Engineering Physics 1
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Module-03
Lecture-04
Interference by Division of Wave front

Interference by Division of Wavefront by M K Srivastav, Department of physics, Indian Institute of Technology, Roorkee, Uttarkhand. In the last three lectures on interference, we have seen that the principle of superposition leads to an interference pattern, when we consider light of the same frequency.

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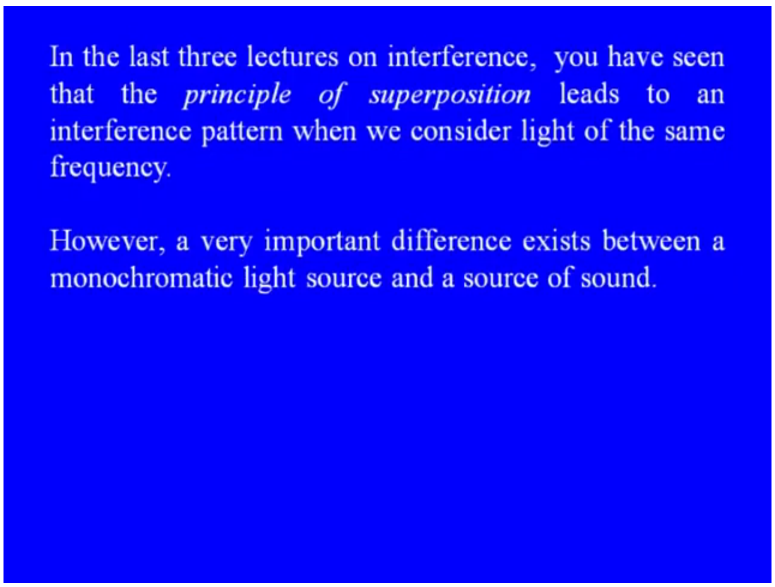

However, a very important difference exists between monochromatic light source and a source of sound.

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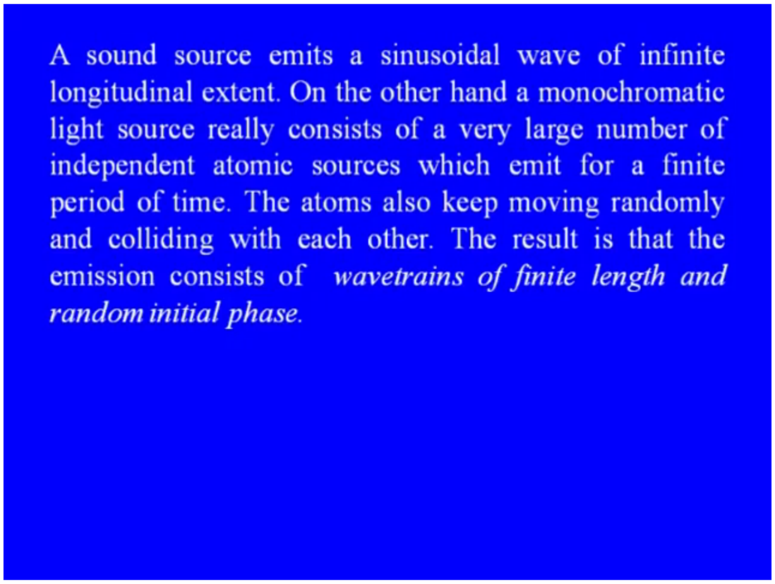

The sound source emits a sinusoidal wave of infinite longitudinal extent. On the other hand, the monochromatic light source really consists of a very large number of independent atomic sources which emit for a finite period of time. The atoms also keep moving randomly and colliding with each other. The result is that the emission consists of wavetrains of finite length and random initial phase.

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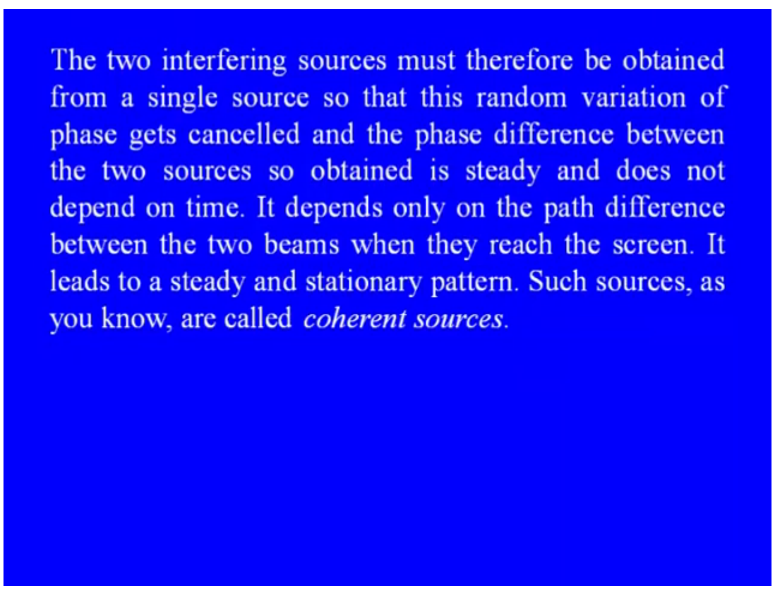

Two interfering sources must therefore be obtained from a single source so that this random variation of phase gets cancelled. And the phase difference between the two sources so obtained is steady and does not depend on time. It depends only on the path difference between the two beams when there is the screen where the pattern is observed. It leads to a steady and stationary pattern. Such sources that you know are called coherent sources.

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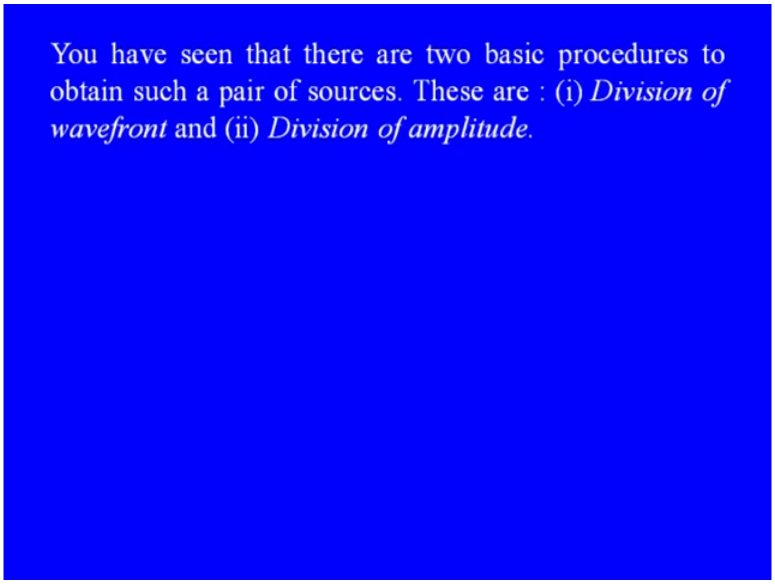

You have seen that there are two basic procedures to obtain such a pair of sources. These are: Division of wavefront and division of amplitude.

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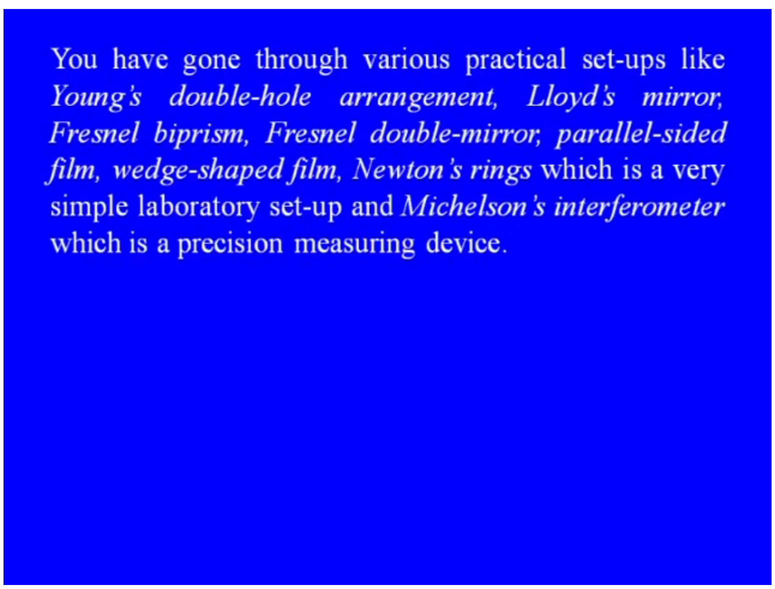

We have gone through various practical setups like Young's double hole arrangement, Lloyd’s mirror, Fresnel Biprism, Fresnel double mirror, parallel sided film, wedge shaped film, Newton's rings which is a very simple laboratory setup and Michelson’s interferometer which is a precision measuring device.

