Engineering Physics 1
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Module-03
Lecture-03
Interference of Light - Part 03

In the previous lectures, I discussed the basic requirement for the observation of interference fringes in the laboratory and discuss some important experimental arrangement to observe the interference fringes in the laboratory. In this lecture I am going to describe some possible engineering applications of interference phenomena of light. We have already seen that Newton's ring experiment can be used to determine the wavelength of monochromatic light, refractive index of liquids and to study the plainness of glass plate.

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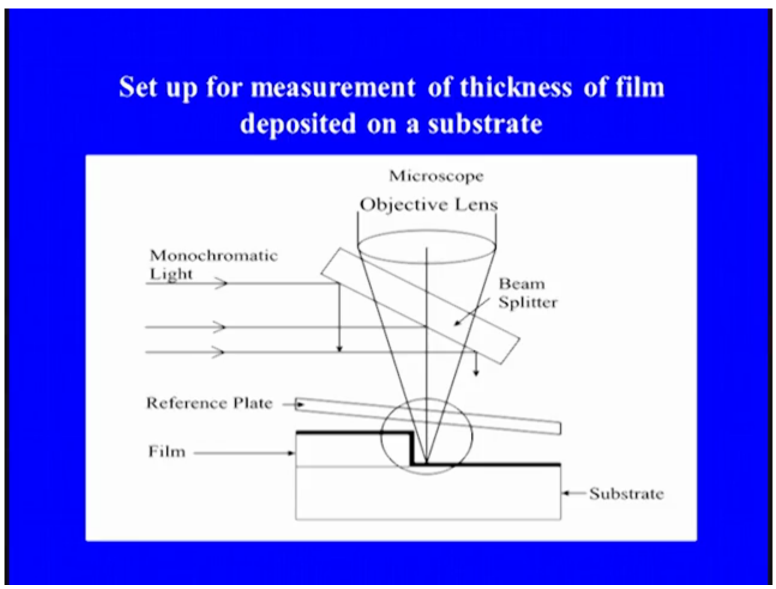

The Michelson interferometer may be used to measure accurately wavelength of light and wavelength difference between the two closely spaced spectral lines of certain sources like sodium. In addition to this, it is also used for evaluation of a standard meter in terms of wavelength of light. Similarly, Fabry Perot Interferometer can be used for similar applications. Here, I am going to describe few other possible engineering applications of interference of light. One important application of interference of thin film is the coating of non reflecting films.

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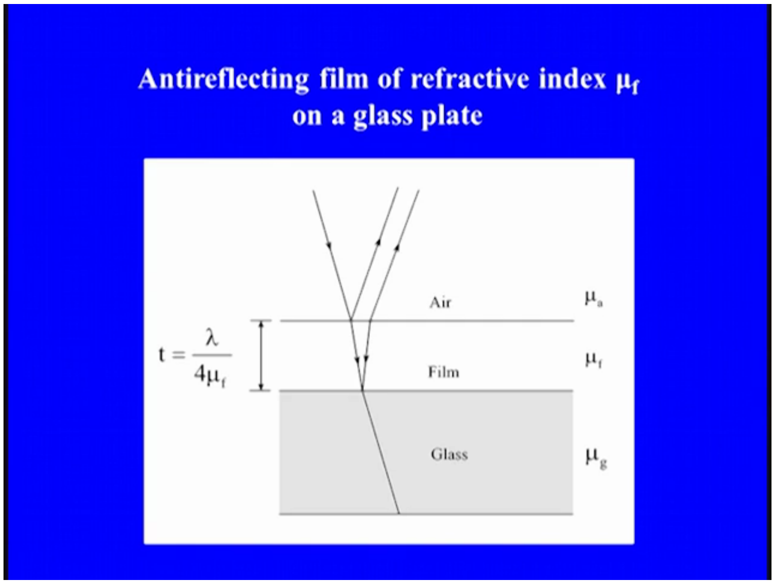

When these films are coated on surfaces of optical elements like lens or prism, the reflectivity of surfaces is very much reduced. Therefore, the loss of light by reflection had various surfaces of the system of lenses or fringe is appreciably reduced. The main idea behind the non reflecting film is the destructive interference between the waves reflected from the air film interface and film glass interface by properly adjusting the thickness and refractive index of the film material.

Suppose, the refractive index of the film material Mu R is less than the refractive index of glass Mu G and greater than the refractive index of air Mu A.

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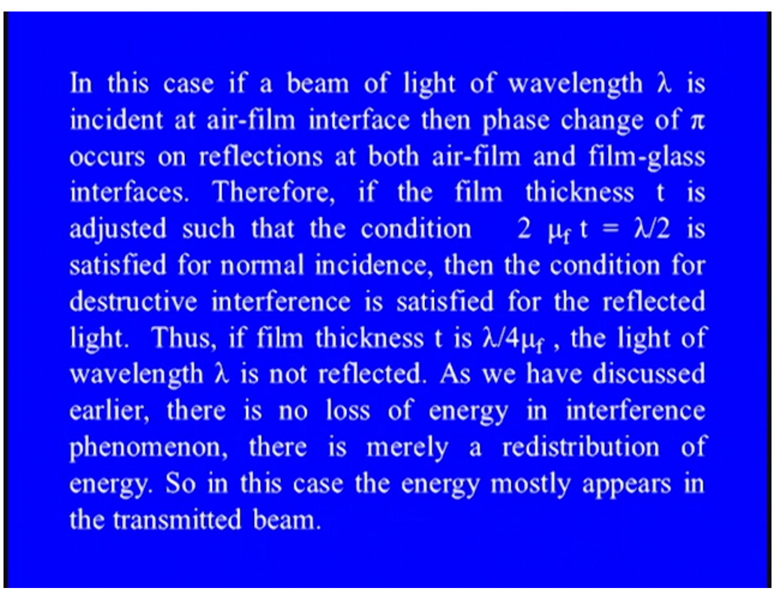

In this case if a beam of light of wavelength lambda is incident at air film interface then phase change of Pi occurs on reflections at both air film and film glass interfaces. Therefore, if the film thickness t is adjusted such that the condition 2 Mu f t is = lambda by 2 is satisfied for normal incidence then the condition for destructive interference is satisfied for the reflected light. Thus, if film thickness t is lambda upon 4 Mu f, the light of wavelength lambda is not reflected.

As we have discussed earlier, there is no loss of energy in interference phenomena. Therefore, there is merrily a redistribution of energy. So, in this case, the energy mostly appears in the transmitted beam. In case of white light lambda is generally chosen near the middle of the visible spectrum, that is lambda around 5000 angstrom.

