Experimental Physics - II

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Lecture - 31
Interference phenomena

we will demonstrate some experiment on interference. to understand those experiments, some basic concept of interference of light or waves should be clear. I will take few lectures on the basic concept of interference of light

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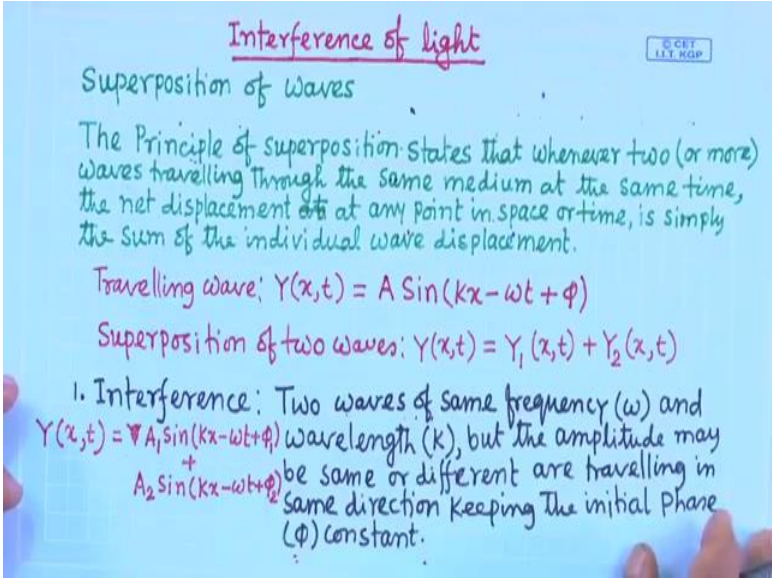

we know that superposition of waves, what is the principle of superposition of waves, so that is very important to see some phenomena. principle of superposition states that whenever two or more waves travelling through the same medium at the same time, the net displacement at any point in space of time, is simply the sum of the individual wave displacement.

they do not disturb each other just superposition principle of superposition states that if two or more waves if they super impose, so just simply it will be the summation of the two individual wave displacement. wave travelling wave we express this Y as a function of x, t. when waves is travelling, so these displacement is the if it is travelling through the medium.

this is a displacement of the particle as a function of x and t, so that displacement is expressed as a A sin k x minus omega t plus phi. A is the amplitude, and k is the wave vector 2 pi by lambda. at it is a function of x. this x is there, and minus omega t omega is the angular velocity 2 pi by t plus phi; phi is the initial phase it is a function of x and t.

there are two periodicity one is in space, so that k is 2 pi by lambda. lambda is the wave lengths, so that is the periodicity in the space. And omega is 2 pi by T capital T time period, so periodicity in time that is T capital T time period superposition of two travelling waves is if these two wave displacement is Y 1 and Y 2, so they are resultant of this superposition that will be if it is expressed as a Y. Y as a function of x t will be equal to Y 1 plus Y 2

depending on the; depending on the direction of the two waves as well as their periodicity time period or wavelength ok, depending on that there are different phenomena we see. mainly three phenomena we see distinctly due to super position. one of them is the interference, interference effect we see. When we see, the two waves of same frequency and wavelength, but the amplitude maybe same or different a travelling in same direction, keeping the initial phase phi constant

If the two waves obey this condition, then we see the interference effect the two waves following this condition their frequency and wavelength are same. k x omega t k x omega t, they are travelling same direction, so both are having negative sign. They are they have constant phase difference Here it is a phi 1, here it is a phi 2, they are they have constant phase, initial phase ok.

their amplitude may be same or may be different I have taken here A 1, A 2. this resultant Y whatever displacement we will get, so in that displacement we will see the effect interference effect ok, so that elaborately we will discuss this part.

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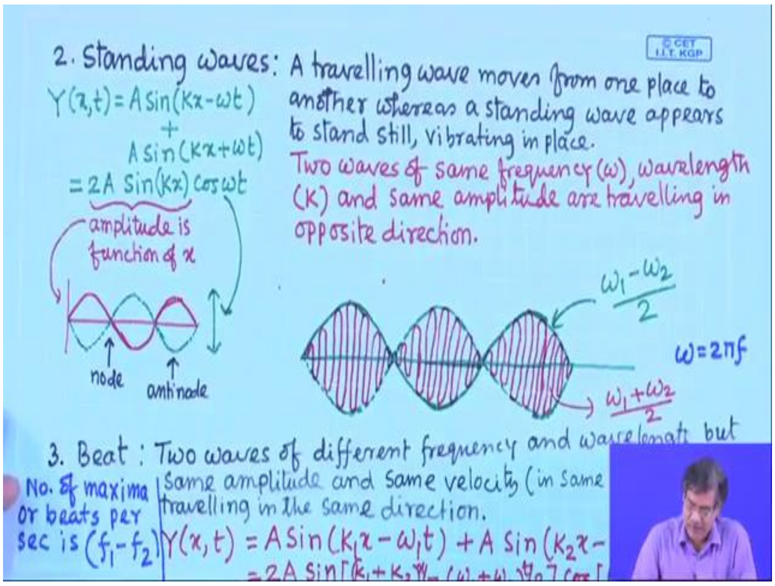