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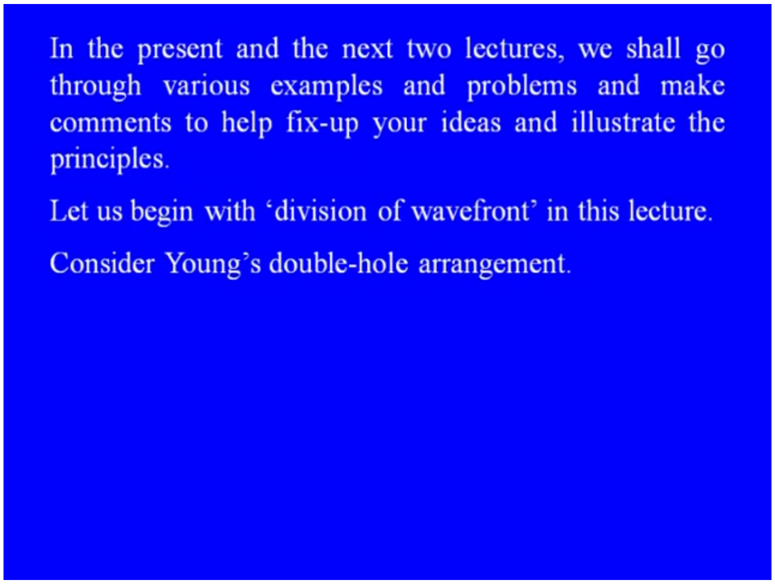

In the present and the next two lectures we shall go through various examples and problems and make comments to help fix up your ideas and illustrate the principles. Let us begin with division of wavefront in this lecture. Consider Young's double-hole arrangement.

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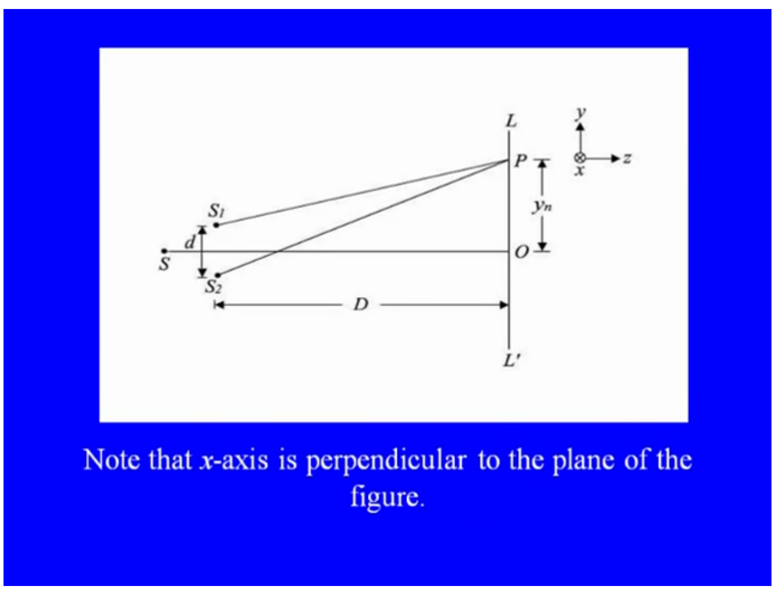

S1and S2 are the two sources which are illuminated by the basic source S. They form a coherent pair; the interference is observed on the screen. We shall consider really how the density varies as we move along the screen parallel the line of sources.

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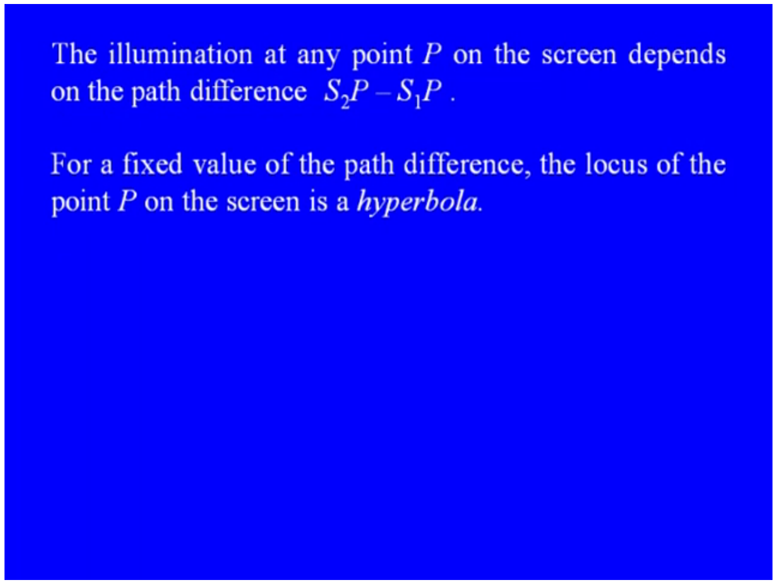

The illumination at any point P depends on the path difference S2P - S1P of the distances from the sources S1 and S2. For a fixed value of the path difference the locus of the point P on the screen is a hyperbola. You see, hyperbola is the locus of a point the difference of who the distances from two fixed points is fixed. Those two fixed points here are S1 and S2. And the fixed difference is the path difference.

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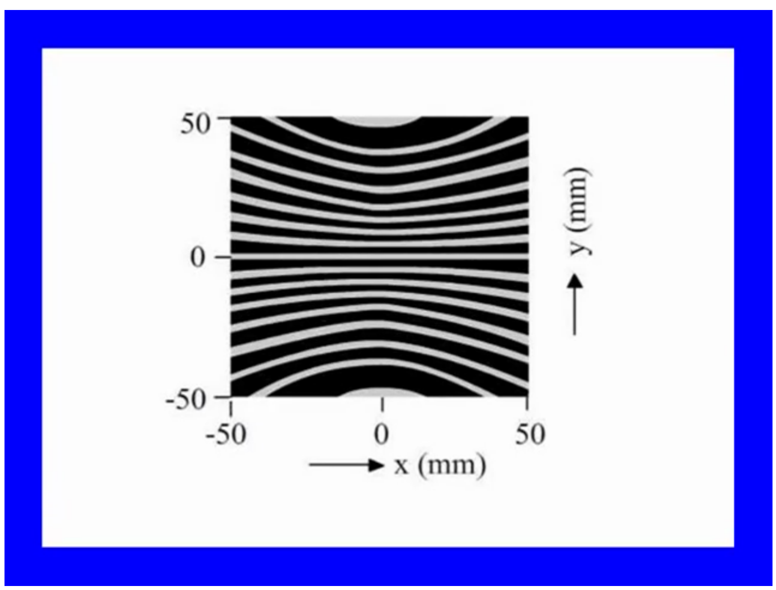

This gives you an idea of the shape of the fringes, hyperbolic for a small values of x compared to the distance D of the screen;

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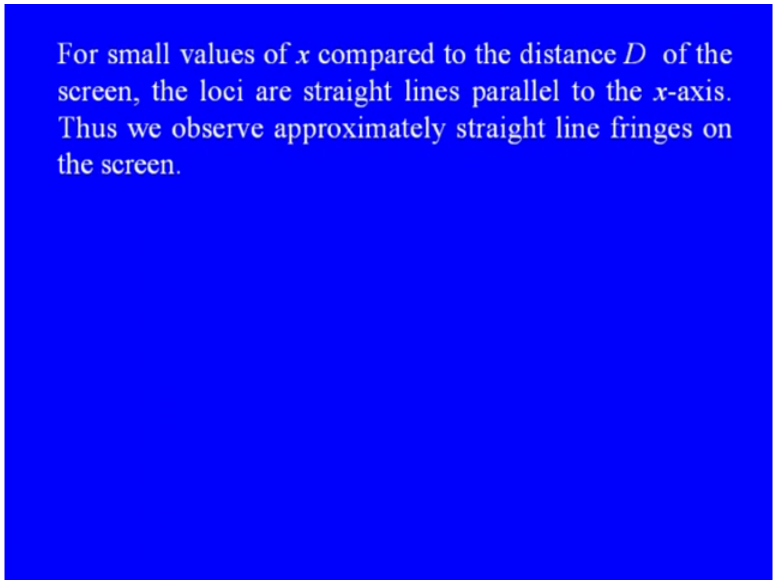

From the line of sources, the lower edge state lines parallel to the x axis that we observed approximately state line fringes on the screen.