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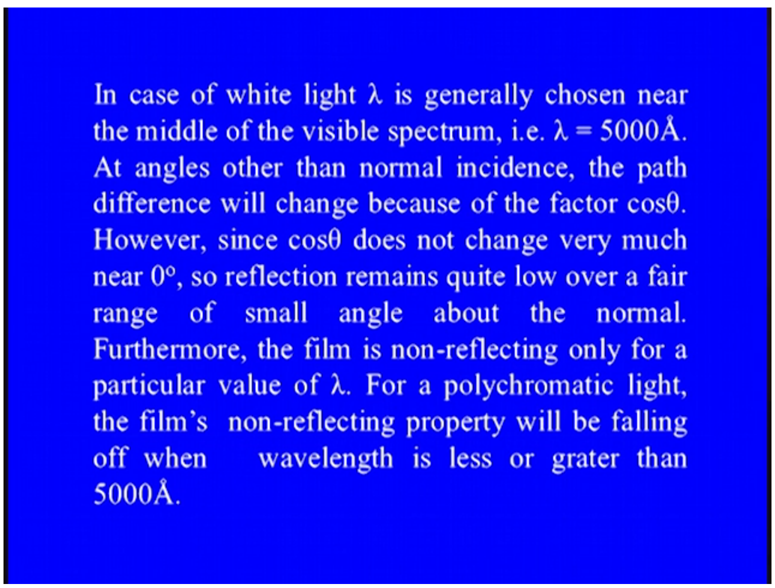

At angles other than normal incidence, the path difference will change because of the factor cosine theta. However, since cos theta does not change very much near 0 degree. So, reflection remains quite low over a fair range of a small angle about the normal. Furthermore, the film is non reflecting only for a particular value of lambda. For a polychromatic light, the film's non reflecting property will be falling off when wavelength is less or greater than 5000 angstrom.

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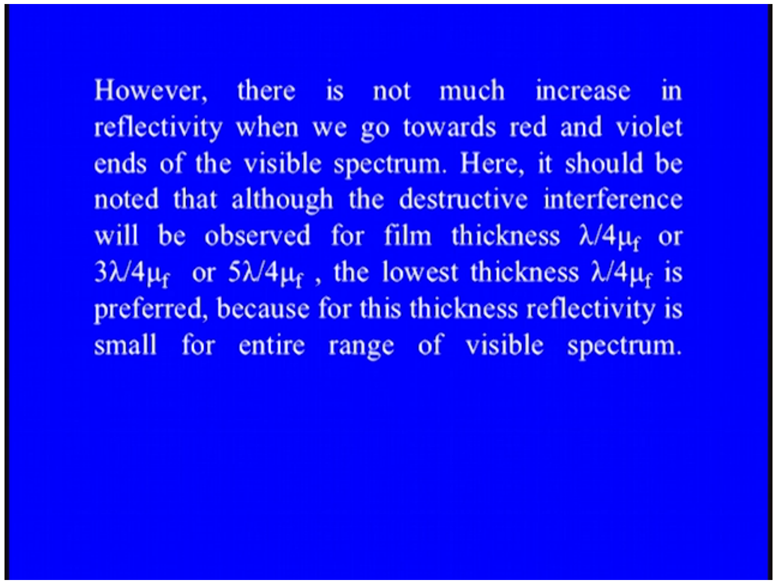

However, there is not much increase in the reflective reflectivity, when we go towards red and violet ends of the visible spectrum. Here, it should be noted that although the destructive interference will be observed for film thickness lambda upon 4 Mu f, or 3 lambda upon 4 Mu f or 5 lambda upon 4 Mu f of the lowest thickness lambda upon 4 Mu f is preferred because for this thickness, reflectivity is small for entire range of visible spectrum.

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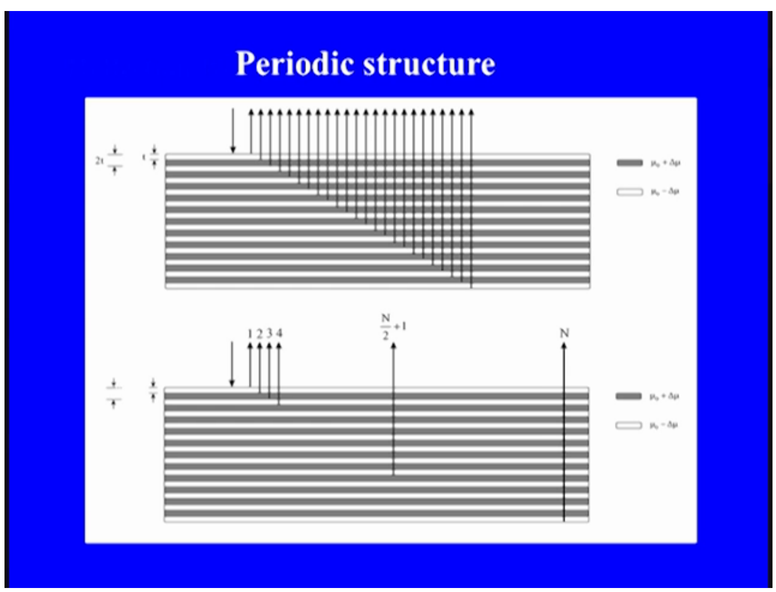

Here we have seen that a film of thickness lambda upon 4 Mu f where lambda is the wavelength of light and Mu f is the film, refractive index which lies between the refractive indices of the two surrounding media acts like an anti reflecting layer. This happens due to destructive interference occurring between the waves reflected from the top and the bottom interfaces.

However if the refractive index of the film is smaller or greater than both the surrounding media then, in such a case in addition to the phase difference, due to the additional part travelled by the wave, reflected from the lower interface, there would also be an extra phase difference of Pi between the two reflected waves.

In this case, a film of thickness lambda found 4 Mu f, therefore, would increase the reflectivity rather than reducing it. Now, if you consider a medium consisting of alternate layers of high and low refractive indices of Mu naught + Delta Mu and Mu naught - Delta Mu of equal thickness t, such medium is called a periodic medium. And a special period of variation of the refractive index is 2t.

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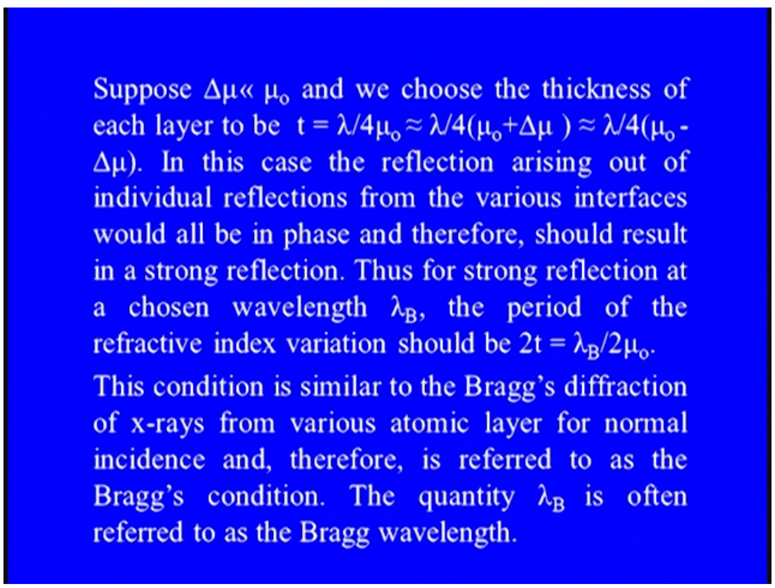

Suppose, Delta Mu is much smaller than Mu naught and we choose the thickness of each layer to be t = lambda upon 4 Mu naught which we can take approximately = lambda upon 4 Mu naught + Delta Nu or approximately = lambda upon 4 Mu naught - Delta mu. In this case, the reflection arising out of individual reflections from the various interfaces would all be in phase and should result in a strong reflection.

Thus for a strong reflection, at a chosen wavelength lambda B, the period of the refractive index variation should be 2 t is = lambda B upon 2 Mu naught. This condition is similar to the Bragg's diffraction of x-rays from various atomic layers for normal incidence. And therefore is referred to as the Bragg's condition. The quantity lambda B is often referred to as the Bragg wavelength. As you move away from the wavelength lambda B, the reflectivity of the period periodic medium falls off sharply.

