Applied Optics
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Lecture: 24
Michelson Interferometer and its Applications - I

Hello everyone, welcome back to my class, we are in module 5 and in the last class we talked about Newton's ring experiment. Today, we will start with a very well known experiment, which is Michelson interferometer.

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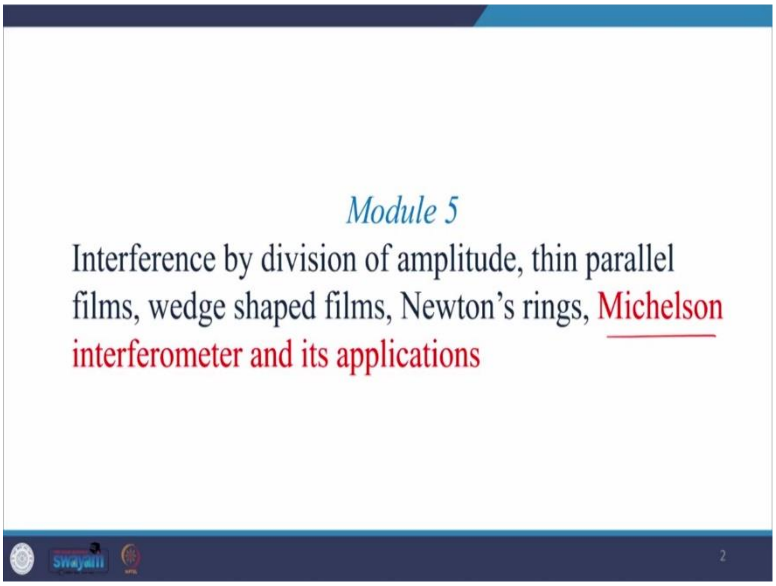

This interferometer has widely been used and it is still being used in interrogating a lot of physical realities. We will talk about this interferometer and then we will talk about its application also. Now, before moving ahead, let us revisit the concept of the interferometer.

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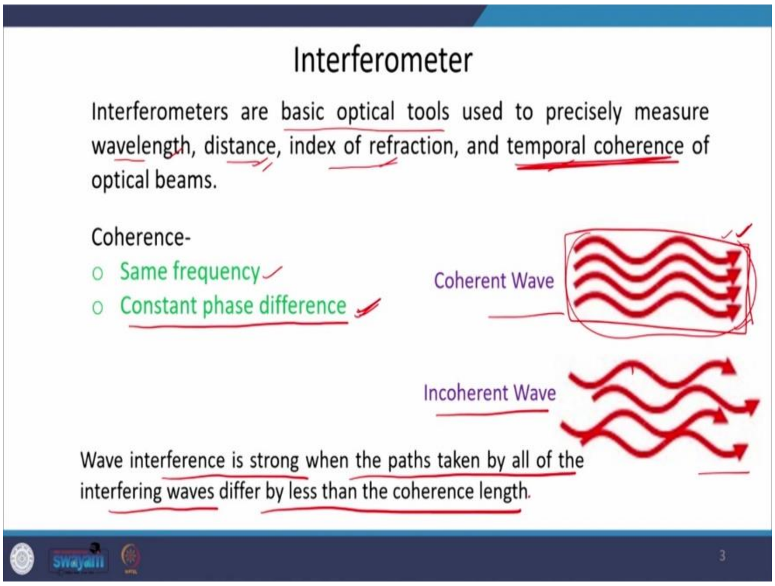

The interferometers are basic optical tools that are used to precisely measure wavelength, distance, index of refraction, temporal coherence of optical beams. We have till now used it in measuring wavelength, distance or thickness of film refractive index, in Young's double slit experiment we use that for measuring the index of refraction of a film or index of refraction is known then the thickness of the film which we call here as a distance and they can also be used to measure the temporal coherence. And whenever we say that two beams are coherence or two light waves are coherence then we must bear in our mind that they have almost same frequency and they must have constant phase difference this is the prime most important requirement.