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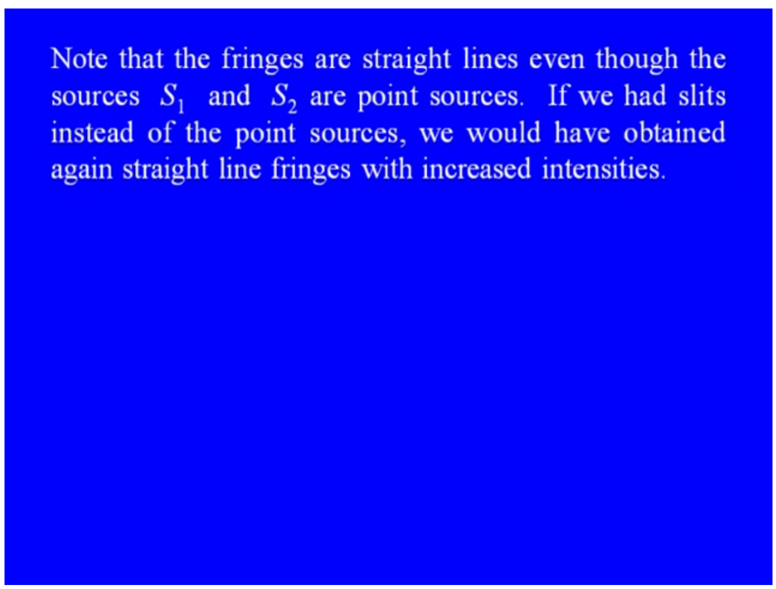

Note that the fringes are the state lines. Even though the sources S1 and S2 are point sources, if we had instant slips instead of these point sources, we would have obtained again the state line fringes naturally with increased intensities.

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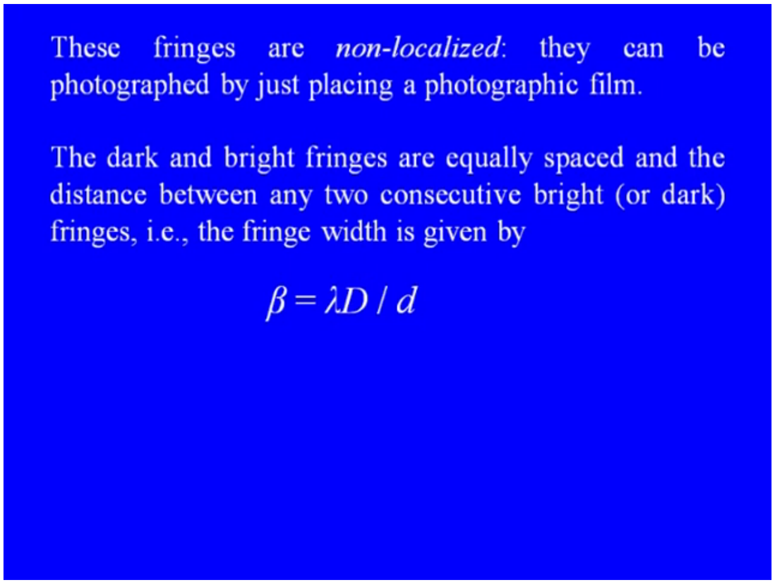

Now these fringes are non-localized. They can be photographed by just placing the photographic film where we have got the screen the dark and bright fringes are you clearly spaced this is the basic characteristic of any interference pattern. And the distance between any two consecutive bright or consecutive dark fringes, that is the fringe width is given by lambda capital D upon small d lambda is the wavelength of the light capital D, the distance of the screen from the line of sources and small d the distance between the pair of sources.

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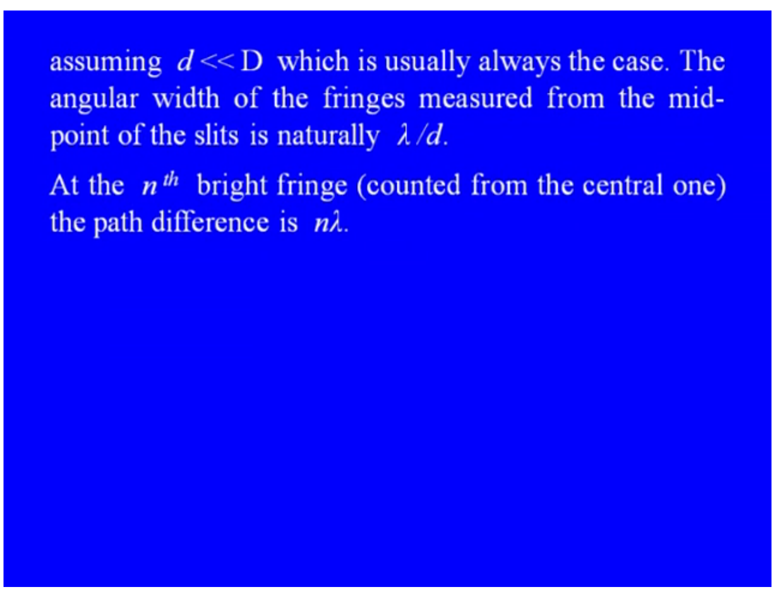

We have assumed in this derivation that is small d is very, very small compared to the capital D which is usually always the case. If we are interested in the angular width then the angular width of the fringes measured from the midpoint of the slits is naturally given by lambda upon small d.

And the nth bright fringe counted from the central one where the path difference is zero, the path difference for the nth bright fringe is n lambda.

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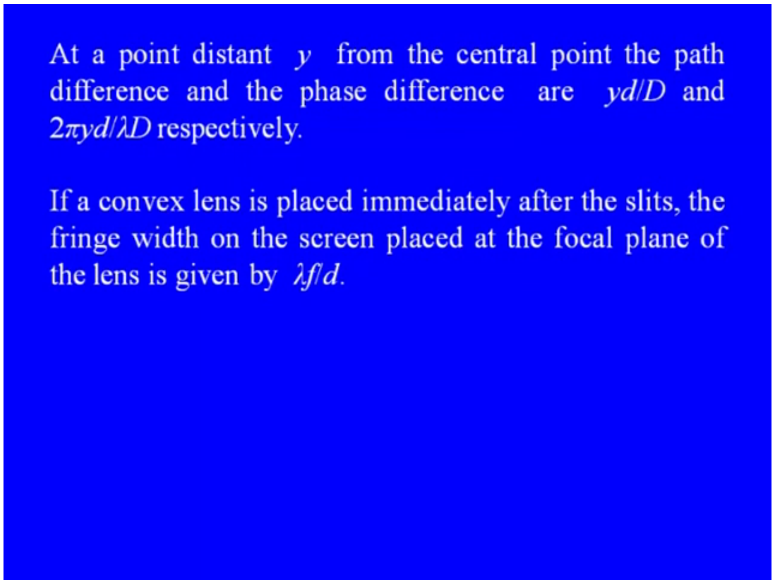

At a point distant y from the central point that is the central 0 is the order of fringe, the path difference and the phase difference are y small d upon capital D and the phase difference 2 pi by lambda times y small d upon capital D. If a convex lens is placed immediately after the slits, the fringe width on the screen placed at the focal plane of the lens is given by; lambda f on d, d has been replaced by the focal length.

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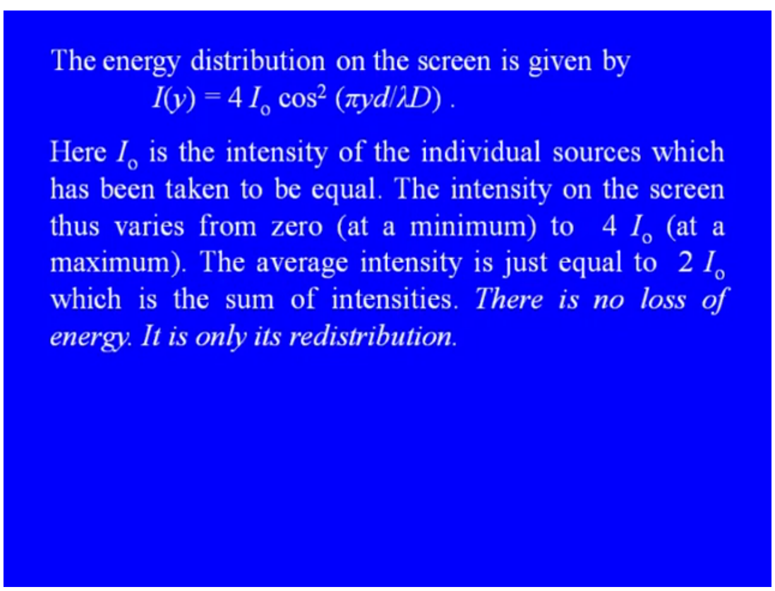

Now then, they are interesting thing the energy distribution on the screen. This is given by either the function of y, the distance of the point from the central point central fringe, is = 4 I naught cos square of Pi Lambda d upon lambda capital D I0 is the intensity of the individual sources which has been taken to be = each other. You see the density on the screen that varies from 0 at a minimum naturally where cos factor is here.

Or the maximum value is 4 times I naught at a maximum, the average intensity is just = twice I naught which is simply the sum of intensities. The main idea here is just to show that there is no loss of energy. The interference simply leads to redistribution of energy on the screen.

