Experimental Physics -II
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Lecture - 38
Michelson Interferometer (Theory)

Today, we will demonstrate Michelson Interferometer, using the Michelson interferometer what we can do in the laboratory.

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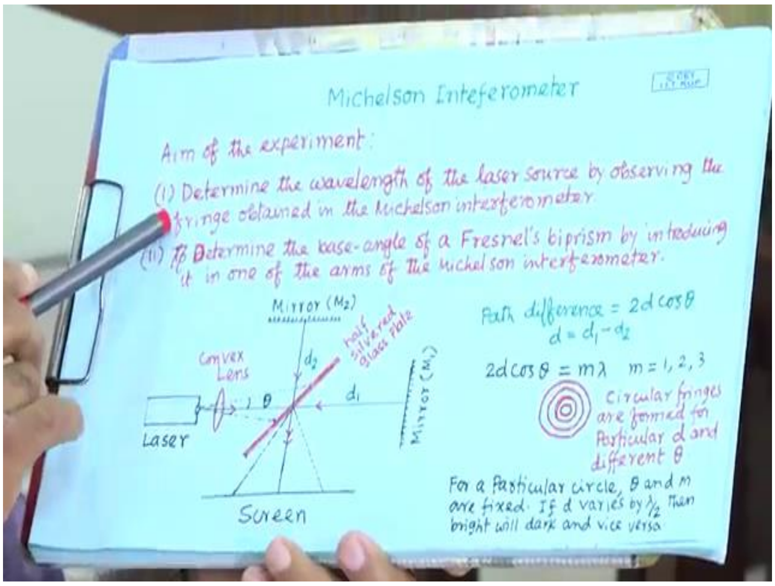

aim of this experiment are the following. Determine the wavelength of the laser source by observing the fringe obtained in the Michelson interferometer. Determine the base angle of a Fresnel's biprism by introducing it in one of the arm of the Michelson interferometer. let us let us discuss the Michelson interferometers what it is. we have a source say laser source, now from laser source light is coming and we are using a convex lens. laser source generally it gives parallel rays its divergence is very small. almost parallel rays we get.

we use, for this experiment we need extended source, if we use normal not laser source normal source generally, we use a glass plate and that glass plate act as a extended source this light falls on this glass plate. glass plate is taken as a extended source. in this case we are using laser to defocus to make the extended source we use lens. lens is not put at the, laser is not put at the focal point of this lens.

If you put focal point of this lens then this parallel rays will meet at the focal point, on the other side. now, it is either greater than this focal length or less than the focal length, then it will diverge, it will diverge, so that means, we are making extended source using this laser. here purpose is different than, generally we use laser for making the parallel rays. Here parallel rays, from parallel rays to we are making we are diverging the light to make the extended source.

Now, the source extended source from this extended source or this divergence light falling on a half silver glass plate or beam splitter. We tell it is a beam splitter. And it is split into two, one part is reflected, and another part is refracted through this glass plate. there are two mirrors in perpendicular direction mirror M 1 and mirror M 2. this light diffracted refracted light. this since it is very thin. there is not much divergence. say it is going the straight, ok, just like transmission it is a transmit through this, it is going and falling on this mirror.

Then it will reflect back from this mirror it will fall on the mirror perpendicularly and it will reflect back. If it is at 45 degree then this reflected ray again it is reflected from this glass plate and come down, ok, it is come down. And another part of this incident ray it is the here from this place is the reflected, again when it is 45 degree, so it will be perpendicular to the incident light, it is, so this ray refracted ray it is falling on the another mirror M 2 perpendicularly, from this mirror again it will reflect back and it will pass through this glass plate and come down.

here in this region we are getting two refracted rays reflected rays one from the mirror one M 1 and another from the mirror M 2, and these two are from the from same source one, one ray is falling here, so it is called amplitude division of amplitude. One part of this ray is going this way, another part of this ray is reflected this way going this way, amplitude, division of amplitude and then these two are travelling these paths and coming in this direction and there these two reflected rays these two rays will interfere and form the interference fringe,

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this is the mechanism for interference between two coherent source. the now the path difference between these two rays which interfere. starting from here, one is going and coming back from here downwards, another is going here coming back and downwards.

this path is same for this for the two rays which are interfering. here it is travelling to d 1 path and here it is travelling twice to d 2 path, path difference path difference will be 2 d 1 minus 2 d 2, if d 1 minus d 2 if it is d, so path difference will be 2d.

