Experimental Physics - II
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Lecture - 40
Theory of diffraction

today I will discuss about the diffraction of light.

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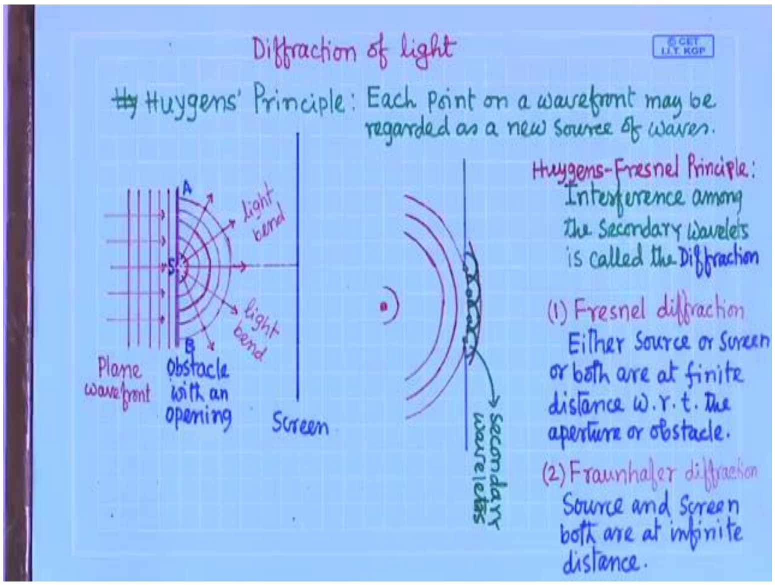

we have seen the interference of light and we have demonstrated the experiment also. we will discuss about the diffraction and then we will demonstrate some experiment in our laboratory. diffraction of light is light bends generally our concept is that light ah pass in a straight line, so that is that is not true all the time because of wave nature of the light it can go in all directions. from a so here have a small hole. it is expected that light will go in a straight line only it will reach here, but it is seen that light also seen in other direction also.

light so whatever light is coming in this direction, so its passing through this is supposed to go in this direction, but it goes to it bends to other direction light bends to other direction also that is what we tell this the because of diffraction. to explain the; to explain this kind of behaviour of light we have to follow the Huygens principle, actually Huygens-Fresnel principle.

Huygens principle is each point on a wave front may be regarded as a new source of waves, so that is the Huygens principle means. This when light so here we have drawn this plane wave, plane wave front means on a plane these ah this phase is same on this plane. phase is changing phase are different from on the different planes, but on a same plane phase are same ok, so that is the wave front, so that that can be plane or that can be spherical.

you tell this plane wave; it is the here its phase is same on this on this surface. then it is the spherical surface. we tell spherical wave, it the wave can be cylindrical wave ok, so cylindrical wave front. here so when so light is falling on this on this say obstacle within with an open, so this one wave front will fall on this. only so this at opening points so this whatever this part of this wave front, so that will act as a secondary that will act as a secondary new source or secondary source you tell, so that will emit light again it will emit spherical waves.

as if this from here this is the new source and it is spreading light in all directions if so, here this here plane wave I have shown here spherical wave I have shown so when reaching this obstacle with an open space. on this wave front so each point will act as a secondary source and they will emit wavelets. this so now so this wave front will be you can if you from this individual wavelets, so you can get a wave front; you can get wave front like this.

as if this wave fronts now from this individual source whatever the wavelets are there, so together ah together it is giving this wave front, so that is wavefronts are moving wavefronts are moving. on each wave front again, they will act as a new source, so they are producing wavelets. whatever the wavelets are produced, so they will give you the again wave front. these are these wave fronts are moving means if you consider that each point on the wavelet or wave front or the new source or secondary source, they are producing wavelets,

from that wavelets as this as a resultant we are getting wave front. vice-versa so this way like moves now that was the Huygens principle, now Huygens-Fresnel principle is tells that interference among the secondary wavelets happens. whatever the secondary wavelets we are getting so they are, so they will interfere, they will interfere and that interference among the secondary wavelets is called the diffraction

diffraction is nothing but the interference, but that among the secondary wavelets. there are two types of diffraction one is the Fresnel diffraction, another is called Fraunhofer diffraction. This classification is based on the based on the distance of source and screen from the diffracting obstacle, if either source or screen or both are at finite distance with respect to the obstacle or aperture, so then we tell there is that the Fresnel type diffraction.

