Applied Optics
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Lecture: 23
Newton's Rings

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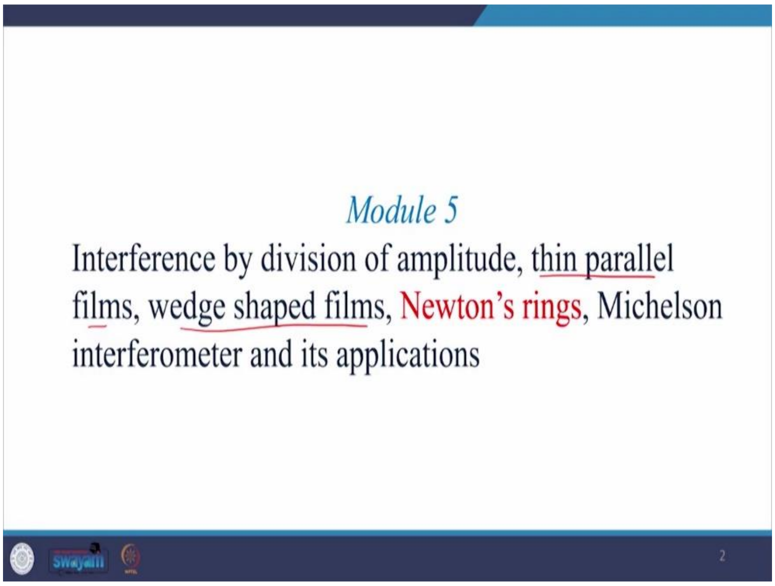

Hello everyone, welcome back to my class we are in module 5. And in the last class we covered interference in thin parallel films and in wedge shaped films, wherein we talked about interference pattern produced by different rays which are generated through multiple reflection and refraction, we considered the interference among various transmitted and various reflected rays. Today, we will start new topic which is Newton's Ring.

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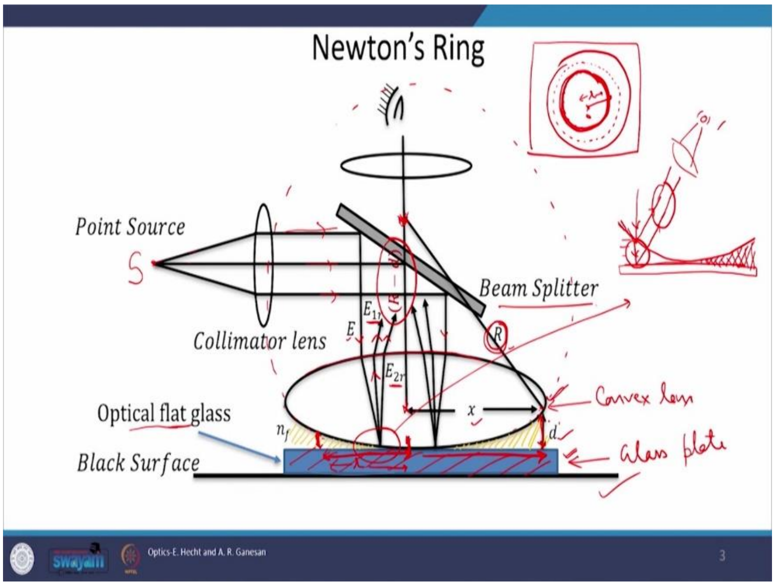

The experimental arrangement of Newton's ring experiment is shown here schematically, now, here the point source as is kept here and from the point source the spherical wavefront emanates and they are made parallel using a convex lens. Now, this parallel beam of light, they fall on a semi silvered glass plate or beam splitter. Now, this beam splitter, what does it do is that it reflect the incoming beams towards the arrangement which is shown here. Now, this arrangement here is a lens kept on the top of a plain glass plate, this is glass plate and this is a flat glass plate and this is a convex lens.

Now when the beam falls normally on this system then from the first interface, first surface of the lens, the beam refract and then it goes to the second interface. Now, between the second interface or lower interface of the lens and the top interface of the glass plate there is an air film let us represent this air film with some color, let us pick this color, this is the air film which is between the lens and the flat glass plate.