But before that what are the two phenomena we see from this superposition of waves, another phenomena that we see that is the standing wave formation, standing wave formation. When we see, a travelling wave moves from one place to another, whereas a standing wave appears to stand still vibrating in place there is a standing wave and travelling wave

Now, two waves of same frequency wavelength and of same amplitude are travelling in opposite direction. in case of interference, they are travelling the same direction, now in this case they are travelling opposite direction. In case of interference, they are the two that amplitude of these two waves maybe same or maybe they are; they are; they are different, but they are closely same approximately they are equal, but may not be equal ok.

but in this case, strictly it should be equal amplitude should be equal and it will travel in opposite direction in that case due to the superposition of these two waves this type of two waves will form the standing waves. in this case, that Y as a function of x resultant one after superposition, so that will be equal to A sin k x minus omega t plus A sin k x plus omega t. they are moving in opposite direction, so that is why sign are in case of interference their sign was same, now sign are different

from here sin A plus sin B, so 2 sin A plus B by 2 cos A minus B by 2. this type of relation trigonometric relation you know. from there you will get 2 A sin kx cos omega t.

here what we are seeing, so this time part and this space part, so now they are separated these two terms are separated here it is it was this and now they are separated.

here we one can think that this part is the, so A sin omega t by A cos omega t that generally we this is the oscillation this equation of oscillation something is oscillating. here from here you can tell that, so it is not travelling wave anymore it is just some oscillation with this amplitude with this amplitude. it is the oscillating in same place it is oscillating.

But what is oscillating here, so this part this part it is the oscillating with time in same place means not same place, this pattern this amplitude, this part is amplitude, but this amplitude is its form is like this, its form is like this sin form sin k x sin form this form this is the amplitude as a whole, now this part is oscillating; this part is oscillating when it is oscillating, so it looks like this.

as if, so this point never will move will oscillate and this point always it will oscillate with the maximum amplitude maximum displacement this is called this where this there will not be any movement, so that point is called the nodes and where maximum displacement, so that part is called antinode. these are static, this is the characteristics of the standing wave we see the node and antinode this is the standing wave. And then third one is beat also we are quite familiar with this so give the superposition of two waves.

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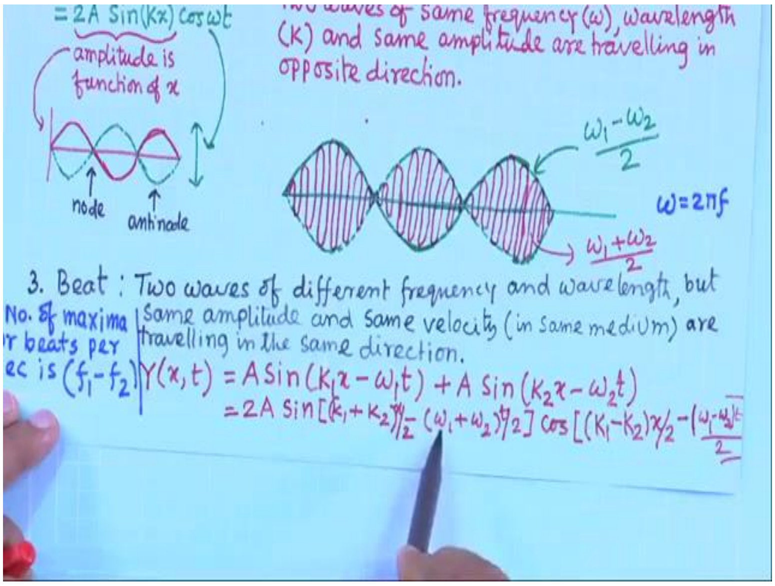

we get this another phenomena, so that is called beat. what is so when we get two waves of different frequency and wavelength, but same amplitude and same velocity in same medium so same velocity, because they are in same medium or travelling in the same direction. in this case other two case their frequency, wavelength was same, but in this case frequency and wavelength are different for two waves and other part is same, other part is same they are amplitude are same and they are travelling in same direction.