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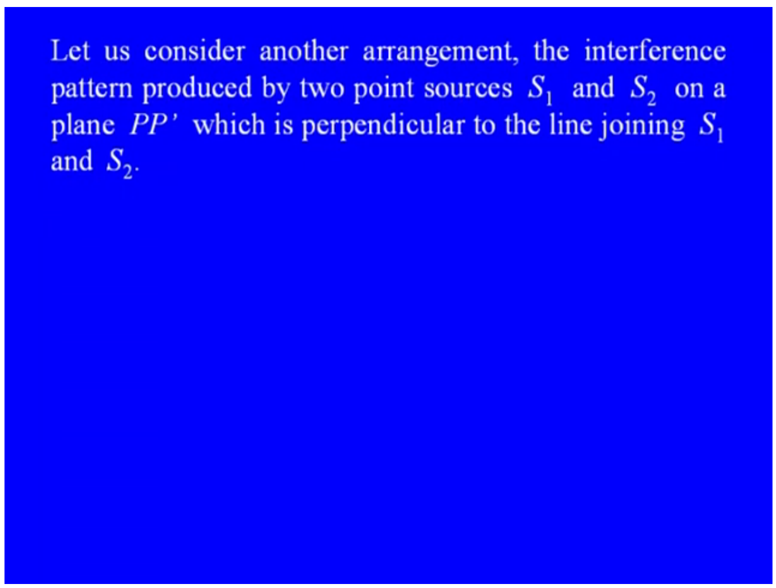

Let us consider another arrangement. The interface pattern produced by two point sources S1 and S2 on a plane PP prime, which is perpendicular to the line joining S1 and S2.

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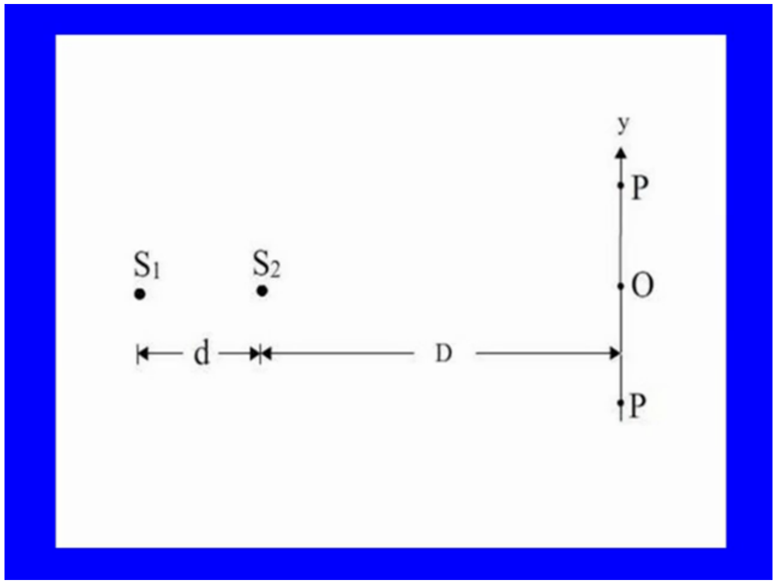

This typically S1 and S2 this line, line of sources is perpendicular to the screen. Capital D is the distance of the screen from one of the sources S2 and for the other source the distance is small d + capital D. We are interested on the pattern on the screen P P. In order to determine the shape of the interface pattern, let us find out the locus of the points P.

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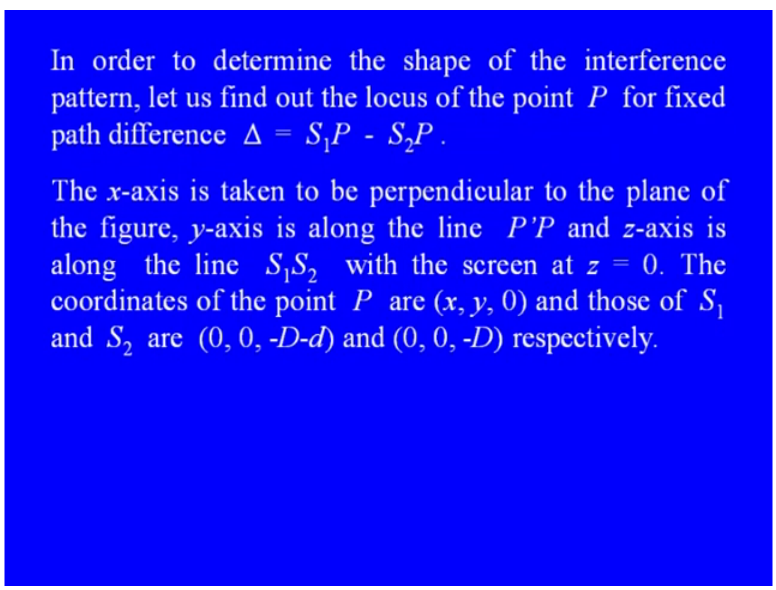

On the screen, for a fixed path difference Delta = S1P - S2P. The x-axis is taken to be perpendicular to the plane of the figure; y axis is along the line PP and the z axis is along the line of sources S1, S2, with the screen placed at the origin which is z is = 0. The coordinates of the point P are x, y, 0. z is 0 and those of S1 and S2 are 0, x and y are both 0; so, 0, 0 - Capital D - small d and for S2, 0, 0 - capital D respectively.

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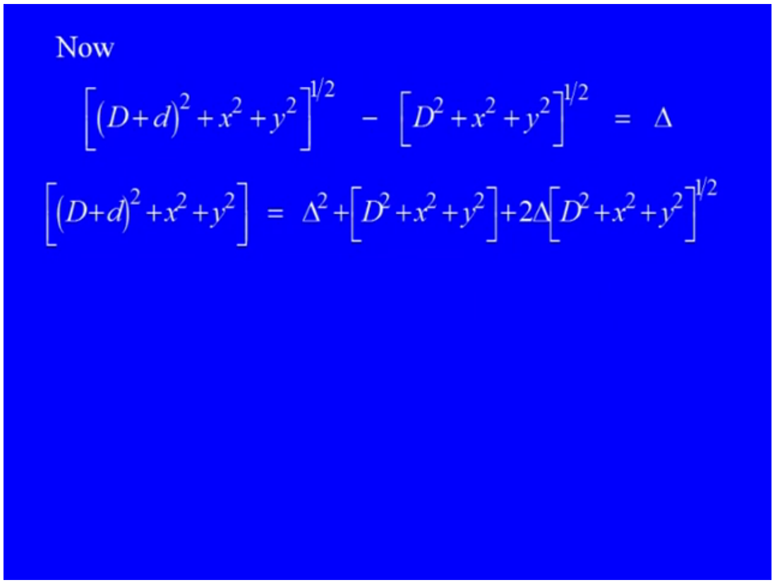

Now, for the path difference, we consider the distances. Capital D + small d squared + x square + y square whole under root, this is one of the distance - capital D square + x square + y square whole under root, this is the other distance. And the difference of these two is = the path difference which is capital D. Now, we transfer one term to the right hand side and then I square this.

That is the usual method of solving such equations. Some of the terms cancel out the result is we get x square + y square is = all of this expression depending on small d, capital D and capital Delta, some constant value.

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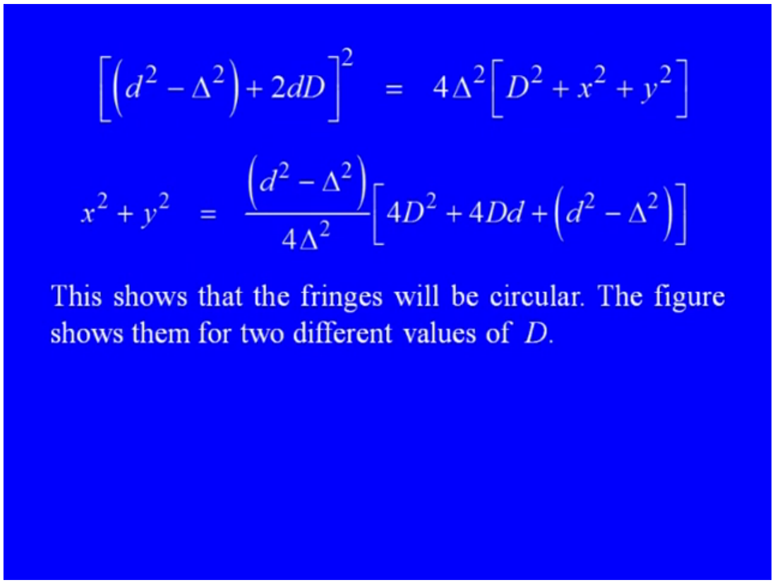

And this shows that the fringes will be circular. That is the interesting part. This figure, next we have, that show them for two different values of B.