And if source and screen both are at infinite distance, so they will tell this is the Fraunhofer type diffraction, we will discuss mainly Fraunhofer diffraction and demonstrate experiment in the laboratory. just partially I will discuss Fresnel diffraction and we will try to demonstrate one experiment on Fresnel diffraction; so Fraunhofer diffraction.

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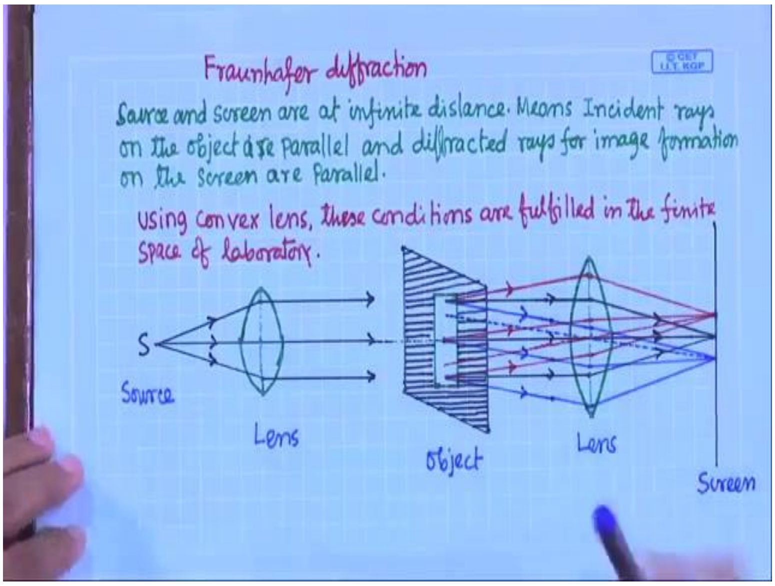

source and screen source and screen are at infinite distance means, incident rays on the object diffracting object are parallel and diffracted rays for image formation on the screen are also parallel, this condition is fulfilled in the laboratory using the convex lens as you know this if source is at a focal point of a lens, then it will produce parallel rays as if as if the source is at infinity ok, so it is falling on an object having the aperture. Now, it will be diffracted it will be diffracted, so these red lines are a set of diffracted rays they are parallel, and these blue lines is another set of diffracted rays which so rays are set different set of parallel rays will get at different diffracting angle, now corresponding image will get ok, when they will so image you will get at infinity, so that image you can get at the focal point of a lens see if you put a lens, so that is what we do we put a lens and screen is put at the focal length of this lens; so we will see the image on the on the screen these are the image for different diffraction at different angles ok, so this is the Fraunhofer diffraction.

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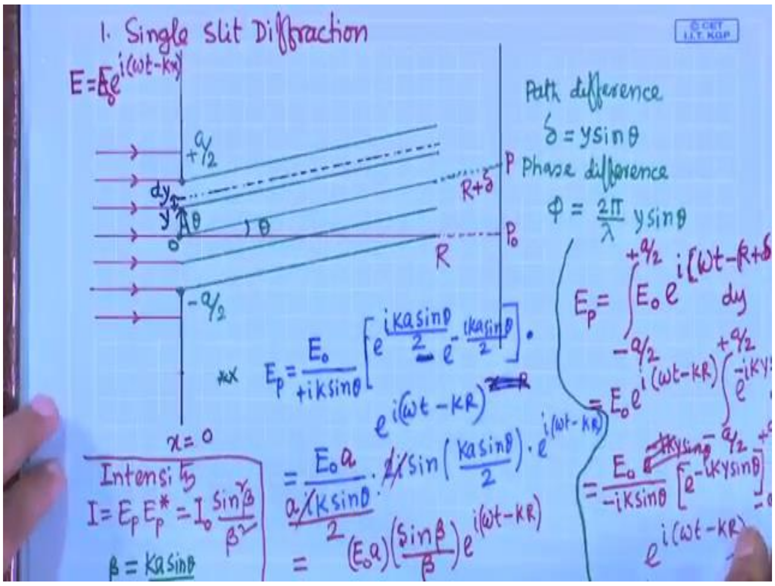