in case of only standing wave, they are travelling in the opposite direction, the other two cases travelling in same direction due to superposition of these two, these types of two waves following this condition. we will get the resultant y, so that is so A sin Y 1 plus Y 2 a sin k 1 x minus omega 1 x plus a sin k 2 x minus omega 2 t so here so this phase initial phase for just I have taken a 0, ok.

if you in same direction, so sin also same. you will get 2 A sin k 1 plus k 2 x by 2 minus omega 1 plus omega 2 t by 2 ok, this is the sin part and cos part k 1 minus k 2 x by 2 minus omega 1 minus omega 2 t by 2 here actually if you look at the so when we describe wave you know, at a time we do not look at both x and t, we generally look for a particular x what is happening with t and then for a particular t what is happening with x. in both cases you will see this wave this pattern ok, oscillating pattern.

here also if we look at the frequency part, if we look at the frequency part, so here this 2 A is now x and t, they are not separated they are not separated see in both term it is there. here you are seeing that frequency, but there are two resultant frequency omega 1 plus omega 2 by 2 as if this average frequency of these two waves and different frequency of the two waves, there is the difference frequency of the two waves.

this is this frequency is difference means lower frequency ok and this is the higher frequency. if you plot them if you plot them or you can consider that so with respect to space and time, so this part with higher frequency is oscillating like this ok, it is oscillating like this. Its amplitude is not constant, amplitude is not constant that amplitude that variation of this amplitude ok, it depends on the other term it depends on another term, so that variation of amplitude here it is following this another periodicity another periodicity, so that is omega 1 minus omega 2 by 2.

here you are getting the two frequency, so one is this the oscillating with this higher frequency and its amplitude is varying there is a envelop ok, so that is the frequency of this envelop is omega 1 minus omega 2 divide by 2, so that is this part. from here you are seeing this amplitude is higher and then very small, amplitude is higher, then very small or 0 a higher or so. As if in case of sound ok, when this kind of population of waves, so sudden and so periodically, you will see you will hear the higher sound or high intensity.

Square of the amplitude is the intensity basically, so that is this, this is called bits. with a period, we are getting higher intensity or higher sound. if you count them if you count them, so that is the it is a number of this bits per second. bits we tell bits per second, so that is it is a omega that in terms of frequency, so that is f 1 minus f 2 difference of the frequency of the two waves; so that is the number of bits basically.

since omega equal to 2 pi f; so, omega 1 f 1, omega 2 f 2. difference of this frequency is called the beat. you can count them; you can count them from here itself. this is the phenomena it is called bit and so this due to superposition of two or more waves under some certain condition, we get very prominent phenomena. this phenomena just these 3 phenomena this we are quite familiar and this 3 phenomena I try to explain you. now, I will since we are interested in the interference, so I will discuss about the interference effect more. let us go back to the interference, let us go back to the interference.

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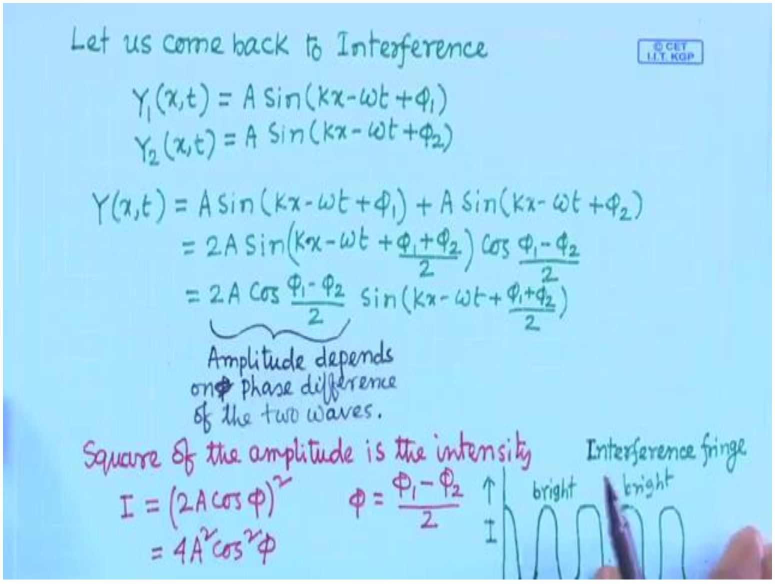

there what we have seen Y 1 equal to A sin k x minus omega t plus phi 1; Y 2 A sin k x minus omega t plus phi 2. superposition of these two travelling wave will give us, give us 2 A sin k x minus omega t plus phi 1 plus phi 2 by 2, this sin a sin a plus sin b ok, so 2 sin a plus b by 2 cos a minus b by 2. from there we are getting two term, one is this term, and another is this term.