Now, vaguely you can bear this concept of coherent and incoherent wave in your mind. We will devote a full lecture on coherence, but for timing suppose that you have waves which are of same frequency and amplitude and they are arranged in this fashion, in this fashion means, they maintain the same phase difference or in this particular case, they are in the same phase. The phase difference between these waves are 0 and if they propagate in such a fashion that they follow these types of criteria then they are called coherent wave and if there exists no phase relationship among them, then the waves are called incoherent wave.

Now, wave interference is a strong when the paths taken by all of the interfering waves differ by less than the coherence lens. Now, what is the coherence length? Now, when a wave propagates then what happens is that the coherence is intact only for a certain distance of propagation or certain time of propagation. Now, suppose two waves are propagating and the coherence is maintained only for a certain time of propagation then this time is called coherence time and the corresponding distance or length is called coherent length. Now, if the path which the wave propagate is less than coherence length then only we can absorb strong interference fringes.

And therefore, we always use lasers in interferometric experiment because the coherence length of laser is very large and therefore, we can easily, without being worried about the coherence length, we can easily perform all the usual experiment in our lab.

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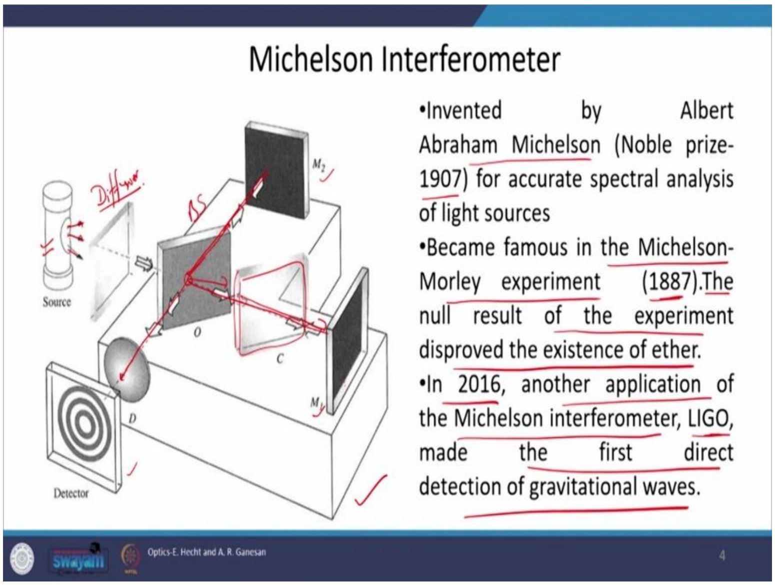

Now, with these Michelson proposed or he devised a very important interferometer which is called Michelson interferometer. This interferometer was invented by Albert Abraham Michelson and for which he got also a Nobel Prize in 1907. And this interferometer accurately analyzed the spectral properties of light sources.

Now, this particular experiment become very famous, in the Michelson Morley experiment which was performed in 1887. Now that we all know that this experiment delivered null result and this null result of the experiment disapproved the existence of the ether, which was the earlier concept.

Very recently in 2016, another application of the Michelson interferometer, LIGO made the first direct detection of gravitational waves. Now, you can understand the importance of this interferometer and this is why we studied. Now, this is typically schematic arrangement of Michelson interferometer where we have source, from the source the light beam emanates and then we have a diffuser here, what does this diffuser do is that, it diffuses the light in various directions and then we have a beam splitter here, the beam splitter is a semi silvered glass plate which splits the light in two parts.

The first get transmitted and the second goes in the other direction which is perpendicular to the direction of initial propagation. Now, the M_1 and M_2 are two reflecting mirrors, which reflects the light which falls on them, but before M_1 we have a compensating plate here. Now, the light after reflection from M_1 and M_2, they again combine at beam splitter and then goes to the detector and at the detector, we observe fringes. This is the arraignment in Michelson interferometer.