Now if you zoom in the area here let us zoom in this part and after zooming it this is what you will see this is the lens and this is your top interface of the flat glass, what happens is that the rays fall here and then it get reflected partially and transmitted partially and the transmitted rays again get reflected partially up.

Now these rays, the reflected one, they interfere, these are parallel rays and then we put lens and then they go in our eyes and there we see the interference pattern. Now, due to this air film, there is a path difference between the two reflected rays and this is similar to the concept of wedge-shaped film.

In wedge shade shape film, we saw that two glass plates are oriented at some angle and this arrangement forms a wedge shape air film here to the convex lens and this plain glass plate it is forming a wedge here and in this wedge air is there and this air film now is responsible for the interference pattern, which we observe here in this Newton's ring experiment.

Now, suppose the incident ray has electric field amplitude E and the first reflected ray means this ray, it has amplitude E_{1r} and the second reflected ray has amplitude E_{2r}. Now this reflected beams E_{1r} and E_{2r} they will interfere and produce interference fringes.

Now, we know that in 3D convex lens is a spherical structure or it has a circular symmetry, convex lens is having a circular symmetry, it has a center around the center there are symmetries now, if we pick a certain air thickness here then this air thickness suppose is at certain distance from the center of this lens then if we move around the lens with the same radius, suppose this is our small r radius then the air film thickness would be the same.

If you view the same arrangement from the top then you will see lens which is like this and a glass plate which is below the lens. And if we pick a certain point which is at r distance away from the center of the lens and then if you draw a circle of radius a small r then the air gap, the thickness of the air gap between the glass plate and the lens would be same on this circle.

And since the air gap is same on the circle, the condition of maxima and minima or the type of fringe which is observed due to this air gap will have the same intensity, what I mean by saying the same intensity is that, if a bright ring is formed due to this air gap then or if bright color is appearing or a dark color is appearing due to this air gap then this dark color would be in form of circle or the bright color would be in form of circle around this center of the lens.

Therefore, the shape of the fringe in Newton's ring experiment will be circular, we will observe concentric circular ring pattern in Newton's ring experiment. I repeat since there is a circular symmetry in this arrangement of air gap which is between the convex lens, lower surface of convex lens and upper surface of glass plate, this air gap will form a circle if we fix the height of the air gap then we will find the same height of the air gap if we move around the center of the lens on circle and this is what we are doing, this is the circle over which the air gap is constant. Similarly, you can again draw a second circle over which the width of the air gap would again be fixed.

Now, since the width of the air gap does not alter if we move on the periphery on the circumference of the circle therefore, the intensity would be the same on this circle and therefore, if a dark pattern is seen on this circle then it would be dark throughout this at all point of the circle, we will see dark and if it is bright then at all point of the circle on the periphery of the circle on the circumference of the circle we will see bright and therefore the fringe pattern in Newton's ring experiment due to symmetry of the setup is concentric circular.

Now, we see that as we move away from the center of this system, this arrangement, the thickness of the air gap increases and therefore we may correlate this system from the wedge shape film which we studied in last class. Now suppose at certain point, the air gap thickness is d which of course would be the function of x and x is the distance of this particular air gap from the center of the system. Here is the center of the lens and from here the air gap which is d width is at a distance x. And we also assume that radius of curvature of the lens is r and we have drawn here the radius of curvature from this point at the circumference to the center of this lower interface here, if you draw a bigger circle here then this bigger circle will have center here and from here we have joined it and distance this would be R, which is the radius of curvature.

If d is given, x is known, R is known, then the from the center to the center of the curvature the distance would be $R - d$, this is the distance $R - d$.