2 A this is the cos phi 1 minus phi 2 by 2, is there is no x and t term here. this we can take as amplitude sin k x minus omega t plus say phi ok, phi 1 plus phi 2 by 2, so in so this is a one phase. this again it is the, it is a travelling wave this is a travelling wave, but its amplitude is this. its amplitude you can see due to superposition like this, we are getting amplitude part the amplitude depends on the; depends on the phase difference of the two waves. amplitude is very sensitive to the phase difference of the two waves, so this the very interesting part.

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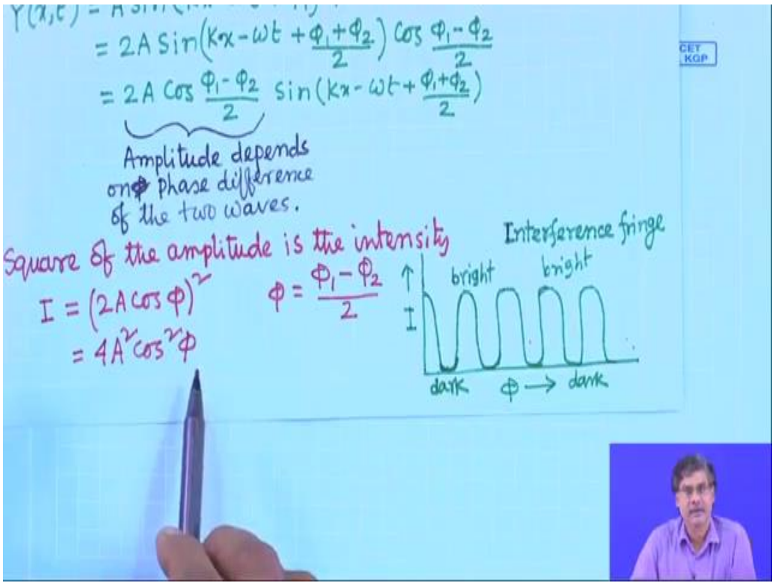

And we get the interference sequence because of this term, if this is the amplitude part, so we will get the intensity, so that is square of the amplitude, so you can write I equal to 2 A cos phi. here in general I have written 2 A cos phi ok, so phi is your phi 1 minus phi 2 by 2, so just we are considering this is the phi, this is the phase difference between two waves whatever we have taken or it is a half of that but in general so we have taken that is phi, phase difference between 2 waves.

square of this amplitude is the intensity, so that is 4 A square cos square phi. so, intensity of this; intensity of this one is square amplitude squared, other one amplitude A; they can be defined, or they can be same we have taken same, so just for simplicity ok, which one can take different also. if you add them individually at their intensity individually. it will be 2 A square whereas, here due to superposition of these two one ok, is the amplitude superposition ok; it is not intensity. their phase part is very important.

intensity is 4 A square cos square phi. variation of intensity due to superposition of these types of wave whatever we have mentioned following that condition. we will get the variation of intensity as a function of phi, so it will follow the cos square phi, Variation of intensity I, so maximum will be when phi 0, so cos square phi 1. 4 A square so maximum intensity will be 4 A square, then minimum when phi is 90 degree see it is 0, ok.

it is 0, then again when it is phi phase is phi phase difference. then you will get minus 1 square of minus 1 is plus 1. whatever the cos function, so its side, both side plus minus now in this case it is a in one side. variation of intensity will be like this, they are equi-spaced. 0 intensity, maximum intensity. this kind of pattern will see and that is called interference fringe. we will get b dark, b dark this kind of variation of intensity. If it is light ok, for other wave also one can see if it is light, so then you will see the variation of intensity of light visible light we can observe it.

here important fact, what is the important fact, it depends on phase, and yes, it depends on phase. And these phase difference should be constant, all the time it should be constant. this phi should not be this phi should not be function of time or space.

it is for a particular time and for a particular space or for, so whatever the whatever the so phase difference wherever at a particular time at a particular space, this whatever the phase difference between these two waves ok, it will remain constant, so that phase may vary not at the same place like at the starting point ok, whatever the phase between these two, so all the time at the study at that place, these phase difference will remain constant.