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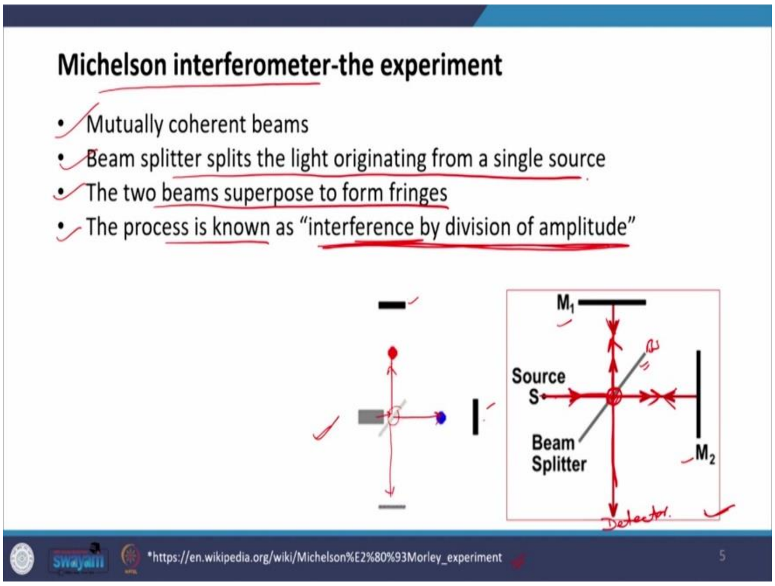