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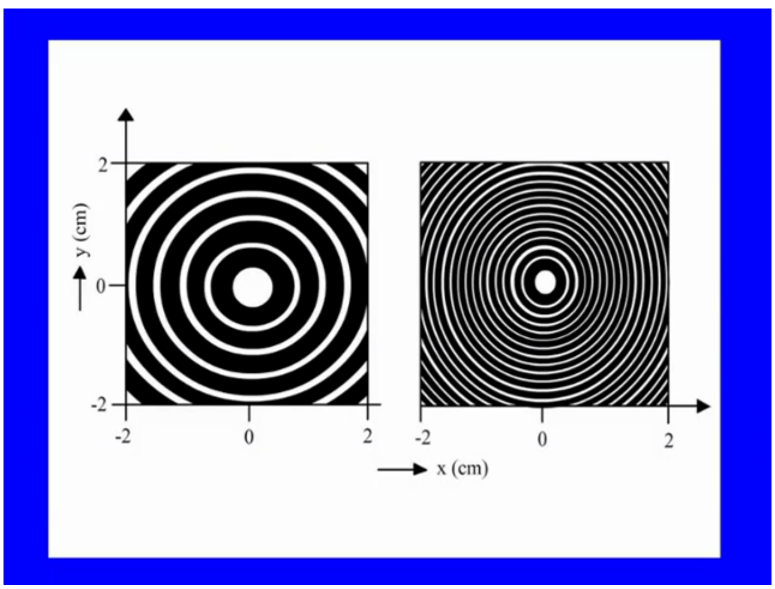

The first one when the d is 20 centimeters and the second figure where things are finer is when the distance is 10 centimeters.

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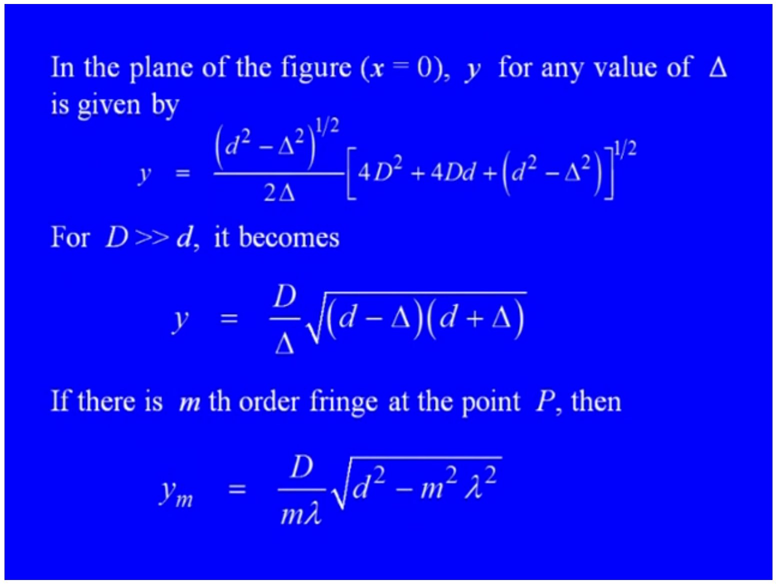

Now in the plane of the figure, we put x is = zero and consider the variation with respect y for any given value of Delta. Then the expression is given by y is = all this complicated expression. But the interesting thing is when capital D is very large compared to small d, it becomes y = some value like here, which is given D upon capital delta and whole square root of the product d - Delta into d + Delta.

If there is an a mth order fringe at the point P, which means Delta is = m lambda which is the path difference then the ym for that is given by this expression D upon lambda multiplied by the square root of d square - m square lambda square.

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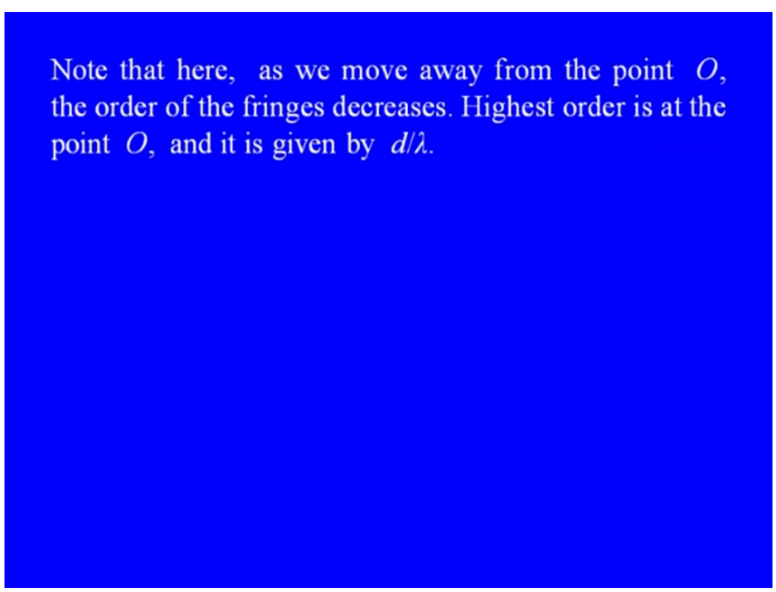

One thing is interesting here and that is as we move away from the point O which was the point in the line of sources on the screen, the order of the fringe decreases. Highest order is at the point O and it is given by d by lambda. You see in the basic Young's two hole arrangement, at the central point the path difference was 0 and as we move away from the center point the path difference goes on increasing.

1 lambda for the first bright fringe 2 lambda for the second bright fringe and like that. Here, the highest order is at the central point. The path difference here is not 0, it cannot be 0 and as we move away from it the path difference decreases, the first bright fringe will be one order less, next bright thing to order less and like this.

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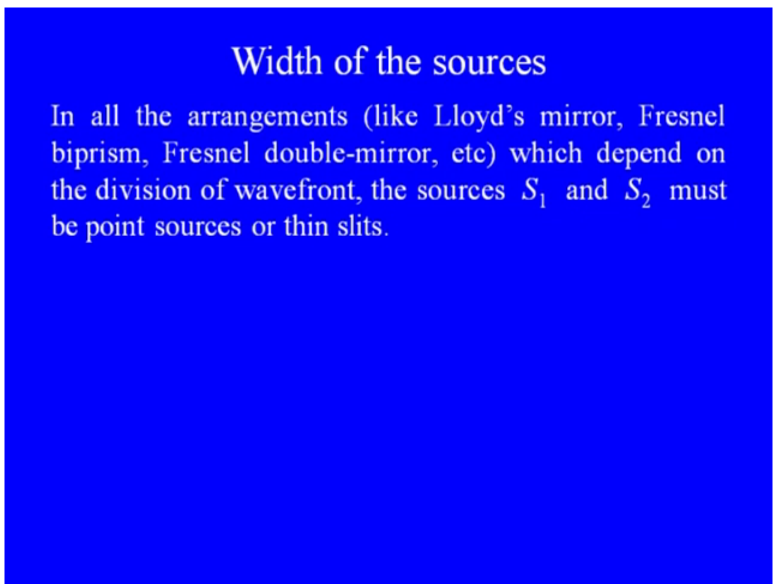

Now, let us consider what should be the width of the sources and how does it affect the pattern. You see, in all the arrangements like Lloyd's mirror, Fresnel Biprism, Fresnel Double mirror which depend on the division of wavefront, the sources S1 and S2, they must be point sources. They should be thin slits that is very important. This is the situation we like for a good interference pattern.

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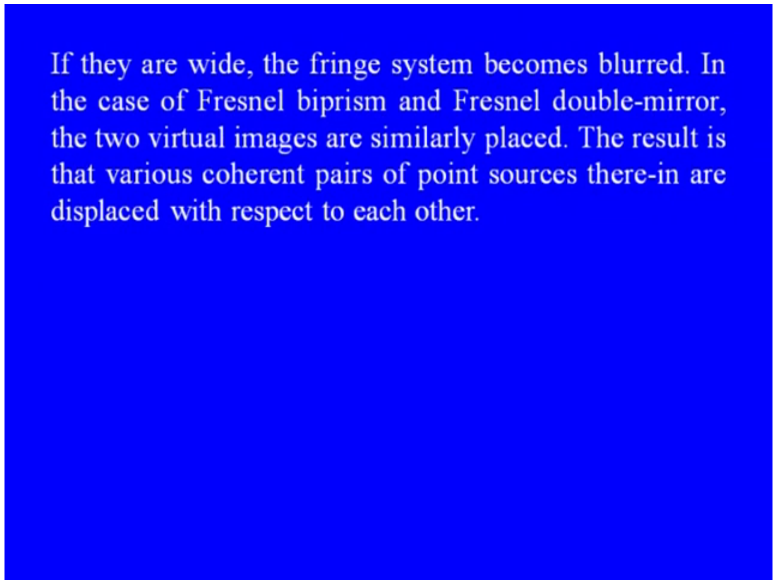

If they are wide not the point sources, not the thin slits, the fringe system becomes blurred. In the case of Fresnel Biprism, Fresnel Double mirror, the two virtual images are similarly placed. We shall see what is the meaning of similarly placed? And the result is that the various coherent pairs of point sources therein in the wide sources they are displaced with respect to each other. So, this is the arrangement one has:

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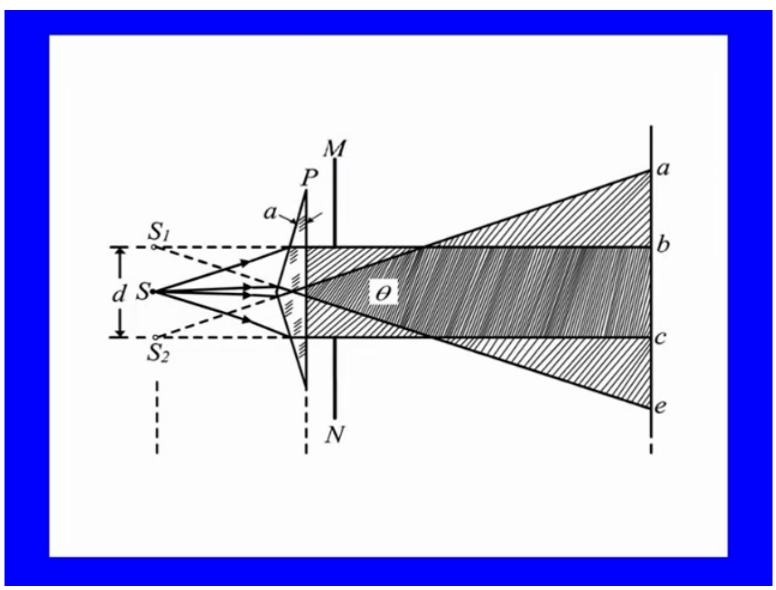

In the Fresnel Biprism S is the basic source and the light passes through the Biprism then, the reflection causes the creation of the two sources S1 virtual sources S1 and S2. But S1 and S2 are similarly placed with respect to S. This is the situation.