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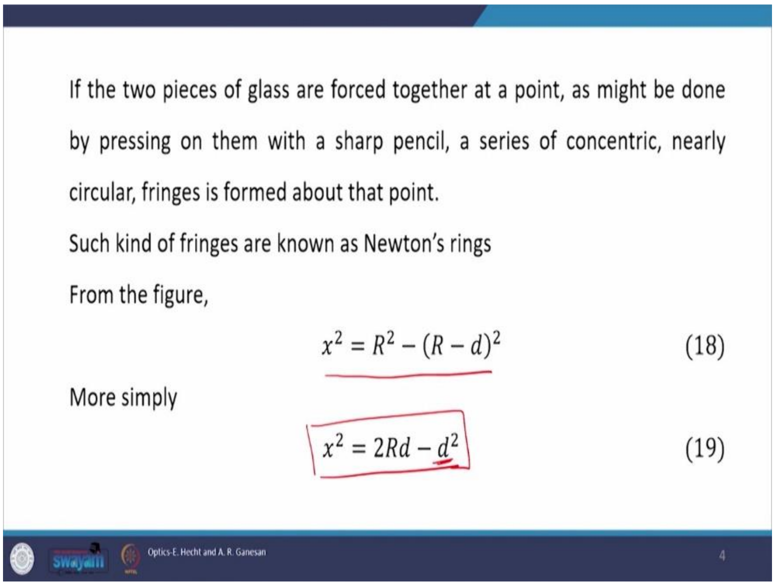

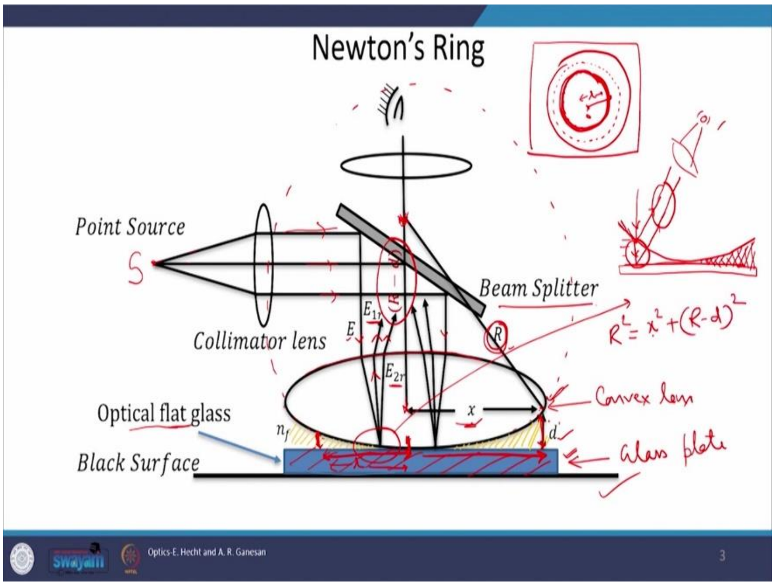

Now, from that figure, using Pythagoras theorem, $x^2 = R^2 - (R - d)^2$, you can see here in this figure, x^2 because R^2 would be found by Pythagoras theorem, $R^2 = x^2 + (R - d)^2$ and therefore, from here the expression of $x^2 = R^2 - (R - d)^2$. Now, if you expand it then after simplification we get this expression for x^2. Now, since the radius of curvature which is usually used in such setup is very large as compared to the other distances involved therefore, we can safely neglect the d^2 because these air gap which is relatively very small.

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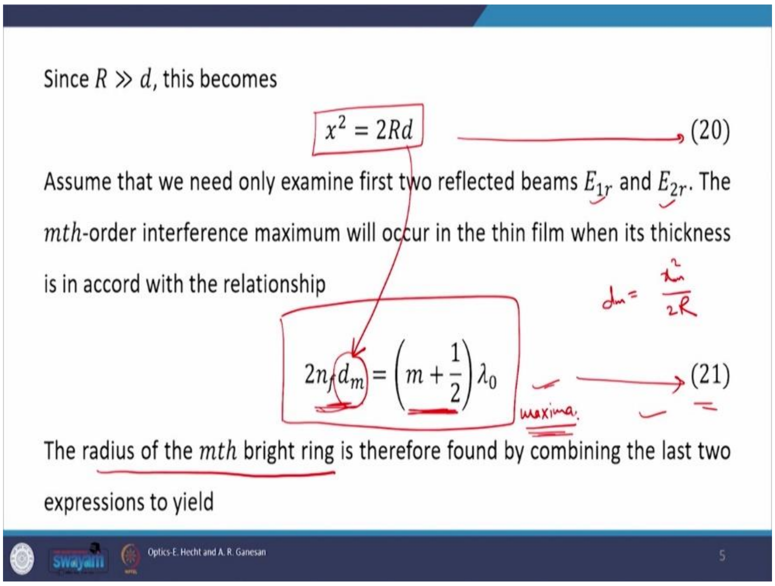