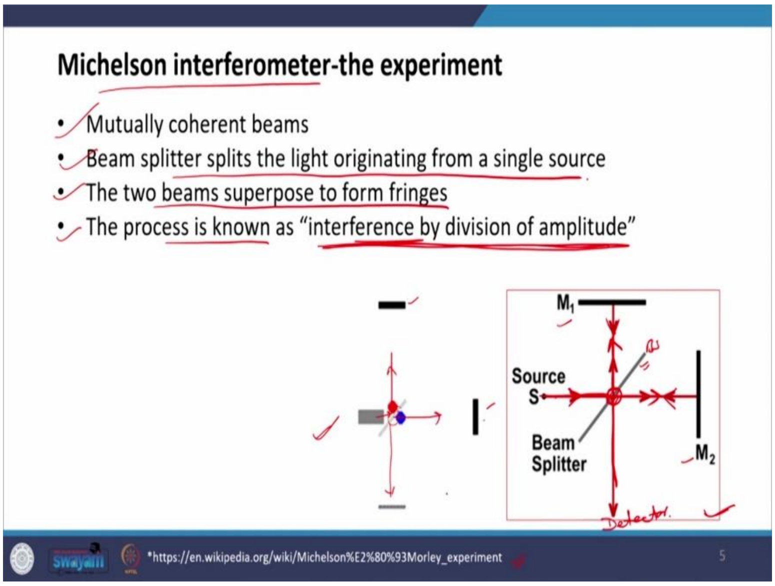

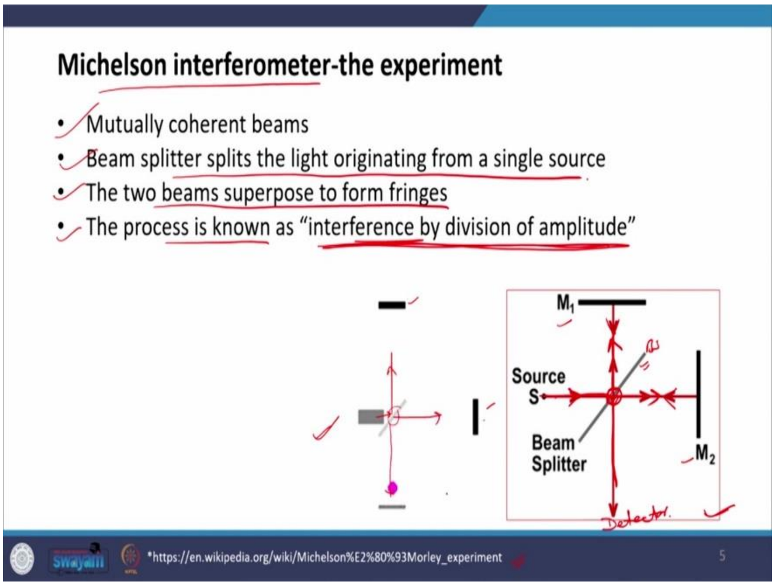

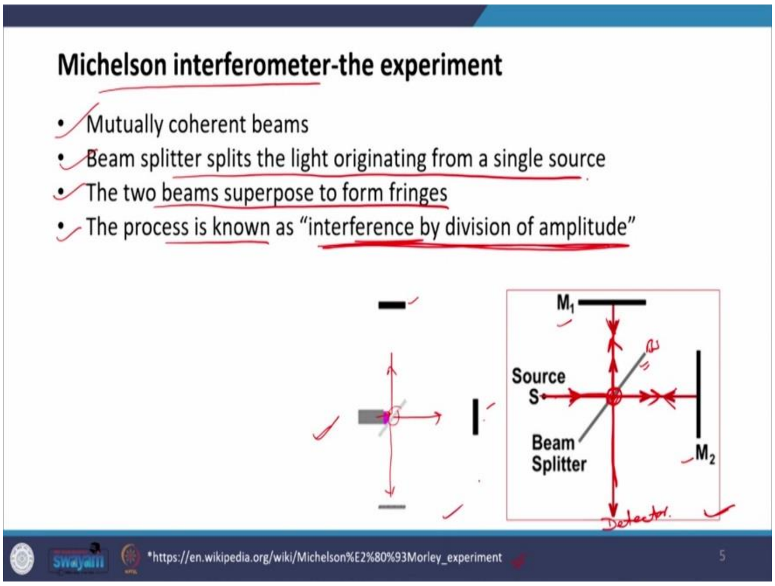

Now, in Michelson interferometer as said earlier, it requires a mutually coherent beams and how do we create mutually coherent beam, we have a source and from the source light beam emanates and the same light beam is splitted into using the beam splitter and therefore, these two splitted light beams are mutually coherent and the simple schematic is drawn here, we have a source which emit light this light due to the beam splitter, it gets splitted into one part goes here and other part goes in the other direction.

After getting reflected from mirror M_1 and M_2, these beams returned back and they combine at the beam splitter here and then it goes to the detector and at the detector, we observe interference fringes. The few concepts which are involved in this experiment is that we require mutually coherent beams, the beam splitter splits the light originating from a single source the two beams superposed to form fringes.

And of course, the process is known as interference by division of amplitude, why because some amplitude is starting from source and the same amplitude is getting splitted in two, the amplitude is getting divided therefore, this particular interferometric setup falls in the category of interference by division of amplitude.

I took this video from Wikipedia, the link is given here in this link too, we see that this is a source and the photon emit or the beam emits from here and then from the beam splitter, it gets split, it first goes here and the second goes here and we have mirrors here and these mirrors reflect them and then they combine here at the beams splitter and goes back to the detector. This is a very nice animation and I liked it and took it from Wikipedia here in my PPT.