Now, this 2d it is a here we are considering this light, this light it is a falling perpendicularly, falling perpendicularly on this mirror it is at 45 degree, if we considers another rays which is coming in this direction dotted line, dotted line, if this makes angle theta then for this ray. it is it will fall on the central fringe, ok, at centre, now this will now this dotted line so they will come at different angle, they will come at different angle, ok, so they will form fringe, other fringe, here angle of inclination will change and will get different order of fringe.

two important things, one is if thickness is then fringe, we get because of the variation of angle of inclination and if thickness varies then we get fringe for a particular inclination, in this case thickness is constant. that is d, d 1 minus d 2, that will depend on a position of this mirror if we fix that one for a particular d, we will get different order of fringe because of different angle, ok, angle of inclination. in general, it is not 2d, the path difference is not 2d, it is 2d cos theta. 2d cos theta that is the path difference now 2d cos theta equal to m lambda that is the condition for b fringe, that is the condition for b fringe, ok; we will get this type of fringe patterns.

Now, here these circular fringes are formed for particular d and different theta, for central one theta is 0, theta is 0, so it is 2d. now, from here you can see 2d equal to m lambda, this is the maximum value because cos theta if varies from 0 to 1. for theta equal to 0, so this side is a maximum value, and the fringe will get at the centre. order of the fringe at the centre is maximum; that means, m will be maximum. if this order is m, so next one will be m minus 1, next m minus 2, m minus 3. when you are going outside from the centre, so you have getting the, you are getting the fringe of lower order,

And another case may happen that if you look at a at the centre fringe, it is the mth order, now or for an any particular circle it is a for about the order, now that is for a particular theta that that circle or that fringe is for a particular order and for a particular aim, then that is fixed. Now, if you vary d if you shift the one of the mirror, so you are varying d. when you will vary d what will happen? The order of the, order of this say central one, it was m, now order of the central one will increase or decrease depending on the value of the d, if d increases you are shifting the mirror this side, m will increase, m will increase.

what does it mean? at the centre, so as if this fringe, you will feel that fringe or are generating and collapsing to increase the order of the central fringe at the centre as if this more rings are collapsed into the centre. If you decrease this d, so m will decrease then what will happen? to reduce the value order of this centre one it was m, now you will feel that this it is this rings are generating from the rings are going out from the going out from the centre, it is going outside. you will feel that fringe is appearing,

if you just very slowly, so if it is b one, so if this shifting if this shifting is lambda by 2, since here, 2d is there, so if d this shifting is lambda by 2, ok, so then it will be this 2d will be lambda, 2d will be lambda. I think that I should not I do not need to consider. 2d actually it was for central fringe it was m lambda. Now, if I so 2d, now d if I increase by lambda by 2. d will be d plus lambda by 2d plus lambda by 2 means, 2d plus lambda by 2 means; actually 2d, 2d, sorry I should write; 2d for central fringe now if d increase by lambda by 2d increase by lambda by 2.

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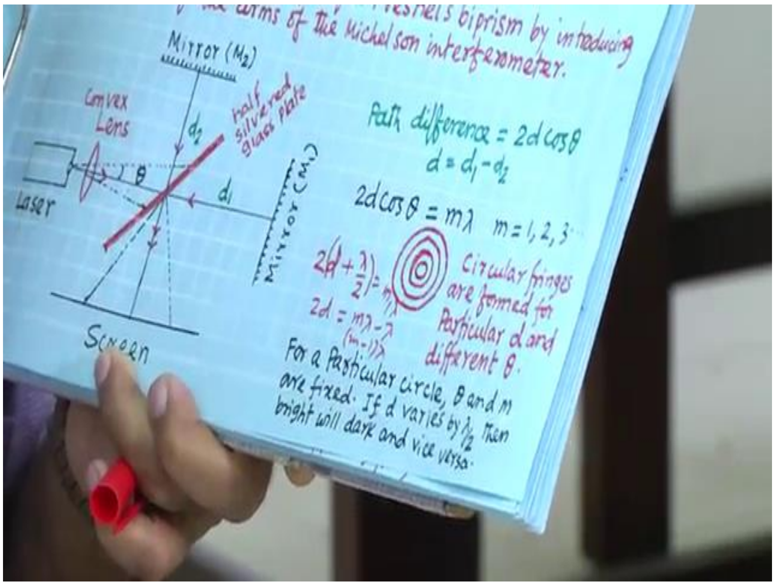