We can obtain an approximate expression for the wavelength deviation Delta Lambda from lambda B which will produce a 0 reflectivity. In order to do this, we first note that at lambda B the waves reflected from each of the N individual layer are all in phase leading to a strong reflection. If we move away from lambda B then the individual waves reflected from the various layers will not be in phase and thus reflectivity reduces.

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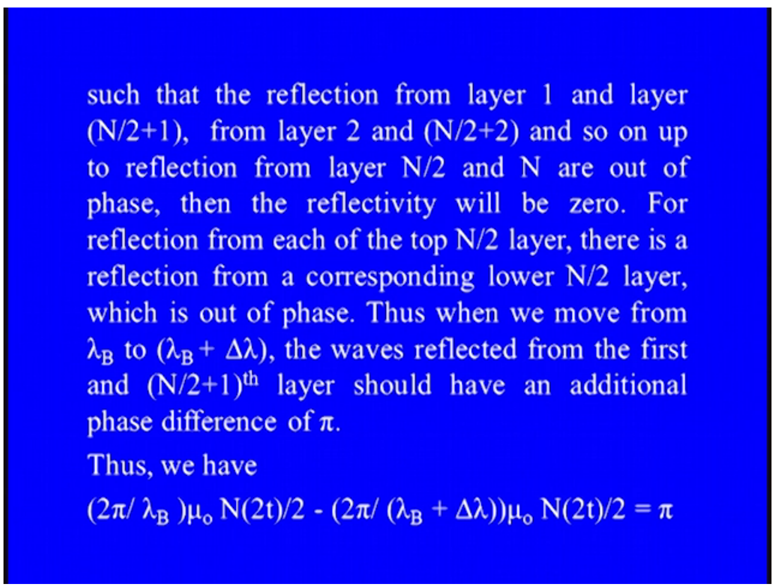

If we choose a wavelength lambda B + Delta Lambda such that the reflection from layer 1 and layer n by 2 + 1 from layer 2 and n + 2 + 2 and so on, up to reflection from layer n by 2 and n are out of phase then, the reflectivity will be 0, for reflection from each of the top n by 2 layer. There is a reflection from a corresponding lower n by 2 layer which is out of phase. Thus, when we move from lambda B to lambda B + Delta Lambda, the waves reflected from the first and n by 2 + 1th layer should have an additional phase difference of Pi.

Thus we have 2 pi by lambda B into Mu naught into n by n into 2 t by 2 - 2 Pi by lambda B + Delta Lambda into Mu naught N into 2t upon 2 is = PI.

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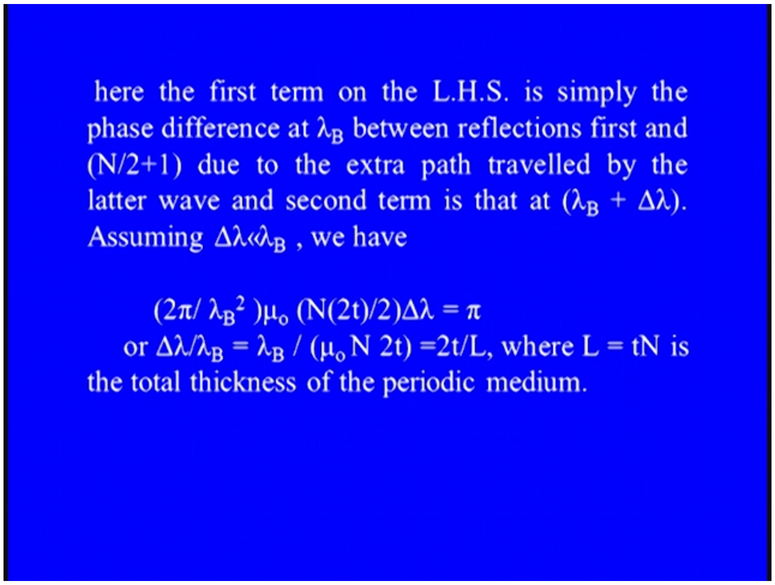

Here the first term on the LHS, left hand side is simply the phase difference at lambda B between reflection first and n by 2 + 1 due to the extra path travelled by the later wave. And second term is that as lambda B + Delta Lambda. Assuming Delta Lambda much smaller than lambda B, we have 2 pi divided by lambda B square into Mu naught into N into two T by 2 into Delta Lambda is = PI and from this, we get Delta Lambda upon lambda B is = lambda B upon Mu naught N into 2 t which we can write = 2 t upon L where L is = t into N is the total thickness of the periodic medium.

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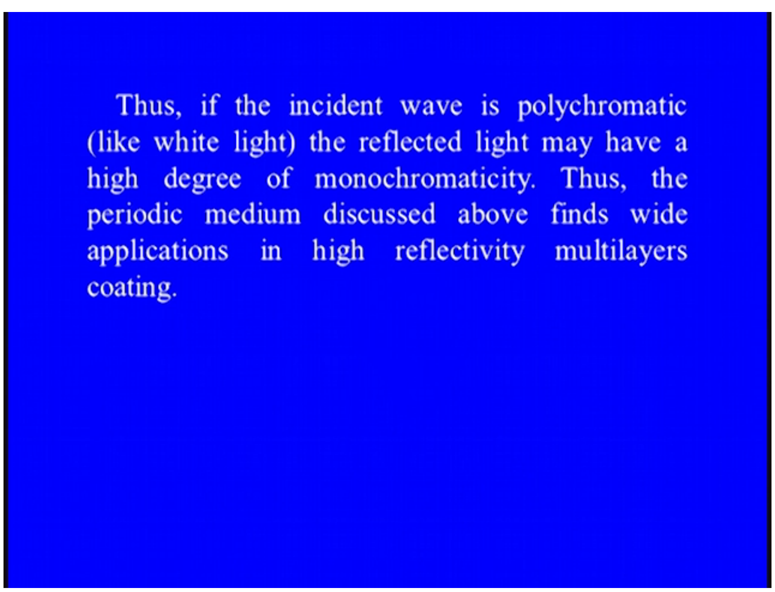

Thus if the incident wave is polychromatic like white light the reflected light may have a high degree of monochromaticity. This principle is used in white light holography thus the periodic medium discussed above finds wide application in high reflectivity multi layers coating. So, now I am going to describe the working of interference filter.

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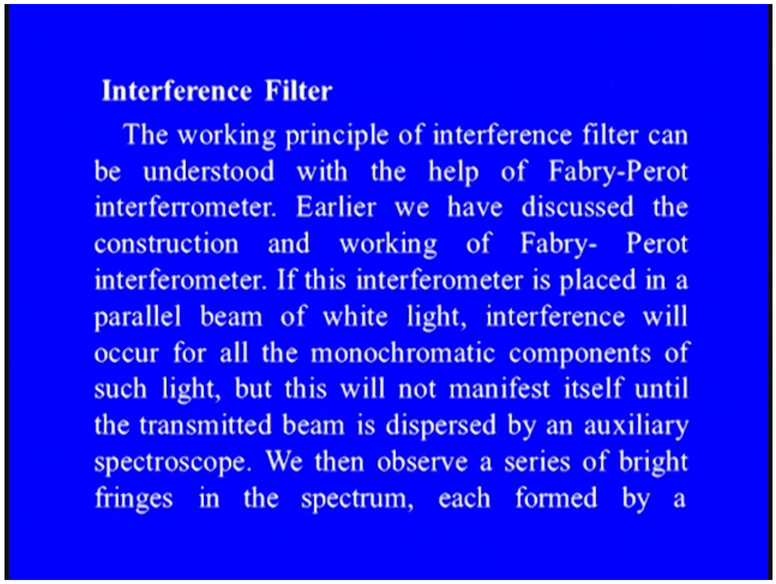

So, working of this interference filter can be understood with the help of Fabry Perot interferometer. I have already discussed the construction of this interferometer. If this interferometer is placed in a parallel beam of white light, interference will occur for all the monochromatic component of such light. But this will not manifest itself until the transmitted beam a dispersed by an auxiliary spectroscope.

