambda by 2. So, additional path difference lambda by 2 will be there and that we need to include. So, we have done this in the last class. So, we are not going to go into detail. What we do today is based on whatever we have done in the last class, we will extend our treatment before going to Newton's ring problem, we extend our treatment to find the interference between slabs having a wedge angle say alpha. So let me just draw the scenario of what we are trying to do here. Suppose we have these two slabs, this is one and this is another with a gap and this angle whatever the angle it is making is alpha the wedge angle. So alpha is the wedge angle, and this is the wave wedge angle. Now, how does the interference take place if I launch a light here perpendicular to the surface then one portion of the light will be reflected from this surface. The lower surface of the plane's first slab and another will be deflected from the top surface of the second slab. So we will have interference between these two. If I draw properly the ray that is coming will hit, so let me draw in a magnifying version, then things may be clear. So the wedge is like this and another is like this. So the ray that is falling here will be deflected from this surface and another will be reflected from this surface, obviously when the ray enters this slab there will be a difference in the path but at the end of the day it comes out, and then goes here and reflects back. So considering that this angle is small we consider that there is not much deviation when the light ray is falling off this wedge. So this is the magnifying version and try to show that from where the light is. So the first light is reflected from this surface and the second light is reflected from this surface. In the first case, this is the lower surface, in the second case it is the upper surface of this wedge. Now this difference, whatever the difference we have is essentially the path difference. Now if n is a refractive index between the two slabs, usually it is air. (Refer slide time: 15:33)



So if it is air then the n value is 1 but it is in general n because you can put some oil here also to find what is the interfer how the interference pattern changes, so it can be anything. So if n is the refractive index between the two slabs, then the total path difference is simply total path difference, this is ray 1 and this is ray 2. The path difference between ray 1 and 2 is simply delta equal to 2nd which is the path difference. Now you can see that in this case, the reflection is happening from the rarer medium to the denser medium, so there will be a pi phase. However, here it is not happening like that, this is the denser medium considering what is in between the two slabs, the medium, the refractive index. Whatever the refractive index we have, suppose I put refractive index ng here and ng here refractive index. Suppose we put some two glass slabs, then n, which is the refractive index of the air is less than ng. So for the ray to reflect the reflection that is taking place from this surface is having a pi phase shift. So the total phase shift is Phi or total phase difference k0 delta plus Pi. So that is the expression we have. Now for bright light, if I have a bright light here, because of interference or for maxima, so this value is simply 2 nd k naught plus pi, where k naught is the propagation constant of the free space. So this is 2 pi divided by lambda. So for bright lines or maxima, what we have is the phase difference phi should be 2 m pi. So, from this expression, we can write that 2 pi divided by lambda into 2 nd that is equal to 2m minus 1 pi because this pi, I can put other side and from here we can write that d is equal to 2m minus 1, then lambda divided by 2n, this d is a path difference. So this is the difference d, so we can have this d value. Why do I put this in terms of d? I would like to explain here, by the way, the value of the m here is from 1, 2, 3, etc. So let me find out, this is the wage we had. So I'm just drawing the surface here, lower surface and upper surface, these values alpha, and that the light is falling here and reflected from here. So the d value is this, from here to here, this is my d value. So if this is my origin and this point, suppose this is the X direction and this point for maxima. Let us consider this is the xm then d will be simply alpha xm for mth maximum. Because there will be a fringe pattern here and that fringe pattern contains minima maxima like the double slit experiment. So from the point o to xm. So when we have the dark bright, like the dark bright fringe pattern. Let me draw it quickly. So this is dark.

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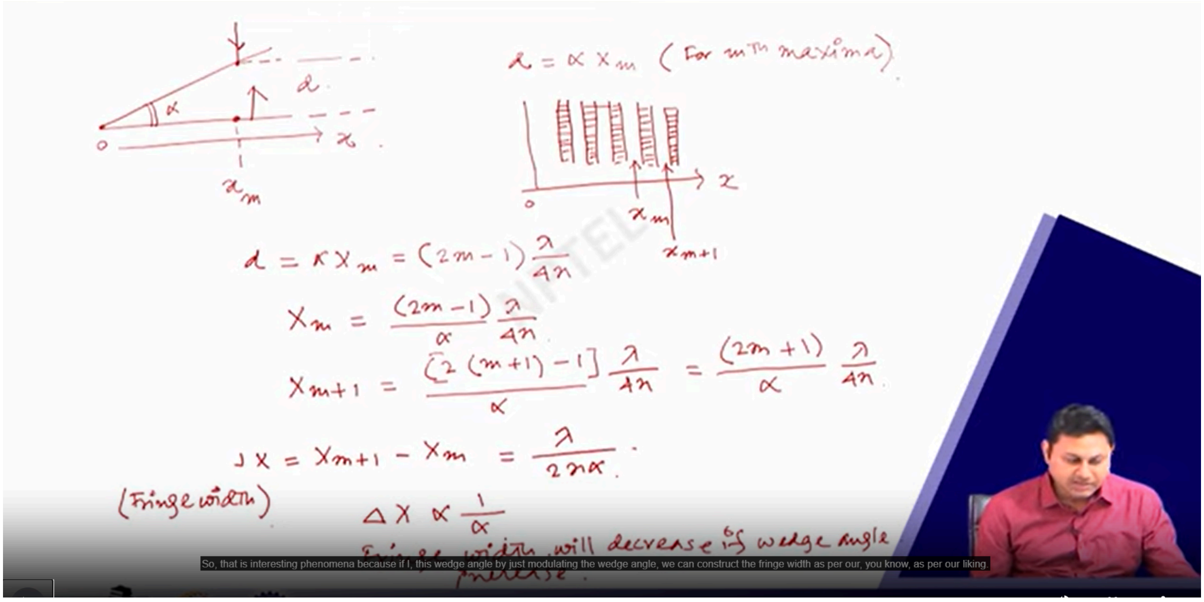