then what will happen? This order m will change. this will be some different order. this if say M 1 lambda, this condition you will get 2d equal to, 2d equal to. that is new d. this you will get 2, this it is our your actually m lambda minus lambda, that is why if you change by lambda by 2 this d then you are getting next order, m minus 1 into lambda, increasing the, so increasing the increasing the distance d for central one you are if increasing the d. order of the central one should increase. that is new d value, ok; this new d value. And if you consider that if you consider that this for d value yeah that is true, for original d value if it is it will be m minus 1 lambda m minus 1 into lambda. Now, if you increase by lambda by 2 then it is going it is it becoming m lambda, ok, so 1 will increase.

for changing d by lambda by 2 it you will get you will get collapsing or appearing of the of the fringe at the centre. if you count, if you count, so starting from b, so you are changing; for lambda by 4 change you will get the dark one. for lambda by 2 you will get the again b one,   what is happening? you are counting the number of fringe collapsing or appearing, changing the distance d, changing the distance d. if you can note down that distance d and how many are appearing or collapsing if we can count then from there you can find out you can find out the lambda value,

here I told that this path difference is equal to 2d cos theta. from here it is not very clear how. It is 2d cos theta it is 2d, so that is clear from this when theta is equal to 0. For other theta how it is 2d cos theta it is not clear. to understand that one we have to, so we have to see this diagram, we have to see this diagram. that is what happens?

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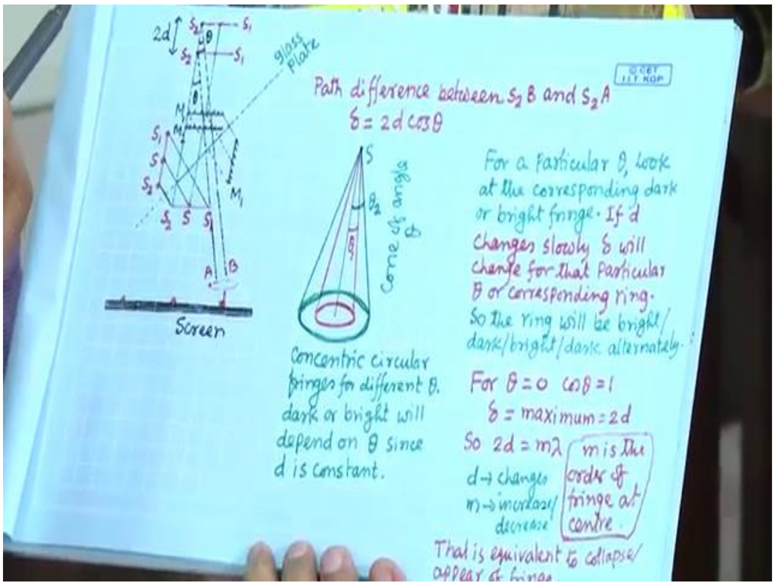

you have extended source as we are using lens, convex lens to diverge the parallel rays, so this a extended source. 3 points I have taken S in middle and this then S 1, S 2, this is the, so this mirror M 1 and this is mirror M 2. Now, this is the glass plate, Now, observer, when this is the screen means observer is seeing the will be able to see the image of the source, image of the mirrors, image of the mirror through this glass plate, that means, it is because of reflection from the glass plate, this glass plate here, so I have just extended I have just extended.