We then, observed a series of bright fringes in the spectrum, each formed by a wavelength

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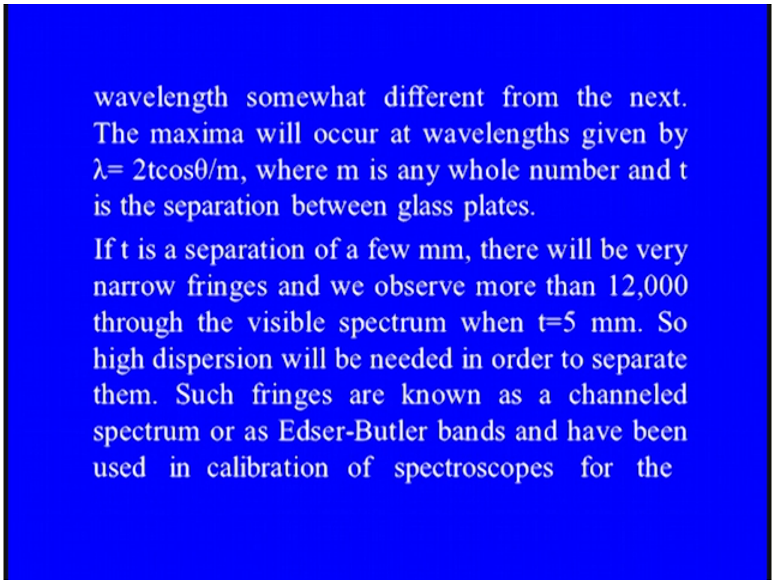

Somewhat different from the next, the Maxima will occur at wavelength given by lambda is = 2t cos theta divided by M where m is any whole number. If t is a separation of a few millimeters, there will be very narrow fringes and high dispersion is necessary in order to separate them. Such fringes are known as channel spectrum or as Edser Butler bands and have been used for example in calibration of spectroscopes

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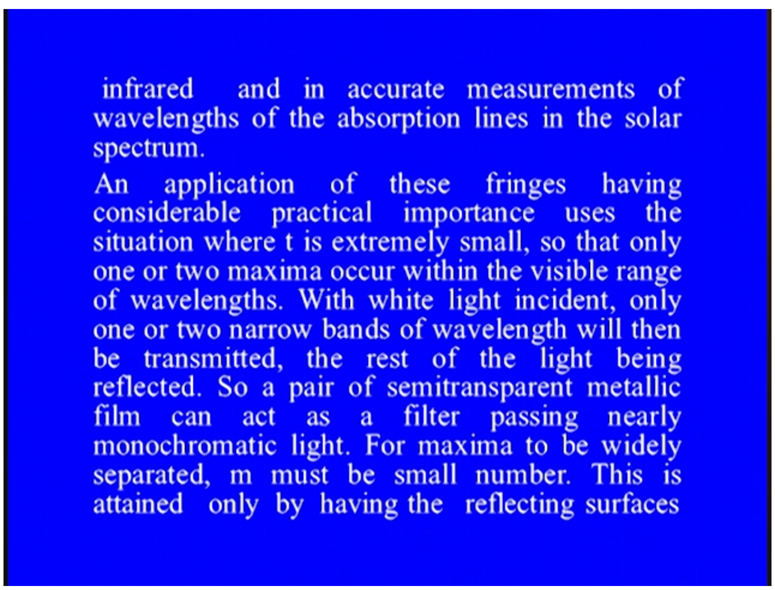

,for the infrared and inaccurate measurements of wavelength of the absorption lines in the solar spectrum. An application of these fringes having considerable practical importance uses the situation where t is extremely small; so that only one or two Maxima occur within the visible range of wavelengths. With white light incident, only one or two narrow bands of wavelength will then be transmitted, the rest of the light, being reflected.

So, a pair of semi-transparent metallic film can act as a filter passing nearly monochromatic light. For maxima to be widely separated m must be small number. This is attained only by having the reflecting surfaces very close together. If we wish to have the maximum for m is = 2 occur at a given wavelength lambda, the metal films would have to be a distance lambda apart.

The maxima m is = 1 will then appears at a wavelength of 2 lambda. Such minute separation can be attained however with modern techniques of thin film deposition. For this a semi transparent metal is first deposited on a glass plate. Next a thin layer of some dielectric materials such as cryolite light is deposited on the top of this and then the dielectric layer is in turn coated with another similar film of metal.

Finally, another plate of glass is placed over the film for mechanical protection. The completed filter then has the cross-section as shown in this figure.

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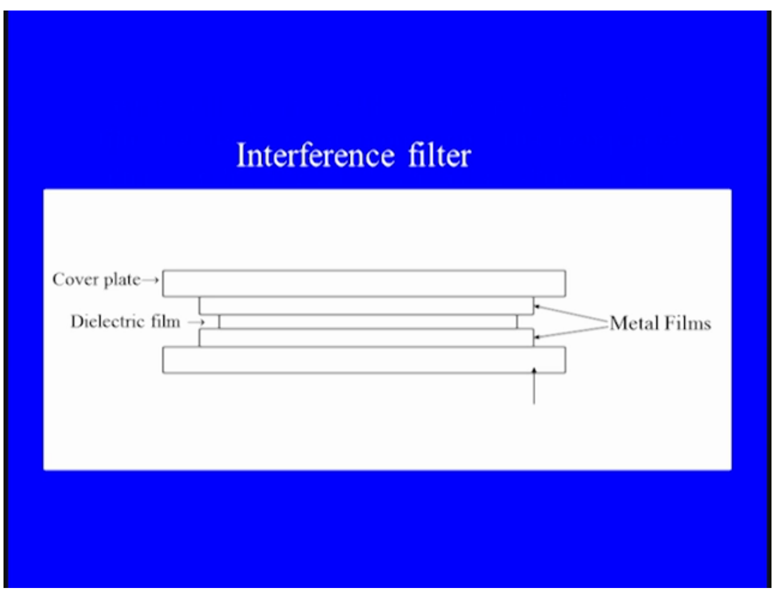

Since the power difference is now in the dielectric appendix and the wavelength of maximum transmission for normal incidence are given by lambda is = 2Nt upon m. If there are two maxima in the visible spectrum, one of these can easily be eliminated by using coloured glass for protecting cover plate. So, up till now we have discussed some important engineering application of interference.

Now I am going to discuss about the coherence of light waves. So, first I will discuss about the temporal coherence and then I will discuss about the spatial coherence.