we will discuss this three cases; one is single slit diffraction, second is double slit diffraction and third is end slit diffraction or multi slit diffraction or grating diffraction, single slit diffraction so a sets of parallel rays are coming. this you can express this light electromagnetic wave that is the E equal to E 0 e to the power i omega t minus k. this is the generally this is the wave equation or the expression in ah we use the use the complex notation. this it will be e to the power i theta you know cos theta plus i sin theta. it will have the both components sin component as well as cos component.

if you take the take the real part or imaginary part, so they will represent the ah wave equation. we are familiar with those equation E equal to E 0 sin omega t minus k x or E equal to E 0 cos omega t minus k x plus minus phi if some initial phase is there. that we have written in complex notation, because it is easy to calculate easy to handle this complex notation. now this is a slit single slit means, it has one opening have a particular length that is a. at the centre of this slit if we take its a o if we draw a normal on this on this slit, and play say screen at that is also normal to this line red line what about the normal we are drawing on the slit. this screen we place that is normal to this line ok, so this is the central line.

now so light is falling on the slit parallel, rays are falling on the slit so it's now light will be diffracted at different angle. here we have shown one angle theta, so light is diffracted light so if these distances are o P 0 if it is R. if you draw a this with angle theta diffracted rays, so these distance at point P with these distance will be R plus delta.

what is delta? Delta is path difference, so delta equal to y sin theta what is y. from the middle if you take a point at distance so I so this is the as if this y axis. this y now at y we have taken a small width dy small length you can say dy at y at y if from this y if light goes if light goes what will be the path of this of this light? So that will be definitely this path length will be different than this R ok, so this path length is one can find out.

if you just this if you just from y if you just draw a normal on this, on this on this ray, so these two are parallel. here if you put normal, so this side this distance of this length of this both rays will be same. these rays will have the additional path, so that is this path. if this is the angle theta, so this angle also will be theta if it is y, so this additional path will be y sin theta; it is the opposite to the theta, so y sin theta

wave this these are the set of parallel rays; parallel rays there are there are path difference, there are path difference among this rays if you take this one is the so this is the minimum distance of the screen that is R with respect to that you can find out the you can find out the path ah path length of any rays, path length of any rays. for a particular theta and from this distance y, so it will be additional path; so, y sin theta corresponding phase difference 2 pi by lambda y sin theta,

so, at P what will be the amplitude or what will be the not amplitude, what will be the wave here, when wave from this slit two it is reaching on the screen, what will be the; what will be the wave there. wave is represented by this that E equal to E 0. this E 0 is amplitude, and this is the e to the power i sin omega t minus k x. if so this if I take this is the at this at the at this side, so all are having the same displacement E or the same strength of this amplitude

now for dy or one can see tell that this these are for this amplitude of our per unit lengths. for dy length, so I can multiply dy with this ok; so, E 0 e to the power i omega t minus R minus R plus del actually at P we are considering. there that minus k x, so in this case x is R plus delta, so minus R plus delta into k, so dy you can say that this for dy d for this small element. what will be the elliptic component or displacement E P, at P so we can write this and then now we can integrate from if it is centre is 0, so minus a by 2 to plus a by 2.

if we integrate, then we will if we proceed integration over the y; so ultimately you are getting if I from here if I proceed so all step I have done, so ultimately you are getting E P equal to E 0 by i k sin theta e to the power i k a sin theta by 2 minus e to the power minus i k a sin theta by 2 into this e to the power i omega t minus k R. as if this was the original one original one waveform ok, it is a form of plane wave ah.