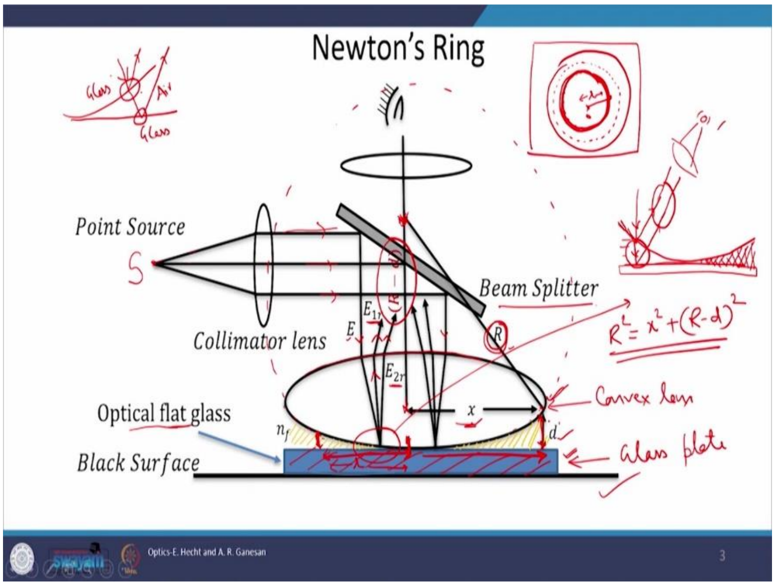

Therefore, x^2 can be approximated to 2Rd. Now, similar to what we did in wedge shape film we are only considering first two reflected beams. Now, if we want to find the condition of maxima and minima, then we will again go back to our previous lecture where we have already found the condition of maxima minima for wedge shape film or for a glass plate of uniform thickness thin glass plate and from there we get this here $2n_f d = (m + 1/2)\lambda_0$ this is the condition of maxima in reflection of course. This we have already derived in case of thin glass plate. The point to be noted here is that $cos\theta$ term is absent from the left-hand side.

Why is it absent because from the figure the incidence is almost at normal, the incidence is almost normal and therefore, the angle which our beam will make with the normal to the interface would be almost equal to 0 and therefore, we can safely neglect $cos\theta$ term and therefore, we do not have $cos\theta$ here in this expression on the left hand side of equation 21, $2n_f d_m$ only, why 2? because the air thickness is being traveled twice by the second reflected beam E_{r2}.

Now, this is a condition of maxima and therefore, it should be integral multiple of λ but you are saying it is not integral multiple of λ there is something else, why there is something extra because here in this figure, what you see is that suppose this is your interface and then the light is coming in this direction and then it is getting reflected here and then it is coming here and then again it is getting reflected.

Now, this first reflection, it is from denser medium to rarer medium because this is air, this is glass, this is also glass. The first reflection is from denser medium to the rarer medium, while the second reflection is from rarer medium to denser medium, here too the extra phase difference of π therefore, appears and that if you take into account then the condition of minima now get converted into the condition of maxima which is appearing here in form of equation 21. Now, if the condition of maxima is known, then let us find out the radius of the m^{th} bright ring, how to find out the radius of the m^{th} bright ring.

Let us go back to the figure and we know the radius is expressed by x and in this expression of 21 we have d, how the d is related to x through equation 21. We will substitute for d here, then $d = x^2/2R$, you will substitute this value of d into equation number 21, what is the value of d, $d_m = x_m^2/2R$, I am associating subscript m with d and x just to indicate that these calculations are for m^{th} bright ring.