Now, when they are moving, so in another point when they are reaching, so their phase their phase difference may be different ok, but at that point it will be independent time independent of time all the time, it will remain constant. at different phase at different place ok, when these two waves will reach, the phase difference between these two waves that can be different from the another, another point another space another place ok, but at that place the phase difference will be independent of time if so.

If that is the necessary condition to see the; to see this type of contrast of brightness to see the, so that is a called interference fringe to see the interference fringe ok, so this condition is very much necessary. it is an independent of time, it may vary with phase to phase ok, but with time in those places, it will remain constant

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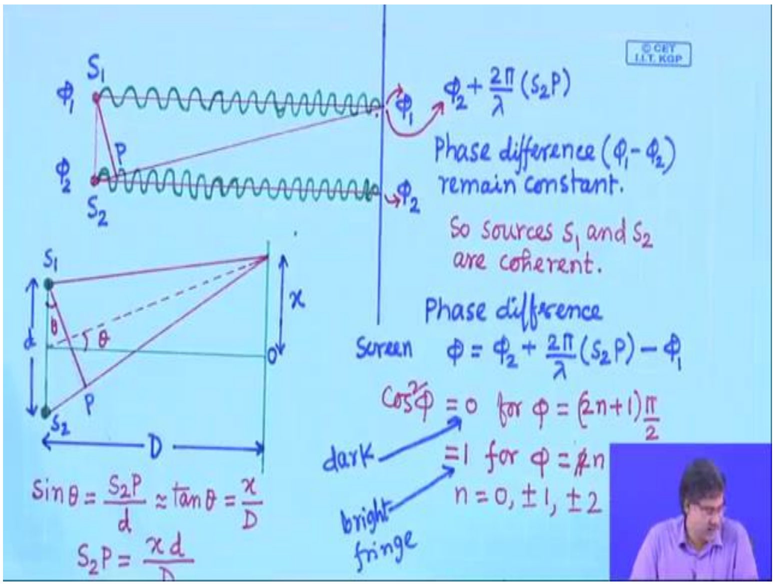

that I, I try to explain here. if you see that two source, so two waves if generating two waves ok, these two waves. they are travelling wave, they have same time period and same space period means wavelength and frequency are same for these two waves amplitude also I have taken same, but it could be slightly different. And their phase here they are phase here. this initial phase of this one is say phi 1 and at this point it is phi 2 ok.

if you so this source will emit light in different direction; in different direction, so wherever the direction is does not matter, but their frequency and wavelength will remain same. And at this point here this its phase, it will remain same for all the time that will be phi 1 ok and here phi 2 two waves are coming this way. when they will reach here, so this is a screen when they will reach here one is here another here. here also their phase its phase, here this is a phi 1 whatever the phase was here, so here it will remain phi 1 and here it will remain this phase phi 2.

these two are parallel same frequency and same wavelength, so their phase; their phase at all this is the it is the wave front; wave front the phase remain constant or remains same on the wave front here what will happen so one light is this, but these two will not interfere because there is no superposition of this two. Now, this slide this wave and another wave I have not drawn this way, but you can consider another wave from the source reaching here, at this point there will be superposition of these two.

they are moving in same direction you can say this. in positive direction say not in opposite direction. here the phase of this one is phi 1 and phase of this one here it was phi 2. Now, here there will be this phi 2 will be phi 2 plus 2 pi by lambda S 2 p. What is S 2 p? S 2 p. this this one is travelling additional path compared to this one

when they are travelling the same path, so they are phase remain intact so but this part if you just draw a normal on it, so this site their path is same of these two waves. But here this will be the additional this S 2 P will be additional path in this way. phase for this path will be 2 pi by lambda into this path it is here when it will be. whatever phi 2 that is there and due additional path. this term will be added.

here at this point this phase difference between these two is not phi 1 minus phi 2, it is the it is different one or phi 2 minus phi 1, it is not that difference of the initial one. additional phase difference is coming now phase difference are different. if you consider the different point of superposition, so this phase difference will be different. But at this point all the time phase remain phase difference remain constant ok, although phase difference is different compared to here

But here another place at that place, the phase difference will remain will be independent of time, it will be it will remain constant. phase difference is varying in space, but at each place it will remain constant for all the time ok, so that is the condition if two source follows these two waves follows this condition. then we tell these two source are coherent.

that is the definition of coherent the phase difference remains constant; its phase difference remains constant between these two waves. it is not that the same phase here it will remain constant here. But in other place; in other place, phase difference remain constant between these two at a function of time But it varies point to point it varies and that variation will giving space the variation of brightness of the light variation of brightness of light on space, so that is nothing but the and depth pattern depth pattern is independent, independent of time that is called; that is called the interference fringe.