Now, if you see from here, so why we will see the image of this one of source? image it depends on the perpendicular distance of see this, from this is the say mirror like mirror. if this is the point, so corresponding image you will see just backside at the same distance. perpendicular if you draw perpendicular and take the same distance in backside; for this S 2 this will be the image position. For this S this will be the image position for S 1 this will be the image position. if you connect it, as if observer here it will see the source not here it will see the source here,

Now, similarly for this mirror this observer will see mirrors, here, image of this mirror observer will see here, this, so now, observer what will see? Observer will see this, this is the source lighter going, lighter going, and these two mirrors are there, there will be. for this source from this two mirror there will be the image of the source like from M 2 the image will be here this one, I have, so same way you can find out the image position just draw the normal and take the same distance in backside,

for this point, so this will be the image for from the mirror 2 and this will be the image for the from the mirror 1, this source image of the source from these mirrors will be this one for mirror 2 and this one for mirror 1. as if from the single source we are getting two virtual source. these two source are coherent, since it is extended source. we will take this source from each point, for a particular rays, for a particular rays, so from this point and from this point, these two are the coherent source and rays from this source this one and rays from this source say this one.

they are coming at a particular angle of theta, they are coming at a particular angle of theta, they will be parallel, they will be parallel now these two ray will interfere. Now, what is the path difference between these two ray? What is the path difference between these two ray? if you take normal from this point two on this, so this will be the extra path on this on these rays, if this is theta, so this extra path will be cos theta, Now, if this mirror distance is d, mirror distance is d M 1 and M 2, this mirror distance is d not these distance, now here these two mirror M 1, M 2, if it is d. this image from this mirror you know that it is become 2d, it will be 2d because the distance from here to here whatever, so you will get this now this distance from here to here and this image of that one again it is a this. it is a, that whatever this d once it is counted. distance this pass this d and then for image again this also this d, extra d will come plus this whatever the distance from the mirror 2,

that is why this image distance will be double whatever the distance of the mirror. if this is d mirror distance between M 1 and M 2 in this diagram, so it will be image distance will be 2d; this from this picture as if now we have two coherent source. Now, from this two coherent source light will falls this way, from these two source they are coming just downwards. from centre of this if we consider from the centre, so it is a downwards,

as if we will get. this is the normal this is the normal, we will get the centre fringe and for any other rays, so one I have consider this from these two source these two rays, they are parallel and they will interfere actually one should use the laser, sorry, one should use the lens and that lens will converge this parallel rays to a point, here there we will get the fringe for this for this rays and these rays are coming at angle theta,

Now, for a particular theta, for a particular theta what will happen? this angle is with respect to the centre taking that as axis. you will get a cone, over a cone, so angle will be theta and over a cone. angle will be same and if you put your screen like this, ok, so you will get the same path difference on the on this circle, because 2d sin theta 2d cos theta. d is constant, d is constant and for a particular theta cos theta also constant,

we will get same path difference over a on a on a circle, for next different angle, so you will get another circle. you will get many concentric circle for different-different angle, that is why on the screen we are getting many concentric circle and this order of the centre one is the maximum is the maximum. here that is what I told this so 2d will be m lambda, so m is maximum.

when d will change the n will increase or decrease depending on d is increasing or decreasing. that is that is required to collapse or appearing of the fringe to get that fringe will we will see the appearing or collapsing of the fringe when we will change the d, we will change the d. that is for a particular order, particular fringe. we will consider the central fringe where the order is the maximum,

if we count if we count the collapsing or appearing the fringe and for and corresponding the displacement of the d, then we can calculate we can 2d by m, we can calculate lambda wavelength of the laser light, this one experiment we will do. Another experiment we will do that how to find out the angle of biprism, angle of biprism using the Michelson interferometer,

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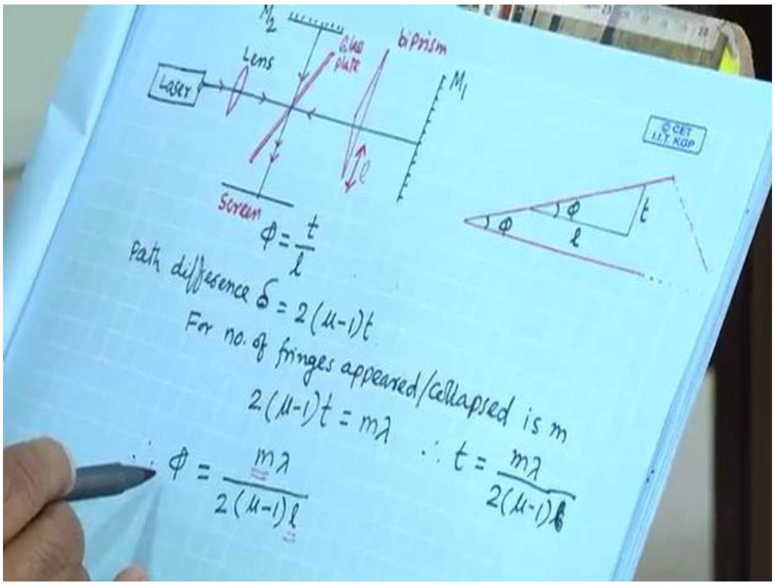