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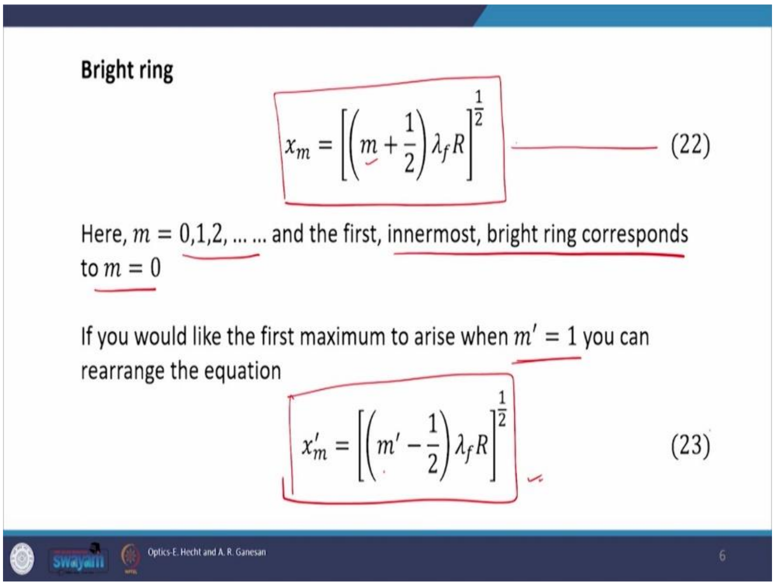

Now, if you do this substitution then for the bright ring, the value of the radius for m^{th} bright ring the value of the radius is here and it is given by this expression number 22, where m of course is an integer number. Now, the smallest value of m is equal to zero and therefore, innermost bright ring corresponds to $m = 0$. Now, you can rearrange equation number 22. And if because we are talking about first bright ring then sometimes people think that m should start from one and if you want m to start from one then the equation get modified slightly. Then after rearrangement equation 22 get converted into 23. They are the same thing but written differently.

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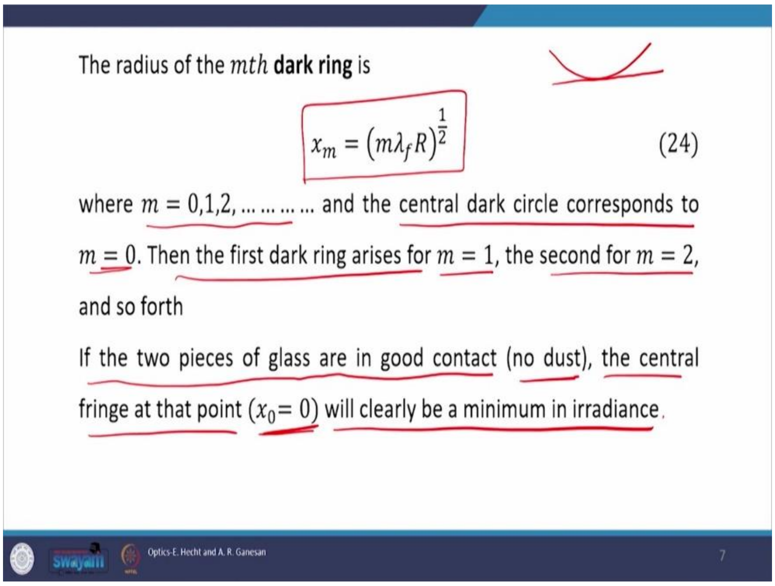

Since $R \gg d$, this becomes

$$x^2 = 2Rd \qquad (20)$$

Assume that we need only examine first two reflected beams E_{1r} and E_{2r}. The mth-order interference maximum will occur in the thin film when its thickness is in accord with the relationship

$$2n_f d_m = \left(m + \frac{1}{2}\right)\lambda_0 \qquad (21)$$

The radius of the mth bright ring is therefore found by combining the last two expressions to yield

Bright ring

$$x_m = \left[\left(m + \frac{1}{2}\right)\lambda_f R\right]^{\frac{1}{2}} \qquad (22)$$

Here, $m = 0,1,2, \ldots \ldots$ and the first, innermost, bright ring corresponds to $m = 0$

If you would like the first maximum to arise when $m' = 1$ you can rearrange the equation

$$x'_m = \left[\left(m' - \frac{1}{2}\right)\lambda_f R\right]^{\frac{1}{2}} \qquad (23)$$

Now, once the expression for our expression for radius of m^{th} bright ring is known, let us find it for the dark ring. Now, we will follow the same thing here, the condition of maxima here similarly, we can get the condition of minima. And there we need instead of odd integral multiple we will resolve to integral multiple of wavelength and from there we get this expression.