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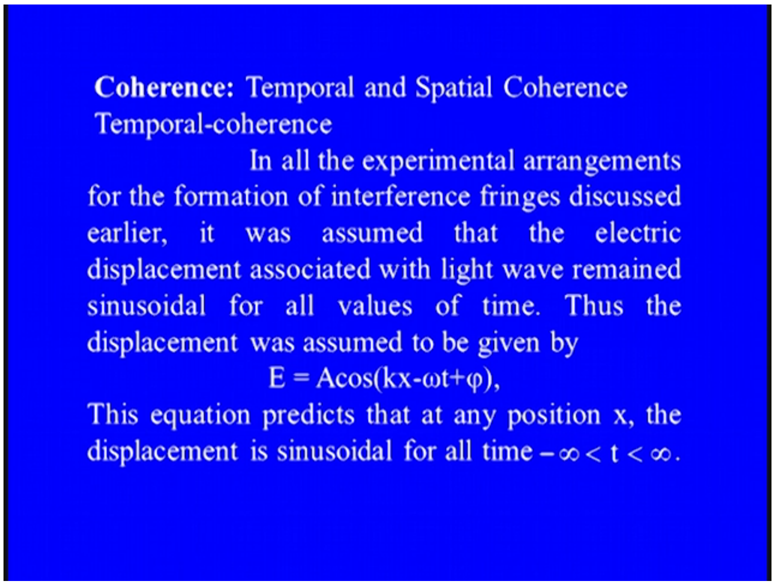

In all the experimental arrangement for the formation of interference fringes discussed earlier, it was assumed that the displacement that is the electric field associated with light wave remained sinusoidal for all values of time. Thus the displacement was assumed to be given by e is = a cos kx - Omega t + Phi. This equation predicts that at any position x, the displacement is sinusoidal for all time varying from from - infinity to + infinity. For example at x is = 0 we have E is = A cos Omega t - Phi and variation of E with time forms infinite wave trends as shown in this figure.

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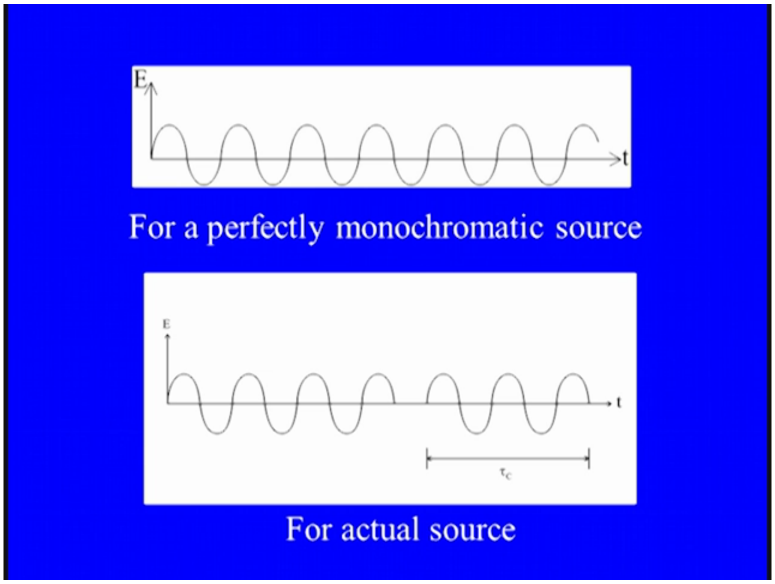

However, this will result only from perfectly monochromatic source and this corresponds to an idealized situation because the radiation from an ordinary light source consists of finite sized wave train. The average duration of the wave train is Tau c that is the electric field remains sinusoidal 4 times of the order of Tau c. Thus, at a given point the electric field at a time t and t + delta t will in general, have a different phase relationship, if delta t is much smaller than Tau c and do not have any phase relationship if delta t is much greater than Tau c.

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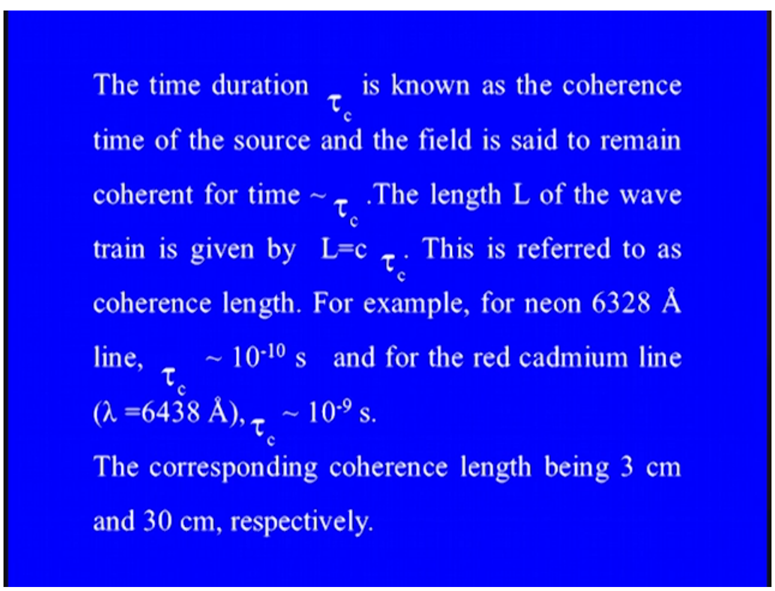

The time duration Tau c is known as the coherence time of the source and the field is said to remain coherent for time Tau c. The length L of the wave train is given by L is = c into Tau c where c is the velocity of light. This is referred to as coherence length. For example, for neon light Tau c is of the order of 10 to the power - 10 second and for the rate cadmium line it is of the order of 10 to the power -9 second and so the corresponding coherence length will be 3 centimeter and 30 centimeter respectively.

The coherent correlation between the wave at a given time and a certain time later is known as the temporal coherence.

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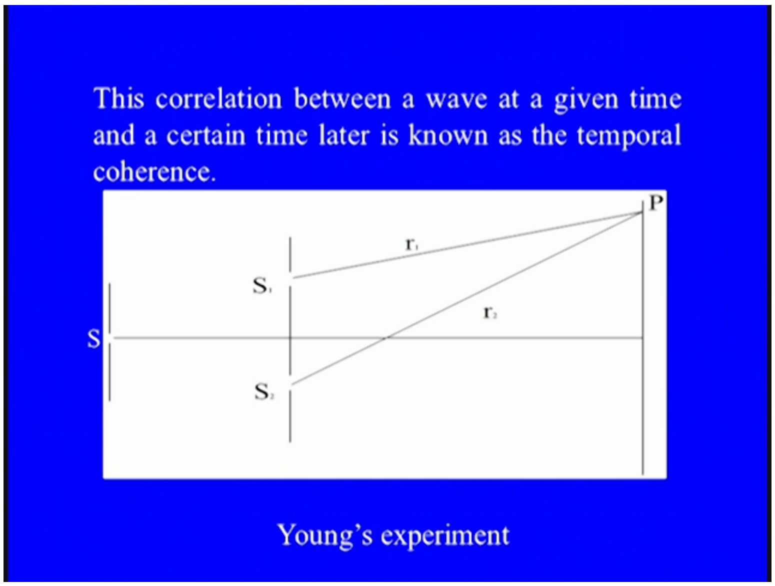

Again let us consider here, the Young's double-slit experiment. In this experiment, the interference pattern observed around the point P at time t is due to the superposition of waves emanating from slits S1 and S2 at time t - r1 upon c and t - r2 upon c respectively,