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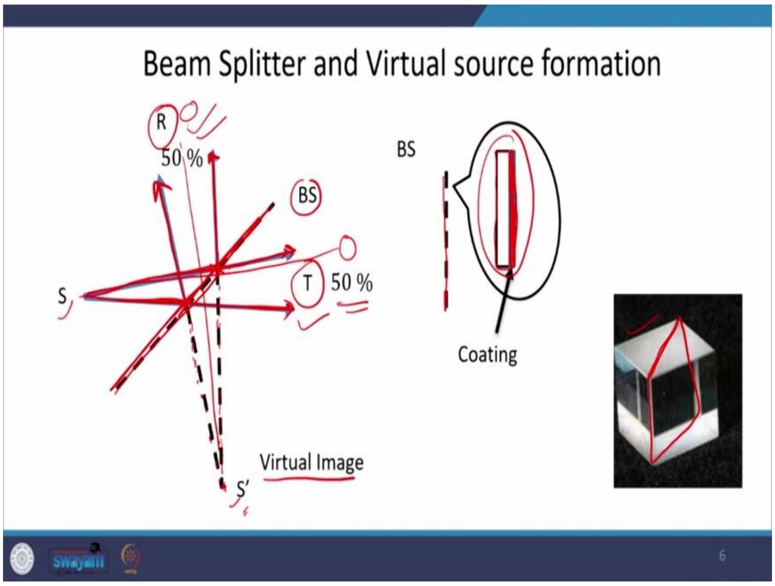

Now, the next question arises is that what is beam splitter? The beam splitter, as I said earlier, it is a semi silvered glass plate, this is the usual beam splitter, if you zoom it then you see this type of structure where we have a glass plate and the back of the plate is silvered partially therefore, it is called semi silvered glass plate. Nowadays it comes in the form of a cube and the semi silvering is done here in this plane, in the diagonal plane.

Now, how does the beam splitter form image now, this is the beam splitter here, the BS stands for beam splitter, it is acronyms for the beam splitter. Now from the source, suppose diverging beam is coming out of the source. Two rays are here. The first ray which falls here on this beam splitter, it gets reflected in this direction and the secondary which falls here it goes into this direction and this is called reflected rays or reflected beams. And if you extend these beams and the part of the beams get transmitted and if the beam splitter is a perfect 50-50 beam splitter then the 50 percent of the light goes to transmitted arm and the 50 percent of the light goes to reflected arm.

Now, if you extend back these two lines then they meet here at S' point. The S' is called virtual image. Therefore, it appears that light is coming from two sources S and S' and then they fall on the beam splitter and then if you put your eyes here then it appears that the light is coming from S' source and if you put your eye here then it appears that light is coming from source S because the beam splitter due to a semi silvered nature, it creates a virtual image of source S.

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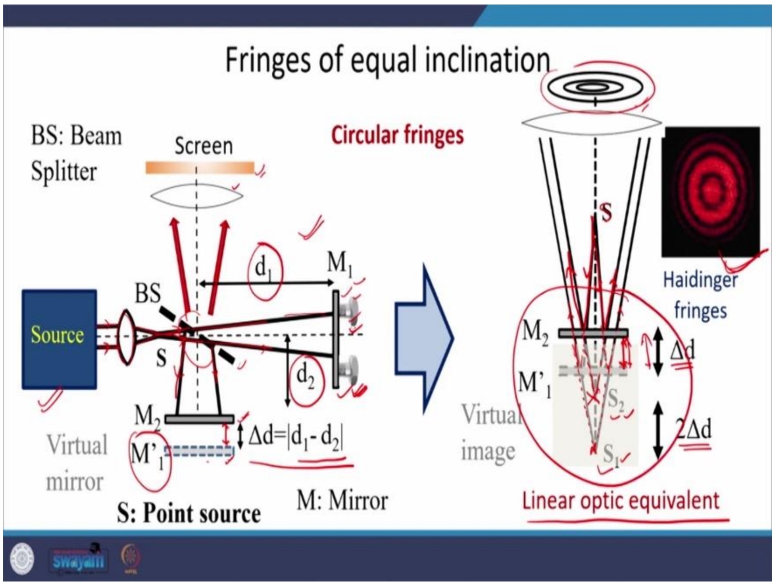