And thus, interference fringe is form in a space and that is independent of time ok, that you get only when these two source are coherent, and this is the condition of coherent whatever so far, we I have discussed. Now, these phase difference when these two so these two coherent source, so from there these two waves meet here. always to see the brightness degree of brightness, you have to find out the phase difference degree of brightness will depend on the phase difference or path difference.

phase difference here is phi equal to so this phi 2 plus 2 pi by lambda S 2 P minus phi 1 cos square phi so here this is the phi, so cos square phi 4 a square four a square cos square phi. now whether cos square phi will be 0 or cos square phi will be 1. when cos square phi will be 0, then due to this phase difference at this point will get dark extreme intensity that is dark and other case one extreme intensity will get that is b ok, so when 1. when cos term will be 0, so when phi is 2 n plus 1 pi by 2 ok.

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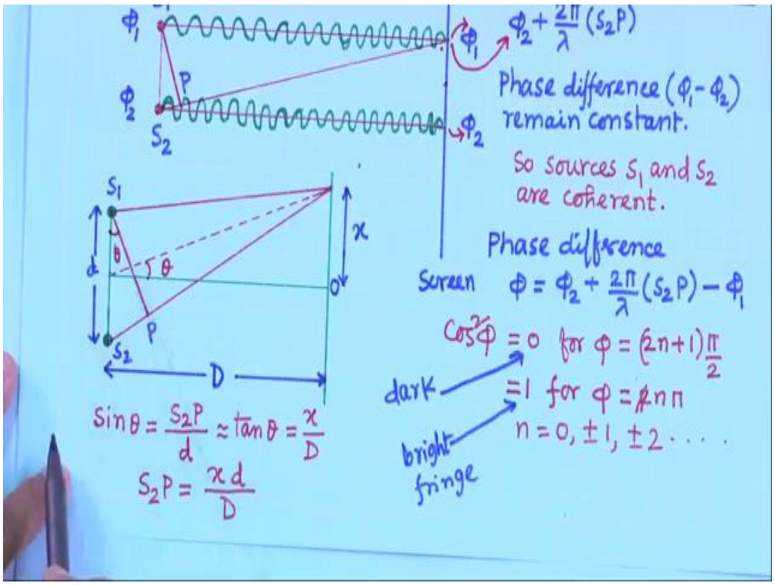

Phase difference is odd multiple of odd multiple of pi by 2 and it is the even multiple of pi not even multiple, I think odd and even both ok, n equal to 0 plus minus 1 plus minus 2 for both cases this for this condition, we will get dark and for this condition we will get b this phase will depend on this position at this if wave comes here or these two waves in middle point so path difference or phase difference will be same, path difference or phase difference will be same.

here we will get the; we will get the phi equal to 0 path difference phase difference. phi equal to 0 mean that is the one maximum intensity. then it will vary following this you know. we will get dark b, dark b, this, this, this side and from symmetry you will get from in other side also. these are called the order of the interference. you will get upside as well as downside also this path difference is to p, one can calculate one can calculate this very important. just as I told that just draw a normal. if this angle, so here if this angle is theta

here we can consider, so in so from this middle point of this source two source. if you draw a line, so these two angles will be same. approximately for you can take. this from the canter point as I told here where from middle point, so if the distance is x, so this x by the distance of the source and the screen if it is capital D. x by D that is the tan theta and sin theta will be S 2 P by this ok, sin theta will be if this is theta this is normal. S 2 P by small d. this small d is distance between two source.

now for small theta approximately you can write this sin theta that is this is the approximation we have to taken. this will be equal to these. S 2 P will be x d capital D. this path difference will depend on the from the center point of the screen what is the at which distance you are taking that x and this d is the distance between two coherent source and capital D is the distance between the source and the screen ok.

these are the condition these are the path difference. Now, so path difference actually will depend on x, if these two other remain constant, so that is why on this screen this x are varying. we will get, so this phi one phi two remain constant all the time. this b and dark that will depend on this S 2 P means on this x. on the screen we will see the variation of the intensity. dark b dark b pattern we will get. these are very useful and derivation for the interference in many places we will use this one I will stop here. I will continue in next class.

Thank you.