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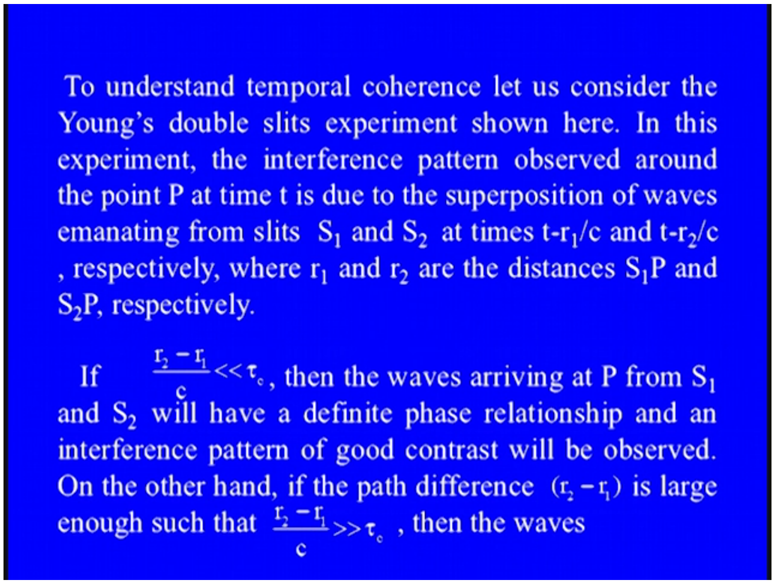

Where r1 and r2 are the distances, S P and S2 P respectively, if r2 - r1 upon c is much smaller than Tau c, then, the wave arriving at B from S1 and S2 will have a definite phase relationship and an interference pattern of good controls will be observed. On the other hand if the path difference r2 - r1 is large enough such that r 2 - r1 upon c is much greater than Tau c

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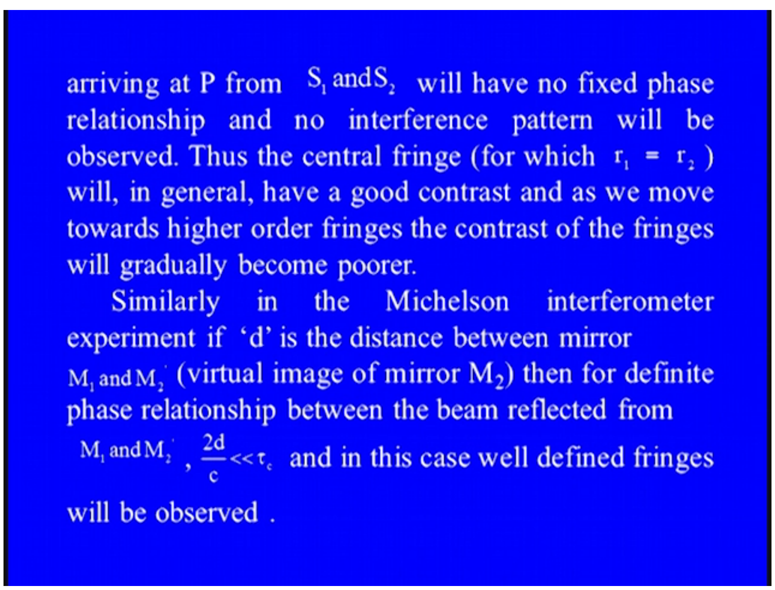

,then the waves arriving at P from s1 and s2 will have no fixed phase relationship and no interference pattern will be observed. Thus the central fringe for which r1 is = r2 will in general have a good contrast and as we move towards higher order fringes, the contrast of the fringes will gradually become poorer. Similarly in the Michelson interferometer experiment if d is the distance between mirror M1 and M2 prime, virtual image of mirror m2.

Then, for different phase relationship between the beam reflected from M1 and M2, that is 2d upon cC much less than Tau c and well-defined fringes will be observed in this case. On the other hand if 2d upon c is much greater than Tau c then in general there is no definite phase relationship between the two beams and no interference pattern is observed.

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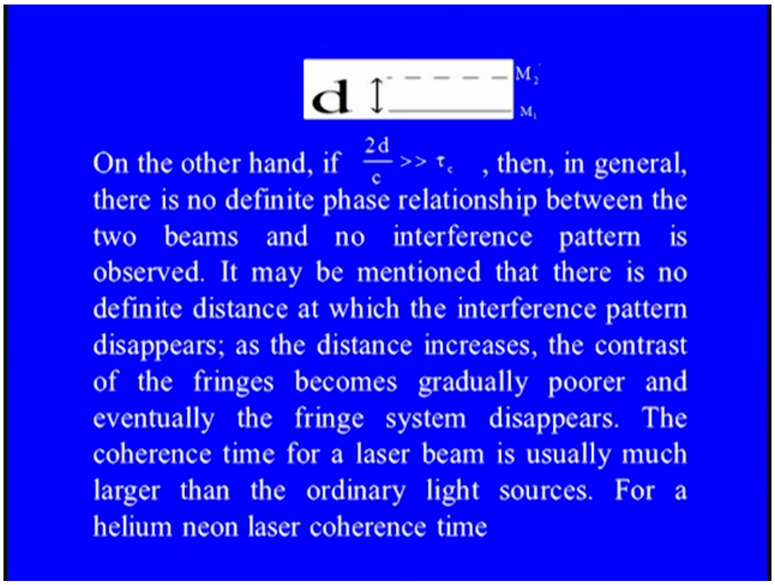

It may be mentioned that there is no definite distance at which the interference pattern disappears; as the distance increases, the contrast of the fringes becomes gradually poorer and eventually the fringe system disappears. The coherence time for a laser beam is usually much larger than in comparison to ordinary light sources.

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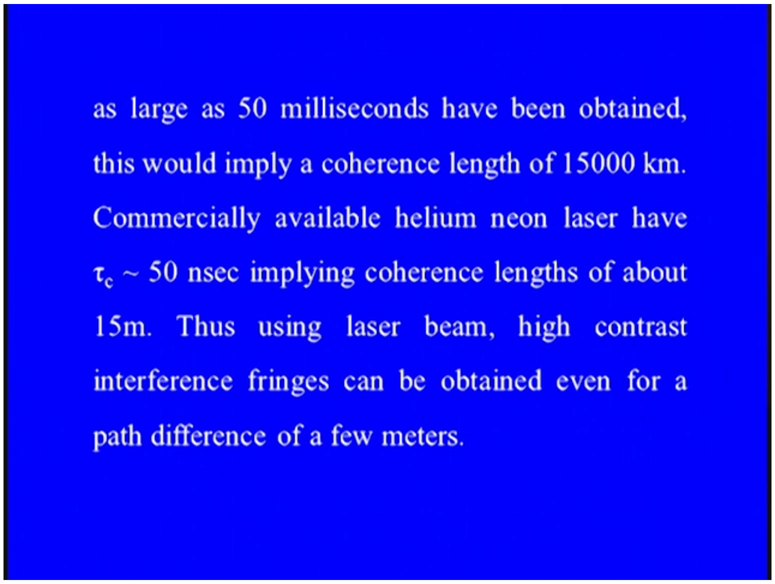

For example, for a helium-neon laser coherence time as large as 50 milliseconds have been obtained, this would imply a coherence length of 15,000 kilometers. Commercially available helium neon laser have coherence time of the order of 50 nanoseconds. This means the coherent length is about of the order of 15 meters thus, using such a laser beam high contrast interference fringes can be obtained even for a path difference of few meters.