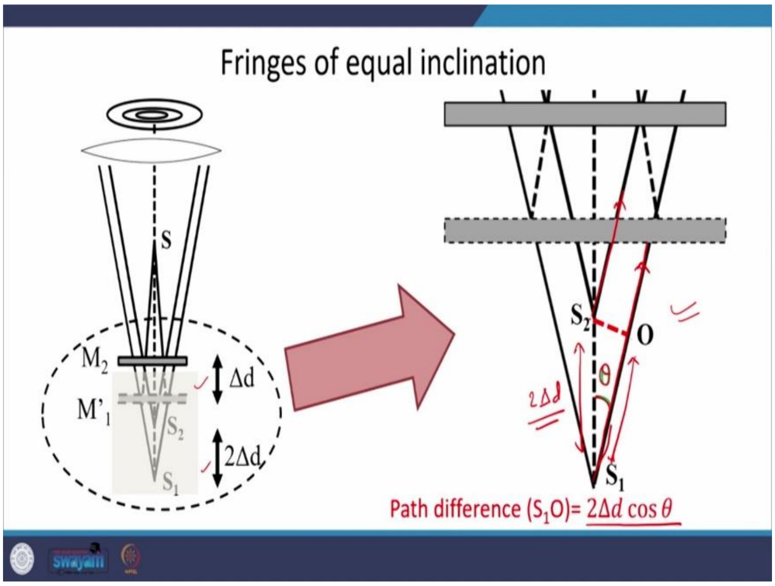

Now, coming back to the schematic setup of Michelson interferometer, we have a source here. Now from the source suppose parallel beam of light is coming and then we use a lens which focuses the light to a point and from here we get a diverging beam, as stated in the previous slide, this is a beam splitter, part of the beam will go to the mirror M_1 which is in the transmitted arm and the part of the beam will go to the mirror M_2 which is in the reflected arm.

Now, there are mirrors M_1 and M_2 on the backside of mirror M_1, we have screw arrangement, there is micrometer screw arrangement, which enables us to shift the mirror one parallelly. Now, we know that beam splitter create virtual image of source and therefore, it also creates the virtual image of mirror M_1 and that image would be created here which is represented by M'_1 this is a virtual mirror.

Now, what happens is that after the reflection or after the reflection from mirror M_1 and M_2, the reflected light combined at the beam splitter and they go into the detector where we have our screen and there we see fringe pattern. Now, suppose mirror M_1 is at a distance d_1 from the beam splitter and mirror M_2 is at a distance d_2 from the beam splitter. Now, by playing with the micrometer arrangement attached with mirror M_1, we can change the value of d_1 and if we change the value of d_1.

The separation between mirror M_2 and the virtual image of mirror M_1 changes, the separation between mirror M_2 and virtual image of mirror M_1 is $d_1 - d_2$, absolute value of $d_1 - d_2$ which is represented by Δd. Now, this Δd defines the optical path length difference and which will of course, ultimately define whether we will get maxima or minima or the fringe pattern type.

This arrangement can be drawn very simple with a lot of simplicity, this arrangement gets a lot simpler if we drive linear optic equivalent. How to draw linear optic equivalent, we have a source here, from the source beams start and falls mirror M_2 and then from mirror M_2 get reflected back, as simple as that.

Now, if you extend this ray then it falls on the virtual image of mirror M_1, from there they also get reflected here and if we extend these rays back then they meet at point S_1 and if we extend these lines then they meet at point S_2 and S_1 and S_2 are the virtual images of source S. Therefore, M_1 and M_2 what does they do is that they form virtual images of source which are S_1 and S_2.

Now, from here we know that the separation between the two mirrors is Δd and therefore, this distance would be equal to Δd which is shown here. While the separation between the images of the source which are formed by these two mirrors would be $2\Delta d$ which can easily be understood through the simple geometrical optics.

Now effectively what we have is that, effectively we have two sources S_1 and S_2 and from these two sources the rays are emanating and they interfere and this gives us a fringe pattern which of course will be circular because the optical path length difference is created by the air film which is between mirror M_2 and virtual mirror M'_1. This air film would now be responsible for the creation of fringes and we know that because of thin film, we get circular Haidinger fringes because here you see that the incidence is almost normal therefore, this type of Haidinger fringes would be visible on the screen.