This is the expression for radius of m^{th} dark ring here again small m is an integer and you can see that central dark circle or central dark pattern corresponds to $m = 0$ because when m is equal to zero, $x_m = 0$ which obviously correspond to the central patch, central dark pattern, then the first dark ring arises when m is equal to one, for the second we will have to substitute m=2.

Now, again this is the lower interface of the lens and this is the upper interface of the glass plate, now you know at for $m = 0$, there is no thickness, the glass plate is touching the convex surface of the lens, this is this type of arrangement, the glass plate is touching the lens, there is zero air gap, if the air gap is zero then the path length difference is also zero. There are the interferences happening between the first two reflected beams, the first reflection is at the interface of lower surface of glass or lower surface of lens and the second reflection is happening at the top surface of glass plate.

These two reflections then interfere, but if the air gap between the two interfaces is zero, then the path length difference between these two rays would be zero and if the path length difference is zero then one can quickly say that it is the condition of maxima. But before commenting this, before making such a statement, we must think about the internal and external reflections which are occurring here in this case.

In our case, the first reflection is from denser medium to rarer medium and the second reflection is from rare or medium to denser medium. Therefore, we must take into account the extra phase difference by which is creating due to these reflections and therefore, even if the optical path length difference is zero due to reflection the extra phase is difference of π is being introduced and therefore the condition or maximize is the condition of minima and vice versa and therefore, even with zero air gap we get dark patch at the center.

But while performing the experiment sometimes happen is that we do not see the dark pattern, people see bright there. This is because insertion of small dust particle, the two surfaces do not contact touches properly because a few dust part sit there and we see some bright patches there too, but if the two pieces of glass are in good contact, good contact means if there is no dust, then the central fringe at point $x_0 = 0$, x_0t means for the zeroth order fringe it will clearly be a minimum in irradiance. Here you will not see any bright patch there, it would be perfect dark.

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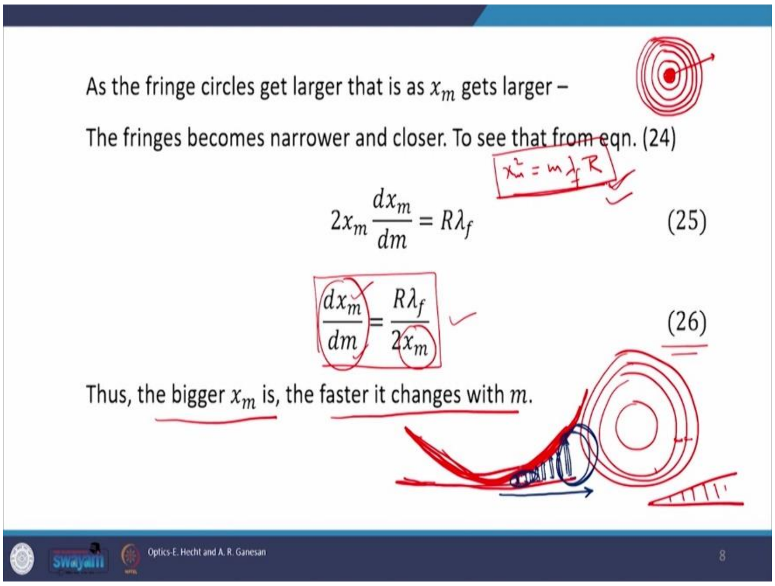