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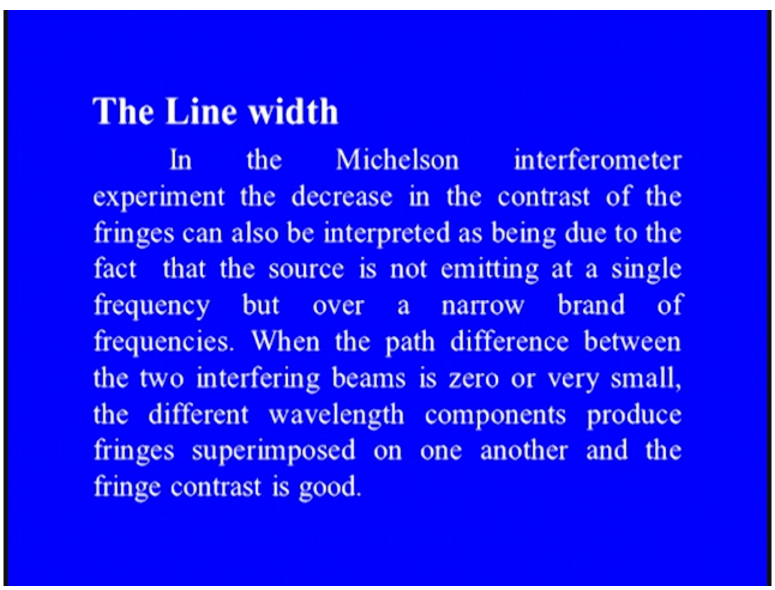

In the Michelson interferometer experiment, the decrease in contrast of the fringes can also be interpreted as being due to the fact that the source is not emitting at a single frequency. But over a narrow band off frequency as shown here, when the power difference between the two interfering beams is 0 or very small, the different wavelength components produce fringes superimposed on one another and the fringe contrast is good.

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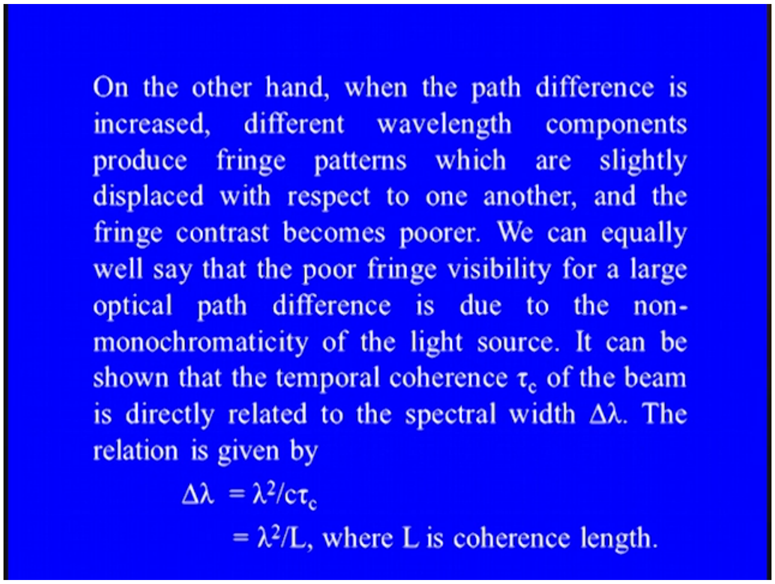

On the other hand, when the power difference is increased different wavelength component produce fringes, fringe patterns which are slightly displaced with respect to one another and the fringe contrast becomes poorer. We can equally well say that the poor fringe visibility for a large optical power difference is due to the non mono chromaticity of the light source. It can be shown that the temporal currents Tau c of the beam is directly related to the spectral width Delta Lambda.

The relation is given by this equation Delta lambda is = lambda square upon c Tau c or delta lambda is = lambda square upon L since frequency is related to wavelength by equation Mu is = c upon lambda.

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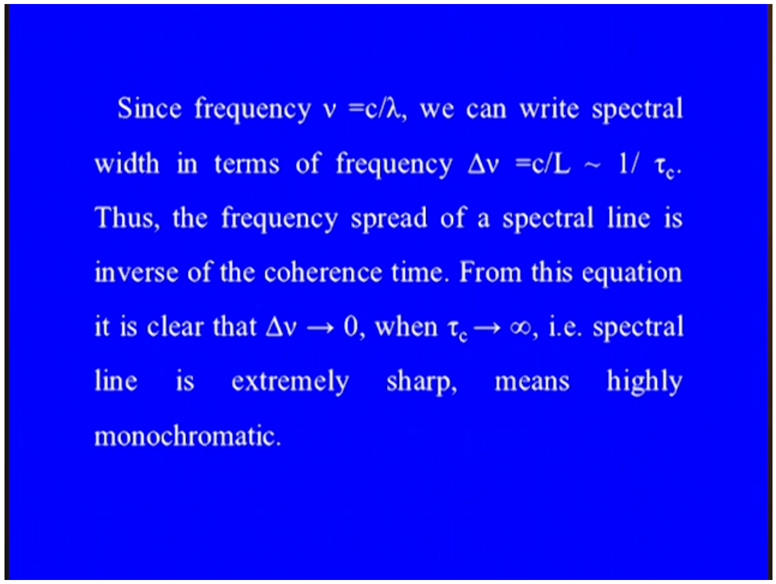

We can write a spectral width in terms of frequency Delta Nu is = c by L which is approximately = 1 over Tau c. Thus the frequency spread of a spectral line is inverse of the coherence lengths. If the coherence time Tau c is large then the value of delta Nu will be small. That is the wave will be more monochromatic. So now, I am going to describe the spatial coherence. That is the correlation between the two points at a certain distance away.

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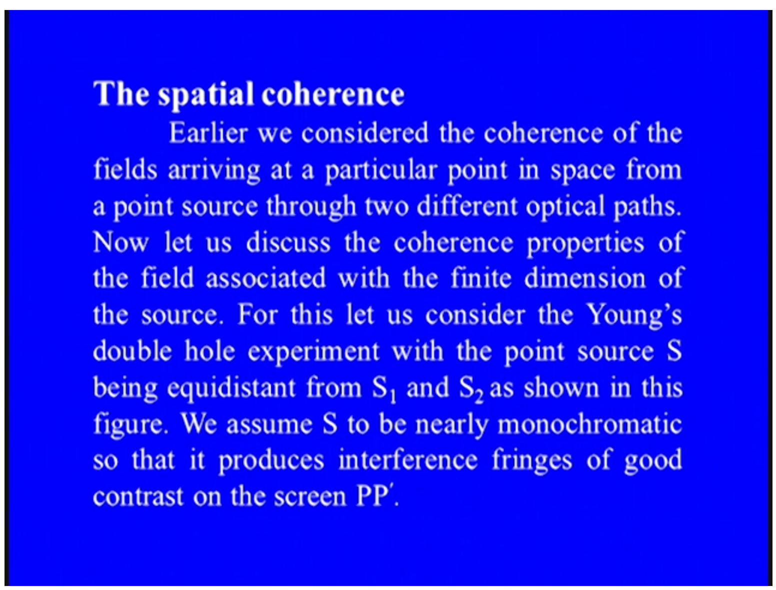

So earlier we considered the coherence of the field arriving at a particular point in space, from a point source, through two different optical paths. Now let us discuss the coherence property, properties of the field associated with the finite dimension of the source.