Now, if you take a zoom in picture of this diagram then you will see something like this, it is Δd, it is $2\Delta d$ that is zoom it more than you get this and if this is the angle θ and these are the rays which are starting from source S_1 and S_2 then the path difference between these two ray would be S_1O, we get it from this perpendicular, we draw perpendicular from source S_2 to this ray which is starting from source S_1 and then S_1O is the optical path difference between the two rays.

We know that S_1S_2 is equal to twice of Δd from this θ is known and therefore, from this we can calculate the path difference S_1O and what would be the value, the value of the path difference would be $2\Delta d cos\theta$.

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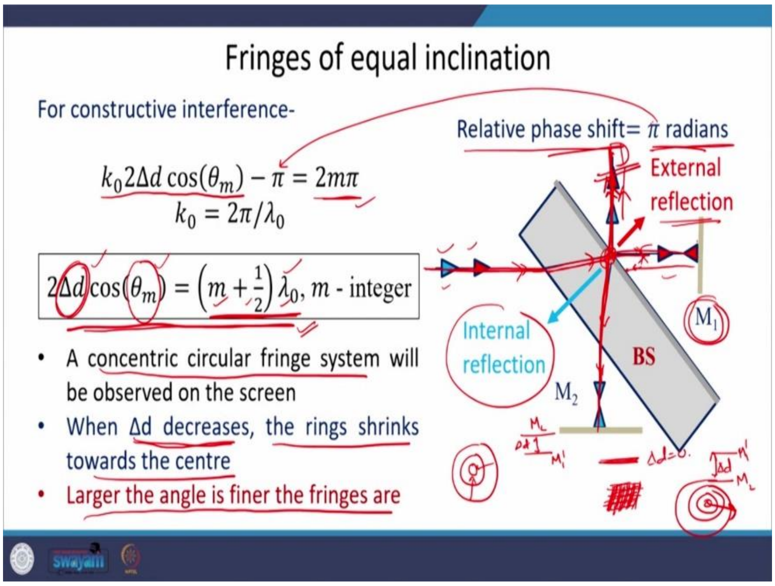

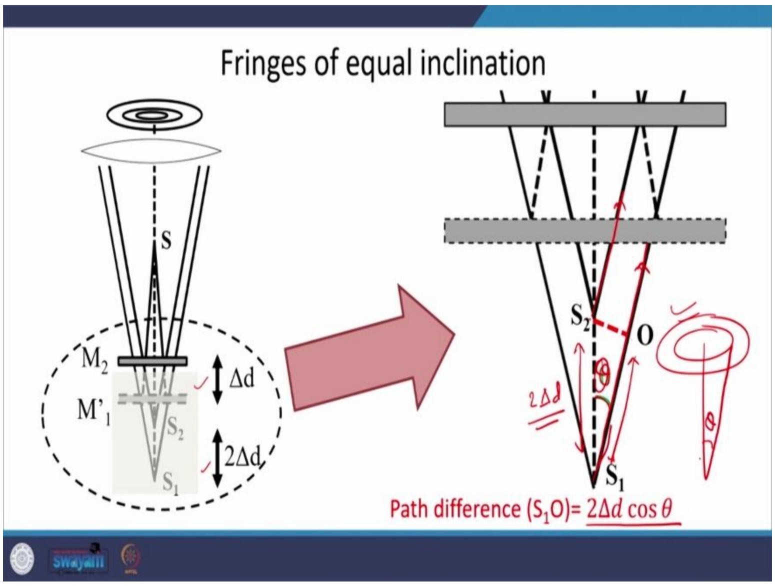
Fringes of equal inclination
S
M2
M'1
Δd
S2
2Δd
S1
O
θ
2Δd
Path difference (S1O)= 2Δd cos θ

Now, once the optical path difference is known, the phase difference can be calculated how just to multiply the path land difference with k_0, the wave number, but the beam splitter which is a semi silvered glass plate is introducing an additional phase difference of π, how? because the light which is incident on the beam splitter, it goes into the beam splitter and then when it faces the back surface of the beam splitter, it gets reflected but part of the light will also get transmitted and when the transmitted light comes back after getting reflected from here M_1 then it also get reflected to other side.