Suppose this is the way the fringes are forming and this is my x-axis so for any bright say mth order bright fringe this is my xm value so d is equal to alpha xm. So I can write that d, which is equal to alpha of xm can be written as 2m for bright fringes. It is 2m minus 1 into lambda by 4n that we derived in this case, so this 2 we just okay, let me go back. So, d, what was the d? I calculated earlier that d is equal to, so there will be 2n but this 2 is there. So I made a mistake here. It should be 4n 2m multiplied by 2 because we have two terms sitting here. So, I made a mistake here. It should be 2m minus 1 multiplied by lambda by 4n. So, from here the thing is I can find out my xm that is the location of the mth maxima in terms of the wave angle, 2 m minus 1 divided by alpha, lambda divided by 4n. Now x m plus 1 the next one will be simply 2 of m plus 1, bracket close minus 1 lambda by 4n, whole divided by alpha. So it is essentially 2m plus 1, divided by alpha lambda by 4n. So that means I am talking about the next bright fringe, which is in this figure, this is my xm plus 1. So from this expression, we can find out the fringe width. So my delta x which should be xm plus 1, minus xm, gives you the idea of the fringe width and this is my fringe width, the separation between the two maxima that value is essentially constant it is lambda divided by 2n alpha, because it is 2m, we have 2m plus 1 lambda divided by 4n alpha. So if I take the lambda divided by 4n alpha common, then we have 2m plus 1 minus 2m plus 1, so there will be a 2 term, so we should get the lambda divided by 2n into alpha. So, you can see that delta x which is the fringe width is inversely proportional to 1 by alpha. So, the fringe width will decrease if we wage if the wage angle is increased. So, if I change this wage angle. So, we will get a fringe having a lower fringe width. So from this, we can say that the fringe width will decrease if the wage angle increases. So, that is an interesting phenomenon because if I, by just modulating the wedge angle, we can construct the fringe width as per our, you know, as per our liking. So, once we understand this procedure, the next step, the immediate next step is to understand a very interesting phenomena that is called Newton's thing. That is a very interesting experiment and we will explain that. So let me first give you an overall idea of what is the setup for this experiment and what are Newton's rings. So the experiment setup is very simple: we have a slab here and then over this slab, we have a lens-like structure like this. Okay so if I know, so this is the structure, what happened? Let me first give you the idea then we will calculate that when the light falls here it will reflect from this lower surface and another light will reflect from this surface which is the upper surface of this block. So these two rays will interfere. So this is ray 1 and this is ray 2. Now if we look carefully at only this region, let me highlight this region, only this region and magnify it. This is nothing but a wedge problem that we have already discussed in the first part of this class. It is like that. So this angle you may remember was alpha, the wedge angle, and light was falling here at this point and reflecting back and another light was falling at this point and reflecting back and these one and two lights were going to interfere. So this is exactly the same structure we have. So the important thing is the path difference and the path difference one can calculate in the same way. Suppose this length is t and for mth order maxima for example or minima, I write a m. Now if I see the outcome we can see that for different planes, from different points this tm is going to change if n, whatever the n I put here is constant. Normally it is air then when this t is changed here the path difference is going to change. So what happened? In this case, we will see a ring-like structure, in one case it is a bright ring and dark ring, a constant ring-like structure one can find. So I will draw before ending the class, I will draw what the experimental setup will look like and what kind of structure one can expect. So suppose we have an extended source and we have a beam splitter here, to see in which direction light is going, just split the light and then we have the Newtonian structure like this setup. This is the setup, so what happened? The light will fall here. So okay this is not the light, so we make a different light source, so we can have a system, and here is the light source. So the light will come from this source like this, this is a lens which makes this light parallel and this parallel light will fall here and then what happens, it will go here in this way and hit the boundary and go back. So when it goes back, the light that is coming here and this the light that is going back they will interfere, and if I put a so I need to shift this viewpoint here a bit. So suppose I have a larger viewpoint, so what happened? This light will go up like this and one can see the entire pattern, So what do they see? You can see that there are concentric circles with bright and dark. I'm just trying to draw to show you that a ring-like structure will form bright consecutive bright dark etc and it will form because of the structure that I had in the central part. We have dark or bright depending on the condition and then gradually based on the phase matching, we will get different kinds of bright or dark structures called Newton's rings. Now the next question is how to measure the radius of this kind of ring and what happens if we change the structure, what happens on the rings, and if I put some kind of liquid here instead of water. Can I measure the refractive index of this liquid? All these are very pertinent questions and we can play with this structure and we can apply this to find out the refractive index of different liquids. We will see that or find out the wavelength as well. Suppose the unknown wavelength is falling here by using this geometry, we can find out the unknown wavelength of the source. So with this note, today I don't have much time. I would like to conclude here, that what we will do in the next class is extend this concept of Newton's ring do the mathematical calculation behind that, and find what is the condition for generating these bright and dark rings on the screen. So thank you very much for your attention. See you in the next class.