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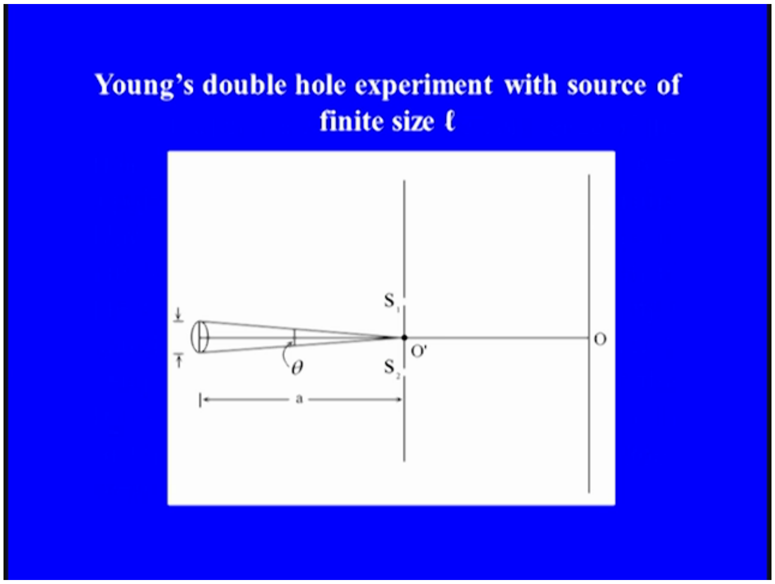

We consider the Young's double-hole experiment with the point source S being equidistance from S1 and S2, we assume S to be nearly monochromatic, so that it produces interference fringes of good contrast on the screen P, P prime. The point O on this screen is such that S1O is = S2O. Clearly the point source S will produce an intensity Maxima around the point O. We next consider another similar source S Prime at a distance L from S.

We assume that the waves from S and S dash have no definite phase relationship. Thus the interference pattern observed on the screen P, P prime will be super position of the intensity distributions of the interference pattern formed due to S and S dash.

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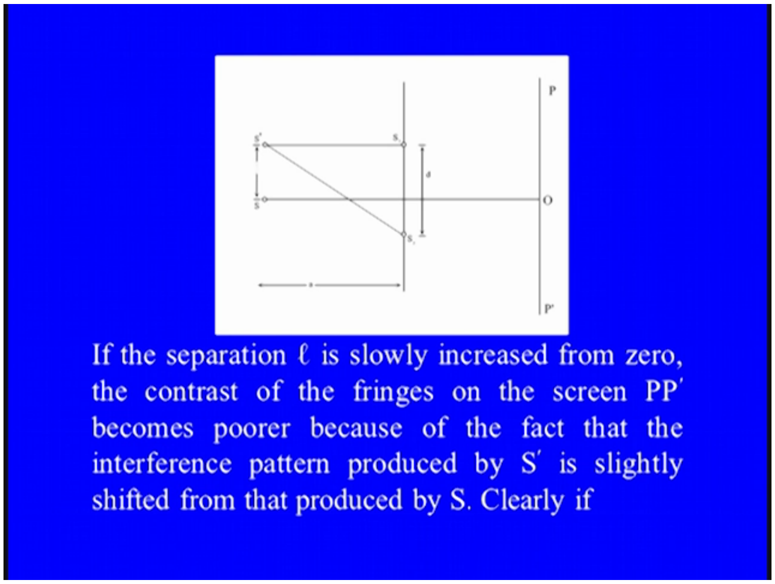

If the separation L is slowly increased from zero, the contrast of the fringes on the screen PP prime becomes poorer because of the fact that interference pattern produced by S dash is slightly shifted from that produced by S.

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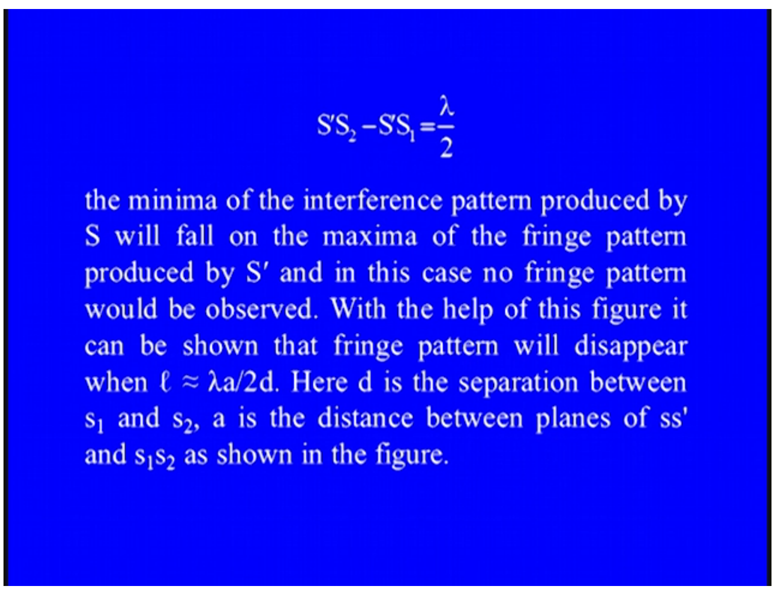

Clearly if S dash S2 - S dash S1 = lambda by 2. The minima of the interference pattern produced by S will fall on the Maxima of the fringe pattern produced by s dash and no fringe pattern will be observed with the help of this figure it can be shown that the fringe pattern will disappear when L is of the order of lambda a upon 2d. Now, if we have an extended incoherent source whose linear dimension is of the order of lambda a, upon d.

Then, for every point on the source there is a point at a distance of lambda upon 2d, which produces fringes which are shifted by half a fringe width. Therefore, the interference pattern will not be observed.

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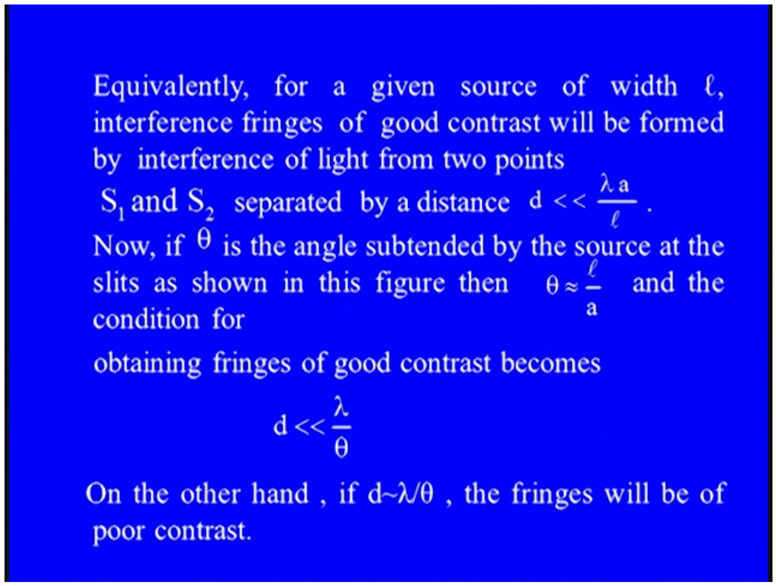

Thus for an extended incoherent source interference fringes of good contrast will be observed only when l is much smaller than lambda a upon d or d is much smaller than lambda a upon l. Equivalently for a given source of width L interference fringes of good contrast will be formed by interference of light from two points S1 and S2 separated by a distance d much smaller than lambda a upon l.

Now if theta is the angles subtended by the source at the slit then theta approximately lambda upon a and the above condition for obtaining the fringe of good contrast takes the form d much less than lambda upon l or d is much smaller than lambda upon theta. On the other hand, if d is approximately lambda by d theta the fringes will be of poor contrast. The distance lambda by theta gives the distance over which the beam may be assumed to be especially current and is referred to as the lateral coherence width l W.