here we are getting this e to the power i theta minus e to the power minus i theta, so that gives 2 i sin term, 2 i sin term theta. these 2 I and here i is there, so i can put these two here by 2; I can multiply with a and a, so it will be equivalent to this term. it is I am getting E P equal to E 0 a, sin beta by beta e to the power i omega t minus k R. here you see here at this point x equal to 0 and this here if you go this direction x direction, say x equal to here this is R and here this length it will be x equal to R plus del, so that is what we have used that is what we have used and we have integrated and we are getting the amplitude, here you can notice we are getting amplitude E 0 a.

whatever E 0 whatever E 0 here, so this amplitude so this as if this amplitude is amplitude of each amplitude of each waves, wavelets. there are many wavelets on this lens this E 0 one can consider that the amplitude per unit length, ok; so for that is why for dy, so amplitude wave E 0 dy, Now, after integration we are getting for amplitude for whole lengths, so that is a. amplitude is E 0 a, so that is why here E 0 a that is the amplitude and with amplitude another term is come, sin beta y beta

ultimately this is the amplitude that depends on the beta is nothing, but the beta is k a sin theta by 2, k a sin theta by 2; so, k is 2 pi by lambda, a is the slit width and this theta. this term will change; this term will change with the beta that means, with the theta for a particular slits slit width and for a particular wavelength. if this is the E P amplitude here, so what will be the intensity that is the amplitude square.

for complex number so E P E P dash conjugate of complex number, so that e to the power i that term will go, start minus i will give you will get I equal to I 0 sin square theta by beta square, so I 0 is nothing but E 0 square a square ok, so that is the intensity for due to the single slit due to the single slit the intensity will vary as a function of theta as a function of theta or as a function of beta huh. on the screen we will see the variation of the intensity. how it varies; how it varies the intensity, so that we will see.

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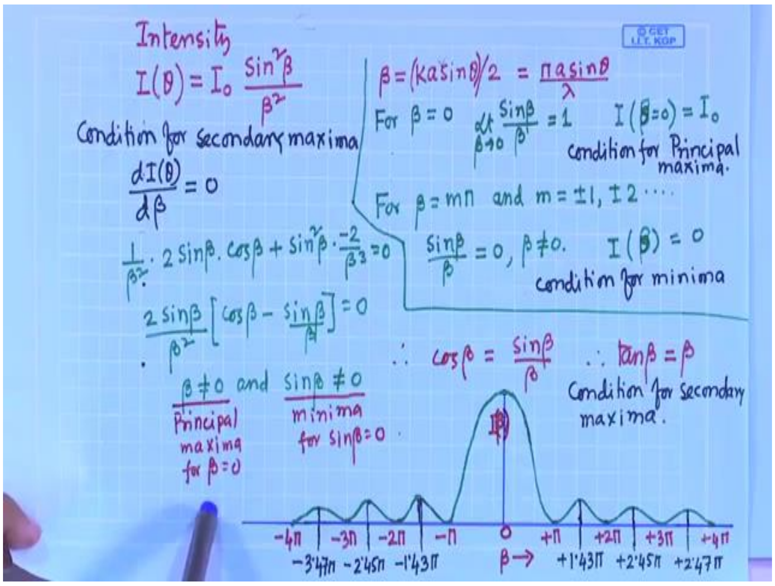

we got the expression intensity expression that that I theta or I beta equal to I 0 sin square theta beta by beta square. you can see this beta equal to k a sin theta by 2, so 2 pi by lambda, so these 2 2 will go pi a sin theta by lambda. now for beta equal to 0. sin beta by beta one has to take limit beta tends to 0, then it will go 1, otherwise it will run defined.

for beta equal to 0 means theta equal to 0, and for that we are getting this I beta equal to 0 or theta equal to 0 equal to I 0, so that will be the maximum intensity, because with that the sin beta by beta. another factor is there that is always less than 1. these the conditions for principal maxima we tell this the principal maximum, we see for theta equal to 0 or beta equal to 0. Now, for beta equal to m pi where m equal to plus minus 1, plus minus 2, etcetera; so, sin beta by beta equal to 0. If beta equal to m pi, so sin pi 2 pi, 3 pi these are 0, but beta is not equal to 0 condition is beta is not equal to 0

then also we get I beta equal to 0 this the condition so these the condition for minima diffraction minima. these are diffraction principle maxima, diffraction minima if I draw the I beta I as a function of beta as a, so I will get a beta equal to 0 will get a principle maximum as I told, I will get a principle maxima. Then we will get minima, where will get minima plus pi and first minima will be m equal to 1 plus minus 1, so at pi plus pi and minus pi, so will get minima.