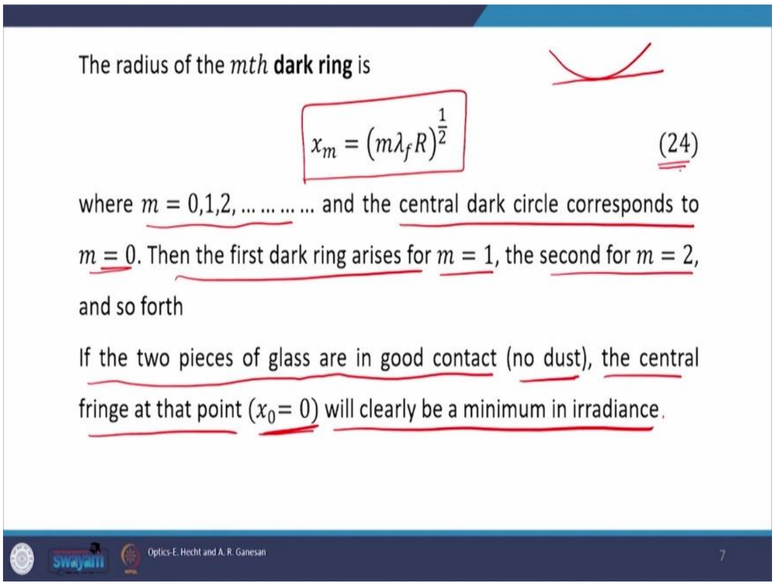

Now, the second observation what people have observed in case of Newton's ring is that the center is obviously dark, this we have understood and then bright and then again dark but if we keep drawing more circles then what happens is that the circle is start to come closer as we move away and their width also reduces.

If you go away from the center, the width of these fringes reduces and this is observed in this case then the people start asking like what is the reason, why does the fringes start to shrink if we move away radially outward, this can be understood from this equation, equation number 24, equation number 24 can be written as $x_m^2 = m\lambda_f R$.

Now, we want to see or we want to observe the variation in the radius of different fringes with respect to change in order, if we go radially outward then the fringe width decreases means, if we increase the order of fringes then fringe width is decreasing or let me reframe it, if we increase the order of the fringe then we see that the fringe width is decreasing and this statement is similar to that if we go radially outward the fringe width decreases.

Now, this decrease in the fringe width can be seen in this relation this equation 24, how differentiated with respect to m now, if you differentiate this equation then you get equation number 26. This represents variation in the radius of fringe with respect to fringe order we see that this variation is inversely proportional to the fringe radius, it means as the radius increases dx_m/dm which is the left-hand side, this becomes fast, here this is what it is written here. The bigger x_m is the faster it changes with m. And the question number 26 exactly says it.

Now, we will see that as we move away from the center, the fringes start to shrink, this fringe become closer and closer, now, but this can also be understood from the fact that this arrangement, this is the upper surface of glass and this is the convex lens surface, this is not perfectly a linear wedge, the linear wedge is like this, it is linearly increasing, but here you see the surface is not a flat here it is having some curvature.

Now, due to this curvature, now, this air gap let me pick a different color, now air gap here is this much, but as we move outward the air gap quickly increases or alternatively what we can see is that the condition of maxima and minima, the maxima goes to minima after $\lambda/2$ distance, why? Because the second beam, second reflected ray travels this air width twice and therefore, as soon as there is a increase in the width by $\lambda_0/2$, the dark fringe will go to bright or bright fringe will go to dark.

As we move away from the center of this arrangement, the fringe thickness or the air gap thickness increases rapidly. The dark screen goes to bright when there is a difference in the air gap by $\lambda/2$. If air gap increases by $\lambda/2$ the dark fringe changes to bright one or the bright fringe changes to dark one. This changeover happens rapidly here when we are far away from the center, but this changeover is slow here, because the width is increasing rapidly here, since the width is changing rapidly here, therefore, the bright and dark fringes appears to be very close, they become very thin, while when we are close to the center, they are very wide