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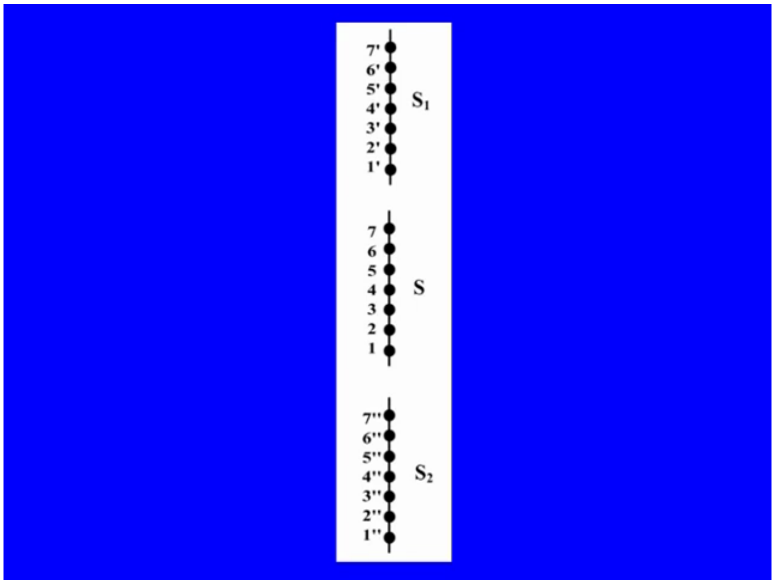

If S is wide, we have shown it say points 1 to 7, 1 to 7 does not mean anything just they are wide sources. And S1 and S2 have been shown. Now, you see, corresponding to the point 1, the two virtual sources are 1 prime and 1 double prime. Similarly, corresponding to the point 2, the two virtual sources are 2 prime into double prime. It is the distance between the corresponding pairs is same so the small d in the expression remains the same. But the midpoint of the two sources that is getting shifted, for 1,1 pair it is 1,4; 2,2 pair again 2;3,3 pair again 3; so it is shifted.

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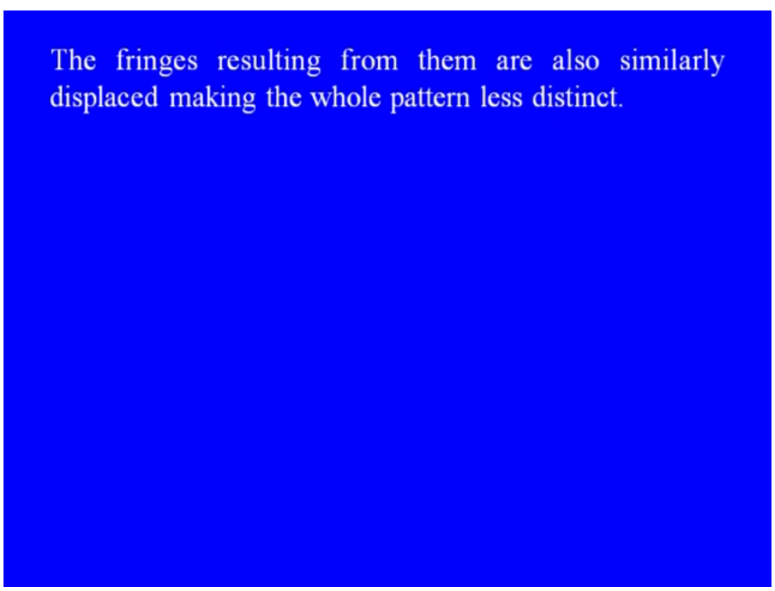

The fringe that is resulting from them are also similarly displaced making the whole pattern less distinct.

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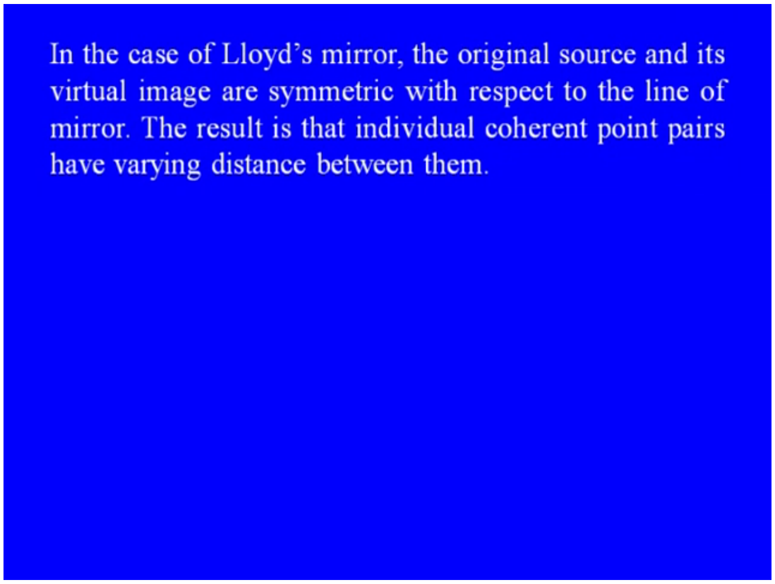

In the case of Lloyd's mirror, the original source and this virtual image are submitted with respect to the line of the mirror. And the result is that individual coherent pairs here have varying distance between them. That is the arrangement in Lloyd's mirrors.

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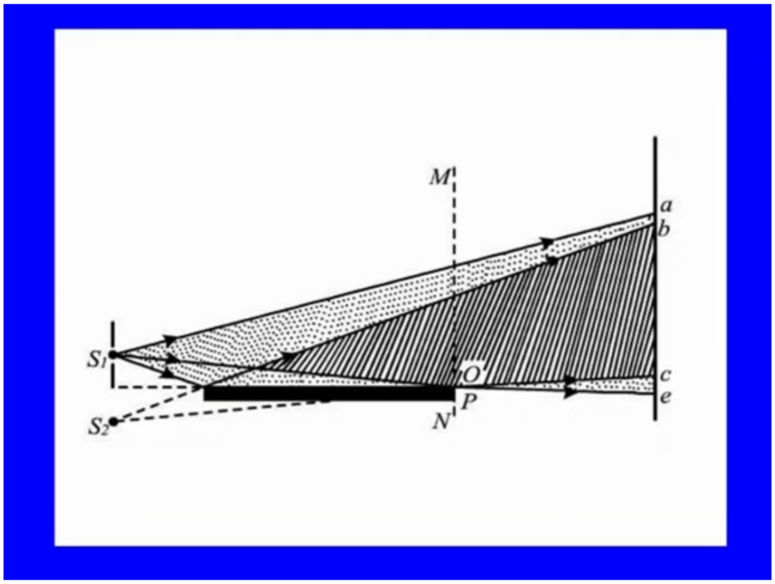

S1 is the basic source the light directly reaches to the point A on the screen then lightly thin wire reflection as if coming from the virtual source S2 and these two superpose and cause interference. Let us consider S1 and S2 it should be point sources or the slits parallel to the plane of the mirror. But if they are wide as shown here,

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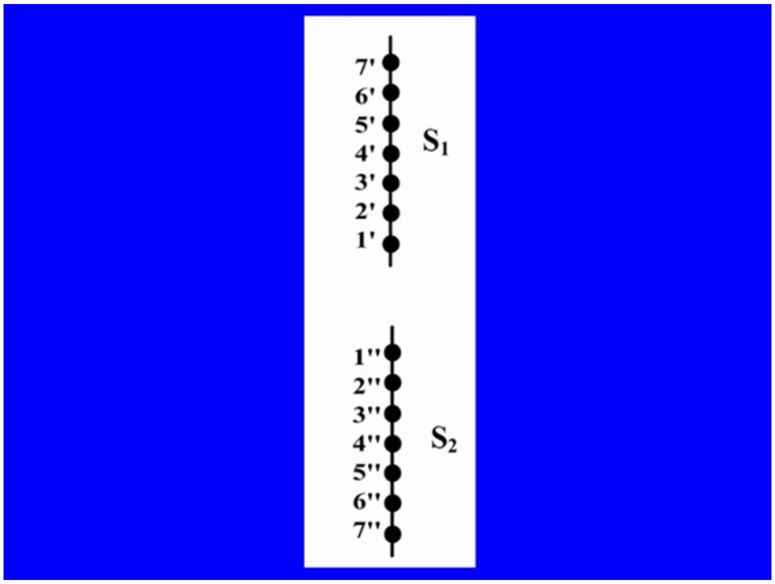

S1 is the basic source as to the virtual image corresponding to the point 1 prime, you have the point 1 double prime, corresponding to the point 2 prime you have 2 double Prime, 3 Prime 3 double prime. You see, the midpoint of the pair is same for 1, 1 pair or 2, 2 pair or 3,3 pair. But the distance between the sources keeps changing 1, 1 pair or the nearest. Then, the 2, 2 pair then, the 3,3 pair then the 4,4 pair.