to understand that one so in one of the arm; this is the set up as I showed you. in one of the arm we will insert the biprism. this is the biprism we will insert the biprism, Now, when we will insert the biprism what will happen? here this optical path instead of instead of t, instead of t when biprism is not there; about this length is t, when we put biprism then the optical path will be mu t, mu is the refractive index of this material of the biprism. this optical path will be mu t,

because of these prisms of biprism what will happen? The path difference additional path difference will be introduced in this arm and so that additional path difference is mu t minus t, mu t minus t. that will be the additional path and you know this. it will be twice because that if d path difference in one arm, so because of the reflection twice, ok, so that become 2d, here also same way this path difference will be 2 mu minus 1 into t, t is this one.

Now, here what happens? whatever the what so whatever the number of fringes appear or collapse if it is m so this 2 mu minus 1 t equal to m lambda. this m and this earlier m are not same. Here before putting the biprism whatever the order was there of the central one, now after putting this biprism. optical path will change of the one arm, ok; before putting if it is M 1 after putting this central fringe if it is order is M 2. due to change of the path difference that is 2 mu minus 1 t additional path difference that is, for that the change of the order of the central fringe will be M 1 minus M 2, that is what it is m. So that means. what we will do?

here the advantage is that the if we can just translate this biprism along this direction we can change the thickness t, we can change the thickness t because this is the thickness this is the thickness. thickness if I push up then thickness will decrease if we push down then t will increase, for a particular what we will do? For a particular position of the biprism we will note down the reading for the for the position of this biprism, and what about the central fringe is there it has some order.

Now, I will translate this one, I will translate this one; that means, I am changing the t and due to that this order of the central one will change, that I can count, ok, It is collapsing or appearing I can count how many are collapsing or appearing, I will count for 30-40. And for that how much translation are required, so that I will be able to note down, that is that that change of thickness,

that translation actually we will relate that is this translation we are telling l and because of that thickness will change. how they are related translation and thickness how they are related, so to get this one here you can see. this is the biprism, so one this part I have shown other part is there, so we are using this part. this is the angle of prism, biprism, this angle we want to find out.

if this we are shifting the biprism by this length by this length then change of thickness will be this t, change of thickness will be the t. this for small angle because this phi is very small; small angle we can write that phi equal to 10 phi equal to this t by l, so 10 phi equal to phi. that is why we have written phi equal to t by l, this t is we are translating this by prism by l distance and for that the change of the centre fringe is m. that will come by appearing or collapsing of the fringe at the centre, that means, m experimentally m we will know, l also we will know, l also we will know, your phi will be phi will be, so phi will be t by l. from this relation t is m lambda by 2 mu minus 1. if I put there, so m lambda by 2 mu minus 1 into l. experimentally we will find out this m, l and this m. Lambda is known from the previous measurement and mu is supplied refractive index of this one. then we can calculate the angle of biprism, this experiment also we will do.

experimental data how we will note down that is a just a let us just review that one.