Then we will get minimum plus 2 pi, plus 3 pi, minus 2 pi, minus three pi. if you have this minima, so there must be maxima in between so they are called diffraction that are called the secondary maxima, that are called diffraction secondary maxima, so these are the secondary maxima.

when will get the secondary maxima, when we will get the secondary maxima, so to find out the secondary maxima, so if you just differentiate it dI beta by d beta equal to 0 put 0? for which value of beta you will get the 0, so means for which you will get the beta value for which you will I beta will be maximum. I am writing I beta or I theta, but both are same as long as k and lambda is constant fixed for a particular experiment.

from here it we are getting this condition. beta is not equal to 0, sin beta is not equal to 0, then this part bracket this will be 0. this is not equal to 0, because when this is 0 said that that gives that principle maxima; when this is 0, it gives the minima. for this present case these are not 0, then whatever this part will be 0, so you will get tan beta by beta this is the condition per secondary maxima this secondary maxima you can find out.

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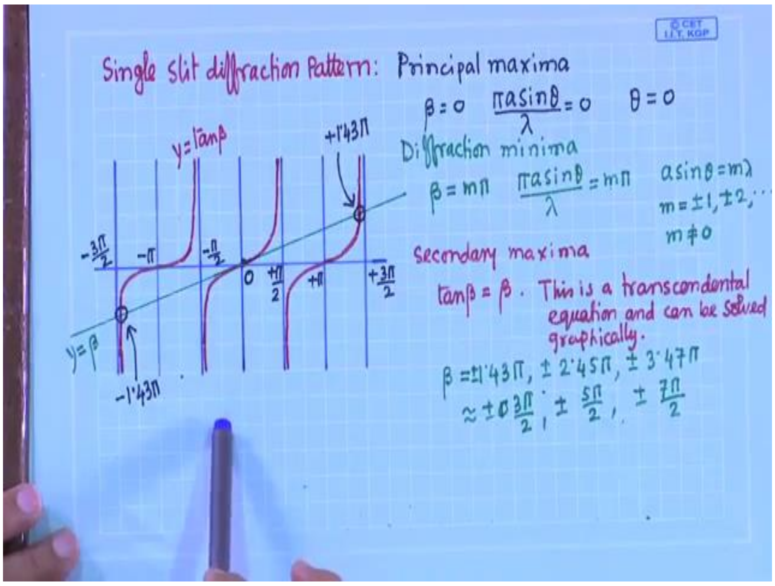

in graphical method, so in graphical method so you plot y equal to tan beta, y equal to tan beta and y equal to beta. whatever the intersection of these two curve that will be the solution of this tan beta equal to beta, And this solution is beta equal to it is not exactly 3 pi by 2, it is not exactly 3 pi by 2; this is its a 0 is the intersection that at 0, but next is you see its the its the close to 3 pi by 2 close to 3 pi by 2, then 5 pi by 2. it is a close y is not exactly, so these value is 1.435

Next one not 5 pi by 2, so it is a 1.45 pi or 1.46 pi, so next 1.475 pi not 1; 2.46, 3.47 pi instead of 7 pi by 2 3.47 these are the so what we got we got the condition for the principle maxima, so that is beta equal to 0, so theta equal to 0. Then diffraction minima beta equal to m pi, so corresponding we are getting a sin theta equal to m lambda, m equal to plus minus 1, plus minus 2, but m is not equal to 0, so there is the condition for diffraction minima.

And secondary maxima, so this is the condition and graphically one can find out, now beta equal to plus minus 1.43 pi, plus minus 2.45 pi, plus minus 3.47 pi. It is the approximately plus minus 3 pi by 2, 5 pi by 2 and 7 pi by 2 ok, so that is why we have so for sing single slit diffraction we will get this type of diffraction pattern, in next class I will discuss double slit and grating, so let me stop here.

Thank you.