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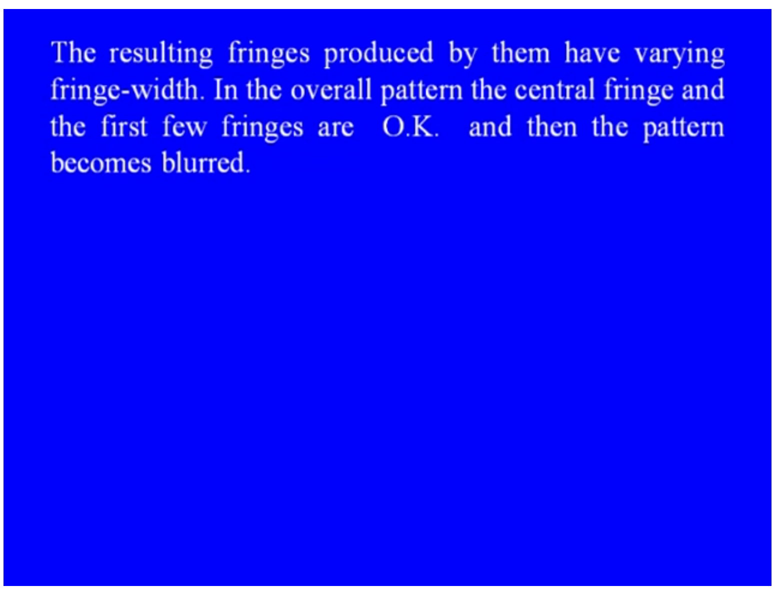

So, here the distance between the sources is waiting the resulting fringes produced by them varying fringe width in the overall pattern the central fringe and the first few fringes are okay. And then the pattern becomes blurred.

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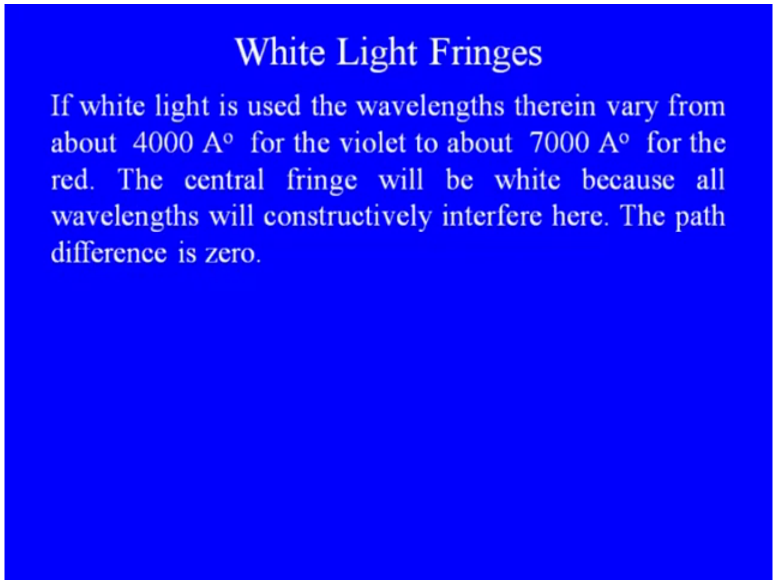

Let us consider what happens if white light is used in place of a monochromatic light, white light fringes. A white light is use the wavelengths therein vary from about 4000 angstrom in the violet region to about 7,000 for the red side. The central fringe now here in this case may be white because all the wavelength will constructively in interfere here. You see, the path difference for the centre fringes 0, 0 for all wavelengths, no problem.

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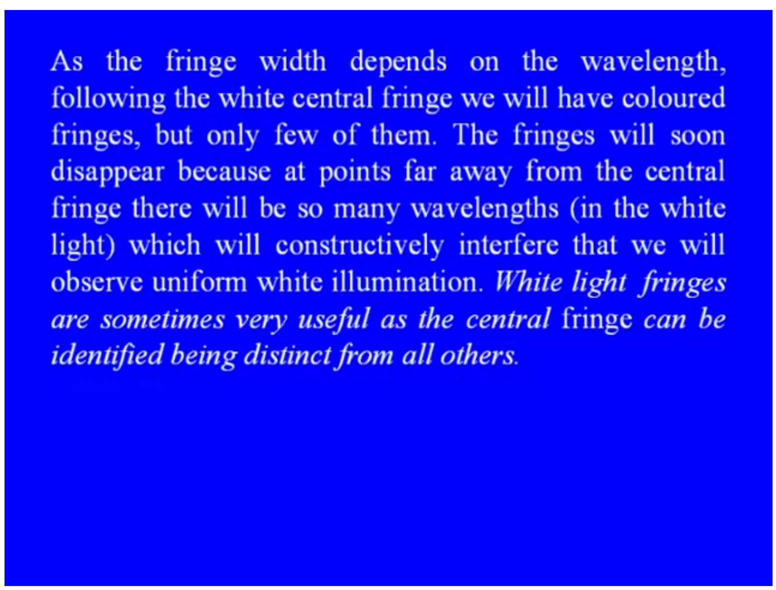

As the fringe which depends on the wavelength, following the white central fringe we will have coloured fringes but only few of them. The fringes will soon disappear because at points far away from the central fringe. There will be so many wavelengths in the white light which will constructively interfere that we will observe uniform white illumination. The white light fringes are sometimes though they are very useful as the central fringe can be identified, being distinct from all other fringes.

Only the central fringes white all other are colored if the light is monochromatic the whole patterns looks alike. You cannot identify if a particular fringe is the central fringe or not. Let us consider another interesting thing a displacement of the Fringes.

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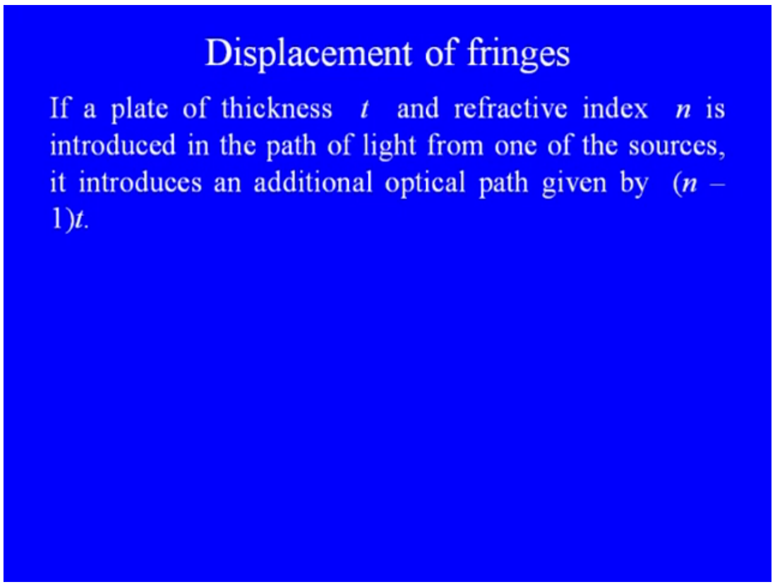

If a plate of thickness t and refractive index n is introduced in the path of light, from one of the sources, it introduces an additional optical path given by n - 1 times t as shown here.