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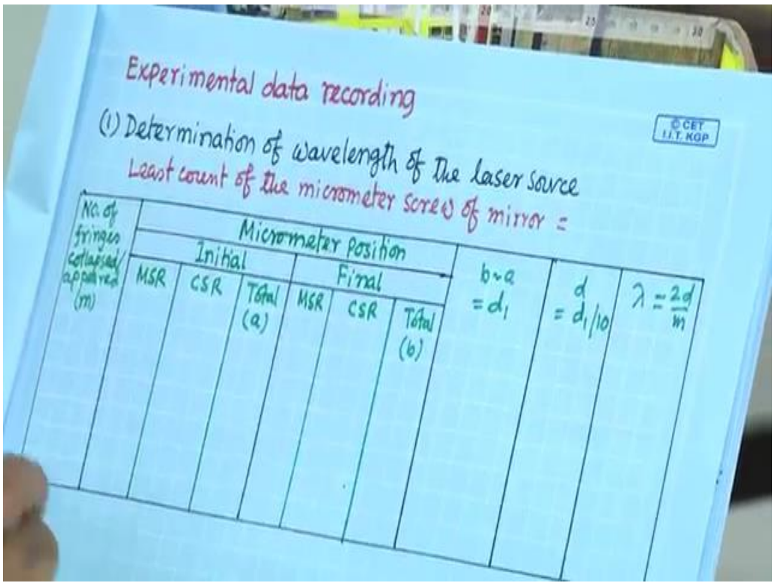

determination of wavelength, so two part of this experiment, one is determination of the wavelength of the laser source, there we have to change the distance of the mirror. least count of the micrometre, screw of the mirror, so that we have to note down. Then what we will do? what is the micrometre position, initial position? Before starting to change the distance of the 1 mirror, so initial reading we have to take, so main scale reading circular scale reading and total say it is a then we will change we will change the distance, and count and count the number of fringe collapsing,

we can take 30, 40, 50 number of collapsing for a particular for slowly we have to change, and we have to count that one and then for a final position say m equal to 30, 40, 30 or 50, or 50 whatever. for that that is the final position of the micrometre for that we will take reading if say it is d, so that d 1, so the d it is a d is distance we are changing d minus a. here I am writing d 1 because in this micrometre here there is an if I change by say whatever the reading from micrometre, we will get actual change.

that is the lever action actual change is 10 times is less, we have to divide it by 10, so that is the mechanism of the micrometre for changing the distance of the mirror, this company has given this ratio 1 is to 10 ratio or 10 is to 1 ratio, we will get d value. lambda equal to 2d by lambda 2d by m and because we are considering the central one, so theta is 0, this m we are counting for a particular d value, for shifting of mirror by d.

we can calculate the wavelength, here number of fringes collapsed or appear, so that is m. this you can at least 3 times you should do and then you will find out lambda what is lambda you can find out, this is one part of the experiment. And second part of the experiment is to find out the angle of the biprism; determination of the base angle of the Fresnel's biprism,

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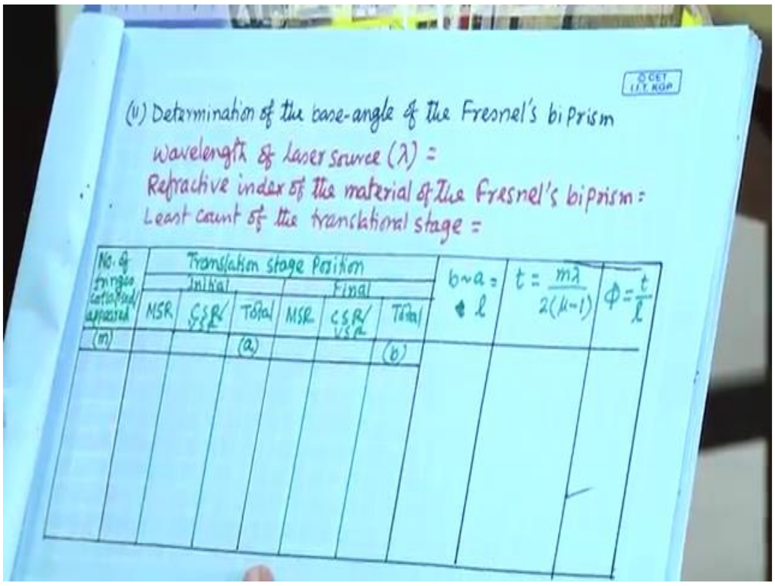

for that wavelength of the laser source, we have measured earlier, or it is supplied, so that you note down. Refracted index of the material of the Fresnel's biprism; that is also supplied, so we have to note down. Least count of the translational stage in this case as I told that we will shift, we will shift the biprism translate the biprism and when we will translate by l corresponding change of the thickness will be t, so optical path optical path will change that is mu minus 1 into t, your effective path difference will be 2 into mu minus 1 into t, that l value for determining the l value, we will use this translational stage where this Fresnel's biprism is attached. that least count of the translation stage we will note down, then we will start experiment here number of fringe collapsed or appeared, so again we are seeing the central fringe theta equal to 0, when we will change the optical path. earlier we change the distance of the mirror, in this case we will change the thickness of the biprism shifting or translating the biprism, now, we are translating slowly and counting how many are collapsed and how many are collapsed or appeared, it depends on whether you are going towards higher thickness or lower thickness.