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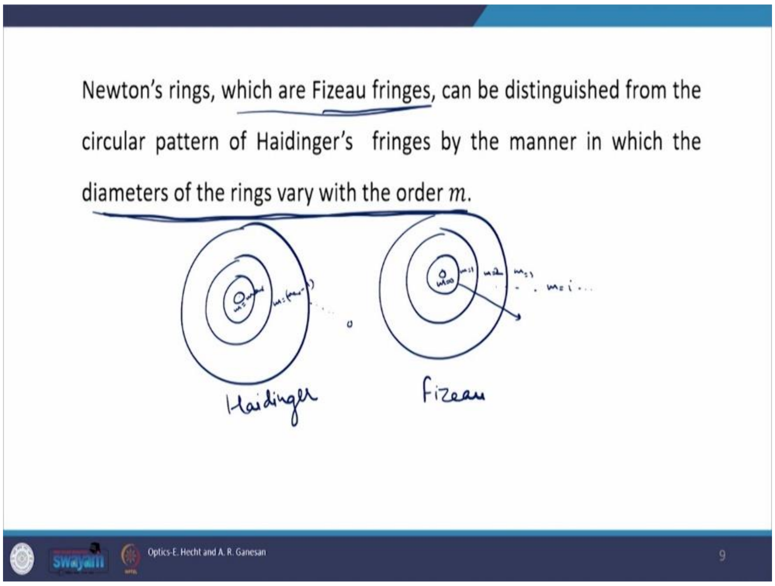

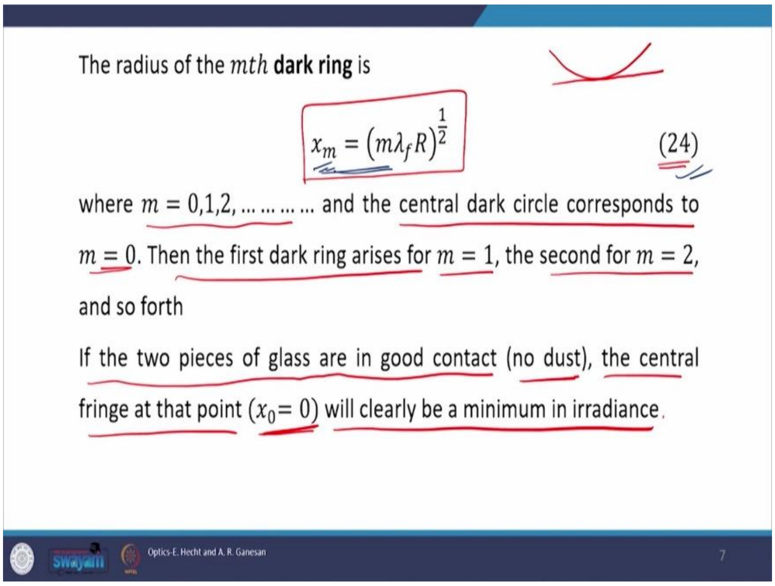

Newton's ring fringes we know that the light is almost falling normally and then we are getting concentric circular fringe better therefore, this satisfies the criteria of the Fizeau fringes. Therefore, these are Fizeau fringes and they are different from Haidinger's fringes, Fizeau fringes are different from Haidinger's fringes, what is the difference, the difference is that the diameter of the fringes, we know that both Fizeau and Haidinger fringes are circular, they both are circular and this is say Haidinger, they both have circular, just by looking at them it would be difficult to distinguish between the two, they both have concentric circular fringes.

Now, if you see the diameter of the rings they vary differently with m, in case of Fizeau fringes, m is 0 at the center and then if you move radially outward then m increases here m is equal to 1 here, m is equal to 2, this is what also happens in case of Newton's ring experiment, here m is equal to 3, and so on. While what happens in Haidinger fringes, at the center m is maximum, m is equal to m_{max} at the center and then if you move away then the fringes reduces $m_{max} - 1$ and the zeroeth fringe appear at the outermost periphery.

The outermost fringe in Haidinger fringes is designated by m is equal to 0 while in Fizeau fringes is designated by m is equal to 0, they are opposite, this is also clear from this expression, expression number 24. This is the radius of the dark ring and this is we see that as m is equal to 0 then x_m is also 0. If as m increases, x_m also increases, it means the central fringe in Fizeau fringes or in Newton's ring experiment fringes, the central fringes of lower starter while opposite is the case in case of Haidinger fringes. In Haidinger fringes, the central fringes of highest order and outermost fringes of lowest order, these are the basic difference between the two types of fringes, and this is all for today. And thank you for listening me. See you in the next class.