Let me repeat this concept, the rays are coming towards the beam splitter from this direction and then goes to the goes to the semi silvered phase of the beam splitter, from there the part of the light gets reflected back to mirror M_2 and then from mirror M_2 the light get reflected again and then it goes back to the detector.

Now, a part of the light gets transmitted from this back interface of the beam splitter this transmitted light goes to mirror M_1 and from M_1 it gets reflected back and again at this interface the incoming light suffers reflection and it goes back to the detector, the detector is sitting somewhere here.

Now you see that I have drawn two color arrows, the blue arrow is going to mirror M_2 and after reflection it is getting back to detector while the red arrow is going to mirror M_1, the blue and green arrows are following entirely different paths. The reflection which is happening for blue ray is called internal reflection.

The rays going in this direction and then getting reflected back to mirror M_2 while the reflection which is happening for red ray which is coming from mirror M_1 after getting reflected it is an external reflection and therefore, there would be a relative phase shift of π radians. This we will have to take into account while considering conditions of maxima and minima.

Therefore, this π phase differences also taken into account here and this will give the condition of constructive interference and there been no π phase shift, this would have been the condition of destructive interference, after a bit of simplification we get this condition. This looks like the condition of destructive interference, but this is a condition of constructive interference again due to this extra π phase difference.

And therefore, till now we saw that we observe a concentric circular fringe system and when the separation between the mirrors decreases then what will happen, suppose Δd is decreasing, Δd decreases then on the right-hand side, m is fixed, λ_0 is fixed, 1/2 is fixed, nothing is changing therefore, θ_m should adjust itself to get the same value on the right-hand side.

Therefore, if Δd is decreasing θ_m should also decrease and what is θ_m? let us go back, this angle is θ and suppose this is your fringes then this is θ and since Δd is decreasing to fix the right hand side of this equation θ_m should also decrease. If this is θ_m and this is decreasing then the ring radius are decreasing which means when Δd decreases the ring shrinks towards the center of, larger the angle is finer the fringes are, this is the similar concept which we confronted in Newton's ring experiment also.

Now, if you keep reducing the separation between the two mirrors the fringes will shrink. Since more and more fringes are shrinking they will disappear at the center of the fringe pattern and the number of fringes in our field of view will reduce if we keep reducing Δd the fringes will keep disappearing and the situation will come when Δd is 0, in that particular case, we will get a dark pattern, sorry not pattern, dark illumination or the field of view will be completely dark.

Now, this Δd separation between the mirror M_2 and the virtual image of mirror M_1, once it is 0 there is no fringe or uniform dark darkness would appear on the in the field of view, but what if this mirror after 0 if we again start increasing Δd in opposite direction. Now virtual image of mirror M_1 is on top and mirror M_2 is in the bottom, in this situation if you keep increasing Δd, the new circular fringes start to appear from the center.

Initially, when you reduce Δd in the case when M'_1 is here and M_2 is here and this is your Δd and if you reduce it, the fringes will shrink towards the center and it will disappear towards the center then a situation appear when these two mirrors are overlapping when Δd is equal to 0 then in this particular case there would be uniform illumination, no fringe pattern uniform darkness instead here the full field view would be dark.

And a situation come when M'_1 appear here and M_2 is here, as you again get positive Δd but in other direction. And in this particular case, you see new fringes appearance of new fringes from the center the fringes will appear from the center and slowly as you increase Δd the number of fringes will increase, the field of view will again get populated. Now, we will talk more about Michelson interferometer, but in the next class. And this is all for today. And thank you for listening. We will see you in the next class.