we will note down the reading position of the translational stage initial before starting, to translate. main scale reading then circular scale or Vernier scale depending on the scale here, so then total say this is a, and after translating by l and corresponding count will be m. that final reading again, we will note down. difference of these two will give you l translation, so then this is your formula t equal to or then we will find out corresponding thickness t m lambda by 2 mu minus 1.

all parameters are known, so m we have counted and yes mu and lambda are given, so we will get t. experimentally we have measured l corresponding t we are calculating. now, angle of the biprism base angle, this base angle of the biprism phi is equal to t by l we can calculate. again, this you can at least take 3 reading, for different translation and different number of corresponding m and we find out phi, and you take the average of this phi,

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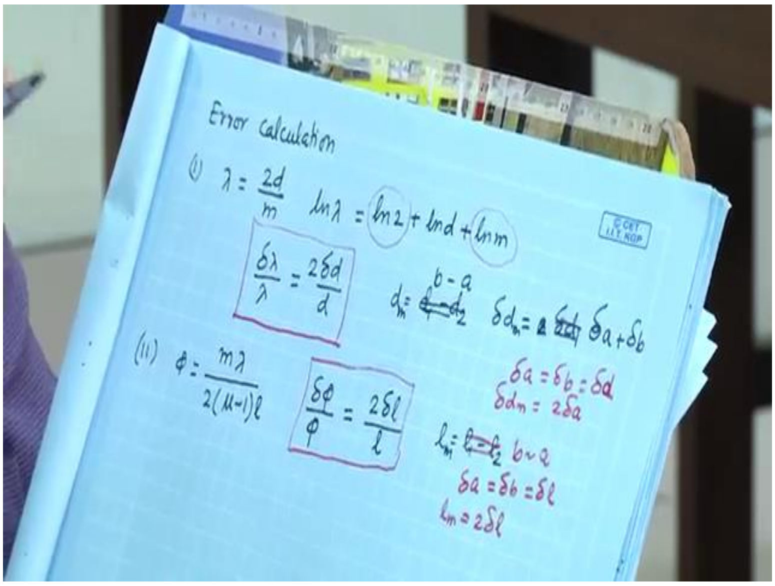

after taking all this data getting the result you have to calculate the error, error calculation one is your calculating the lambda wavelength. which formula we have used? Lambda equal to 2d by m; just let we take log lambda equal to log 2 plus log d plus log m. 2 and m, m is counting there is no possibility of errors, we are, it is not instrument I am counting,

these two have no it will not give any errors. only in instrument is giving this d value. delta, so then take differentiation delta lambda or lambda by lambda equal to delta d by d, delta d by d. here I have written two delta d by d because this d is we are taking difference of two reading that is b minus a, error is delta a delta a plus delta b and delta a equal to delta b equal to we are considering delta d.

this is least count of your micrometre or translational stage whatever scale you are using, that is why it is a this is your formula for error calculation. Similarly, phi equal to m lambda by 2 mu minus 1 l, take log. lambda is applied so there will not be error attached to with it, mu is supplied there will not be error attached to with it, m also you are counting there will be no error attached with it. only it will be attached to with l, delta phi by phi will be delta l by l.

I have written again 2 because this l we are finding out from the difference of the initial position and final position difference of two reading. that is why this will be double 2 delta l. 2 into least count of the translation stage, that is the one has to put because least count I know. this is the formula you will use for the error calculation to find out the base angle of the biprism,

this working principle of this instrument Michelson interferometer and how to take data I tried to explain. If you understand this one, so it is a doing experiment will be very easy and taking data also it is a more reliably you can take the data and you will get better result,

in next class we will demonstrate the experiment in the lab, how to do experiment and take data. in next class I will demonstrate.

Thank you.