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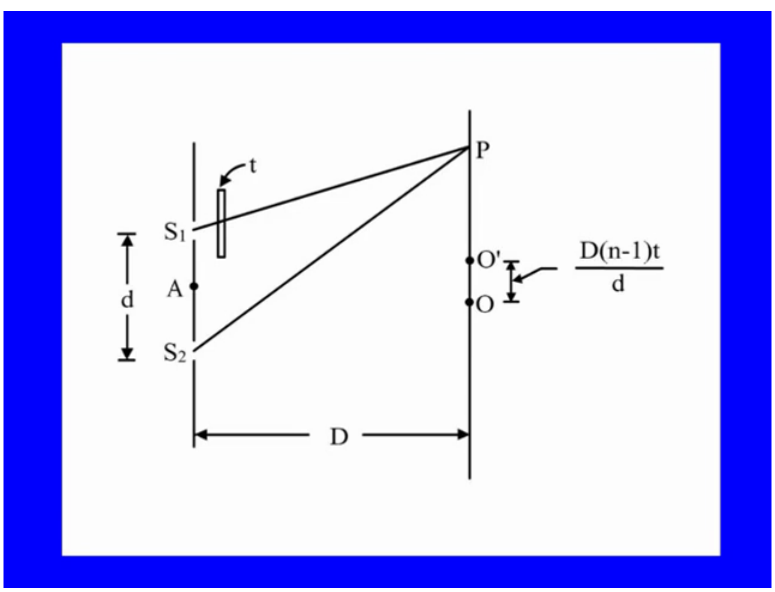

S1 and S2 are those two sources; this is small plate if introduced in the path of one of them. So, we consider the light reaching the point P from the source S1 and S2. Small d as before, the distance between the two sources, we want to see how the fringe pattern gets shifted, gets changed the originally central fringe is that the point O. And now it has got shifted to the point O Prime.

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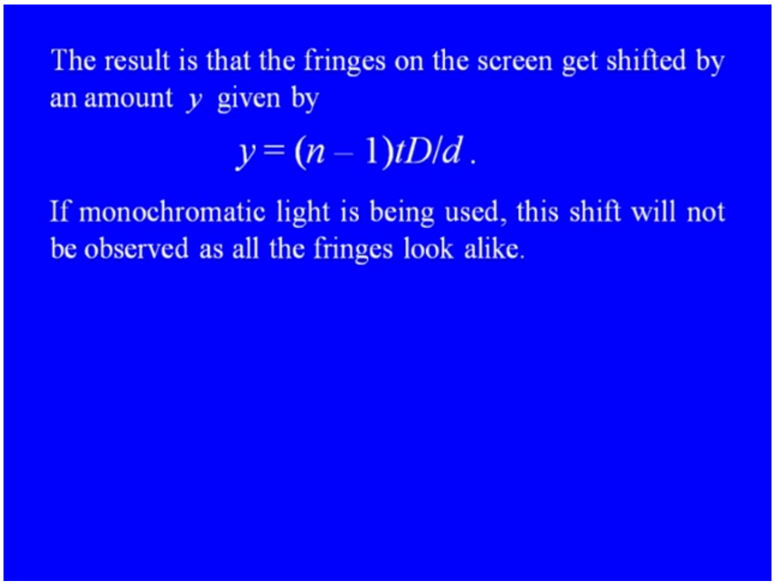

The result is that the fringes on the screen gets shifted as we saw in the figure by an amount y which is given by n - 1 times t capital D upon small d. Now, if monochromatic light is being used, this shift will not be observed and all the fringes look alike. Whether you put the plate or you remove it, you would not find any change in the patter. You would not be able to observe the shift.

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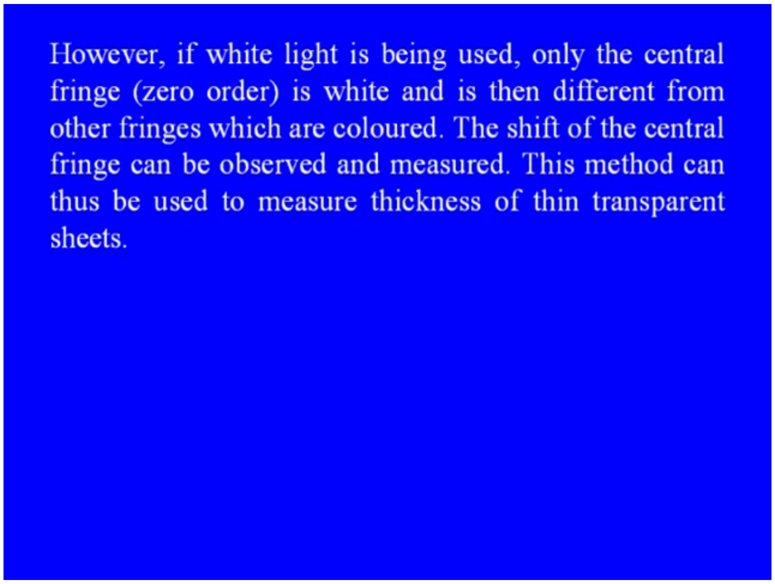

However, your white light is being used, only the central fringe 0 order is white and is then different from other fringes which are colored. The shift of the central fringe can be observed and measured. This method can then be used to measure thickness of thin transparent sheets.

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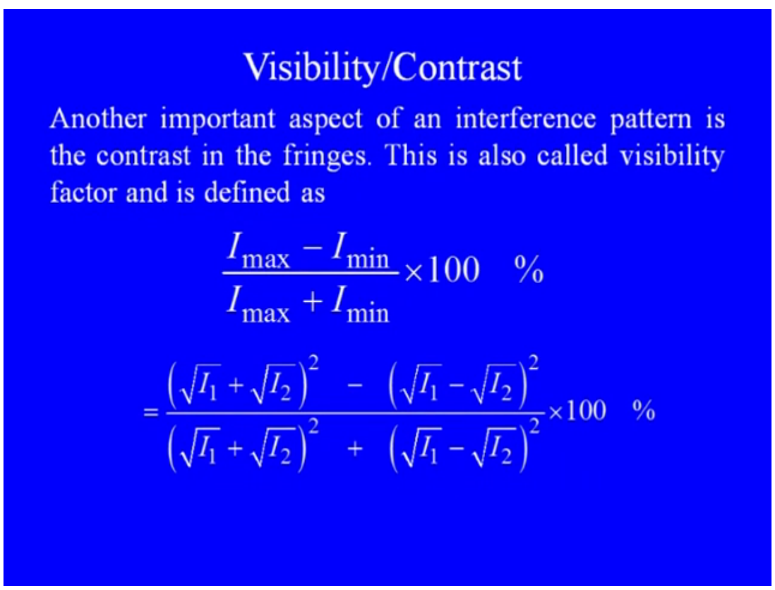

Okay and the interesting thing is the contrast in different pattern, the visibility factor. That it is defined as the difference of the maximum to - minimum intensity divided by their sum multiplied by 100, expresses as a percentage. Now, the maximum intensity is naturally, the, depends on, some of the amplitudes which is quiet. So if I1 and I 2 are the intensities of the two sources the square root of I1is proportional to the amplitude.

So, the amplitude from one of the sources + the amplitude from the other source, whole thing is quiet is proportional to the maximum intensity. Similarly for the minimum, when they are in opposite phase, square root of I1 is the amplitude of 1, square root of I2 is the amplitude of the other, whole thing is quiet proportional to the intensity at a minimum where the two sources I mean, the disturbance reaches in opposite phase.

So, we have got this expression. These two factors difference between them and some of these factors multiplied by hundred.

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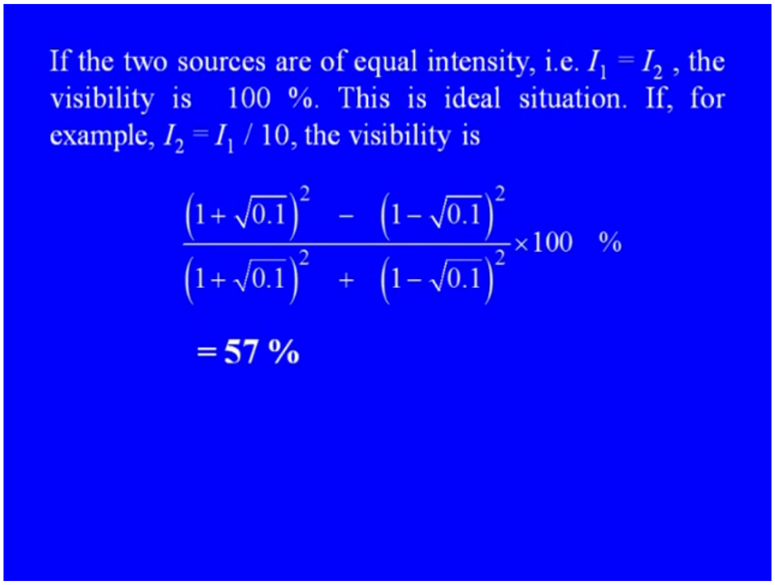

So now, naturally you can see here, if the two sources are of equal intensity I1 is = I2 you will find that the difference factor will be 0. And then, in that case, visibility will be 100 per cent. The patterns will be very bright crisp sharp. This is the ideal situation but in for example let us take a situation where I2 is only one tenth of I1, okay. Now again we have calculated the visibility factor 1 + square root of .1 whole squared, that is for the maximum;

And 1 - square root of .1 whole square that is for the minimum. So, I maximum - I minimum divided by I maximum + I minimum. In this case multiplied by 100 makes it only 57 %. So, the contrast has fallen quite a bit. Okay, I think this is all what we plan to do in this lecture. So, we have come to the end of this. Thank you.