Practical 7
YOUNG'S EXPERIMENT

1 Introduction

Referring to Fig. 1, two coherent light sources S1 and S2 produce an interference pattern on the screen parallel to the line connecting the sources. The distance between two successive interference maxima (or minima), usually called the fringe width Δx, can be calculated if the distance between the sources d and the distance from the sources to the screen L are known. Assuming that $L \gg d$ the fringe width Δx is

$$\Delta x = \lambda L/d, \tag{1}$$

where λ is the wavelength..

In the case of real light sources, an interference pattern is not always observed. For example, two small electric light bulbs do not produce any interference picture. Even two very small slits illuminated by a single lamp does not guarantee an inteference picture. One of the classical optical schemes that allow observing an interference picture is one proposed by T. Young. He used two small holes illuminated by a small or distant source. Using modern terminology, we would say that Young proposed a scheme that satisfies the conditions of spatial coherence.

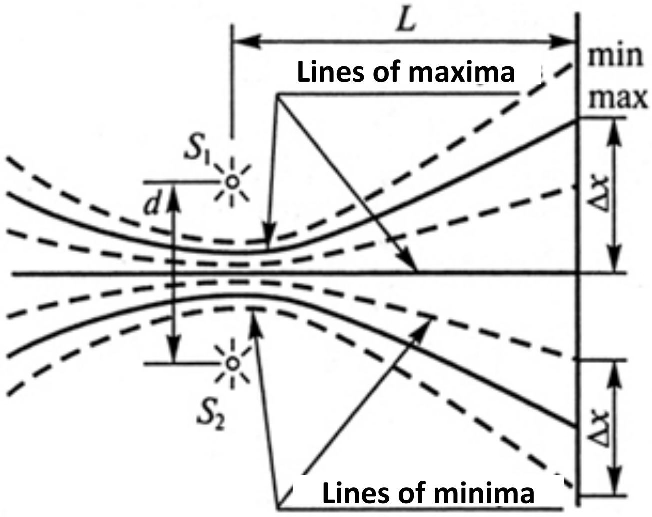

Figure 1: An interference pattern.

Consider Young's scheme (Figure 2), in which the source is located at a relatively small distance from the two holes. Even in the case of an ideally monochromatic source, the interference pattern will only be observed if

$$b\ sin\omega < \lambda/4, \tag{2}$$

where b is the spatial extent of the source (the size of the diaphragm), 2ω is characteristic parameter of the setup called the interference aperture.

Practical 7 includes four parts. In *Part I* you study the dependence of the interference pattern on the parameters b and 2ω. The relationship between these parameters determines the level of the spatial coherence of the setup.

In *Part II* you study the influence of spatial coherence on the interference pattern.

Part III of Practical 7 is devoted to the effect of polarization of

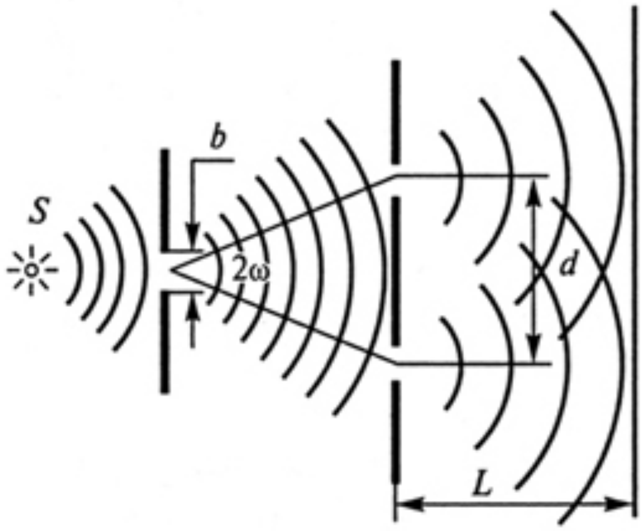

Figure 2: Young's experiment.

light waves on the interference pattern. It is usually assumed that the light waves under consideration are linearly polarized. However, even in the case of two linearly polarized waves, the result of their superposition depends substantially on the angle between the planes of polarization of these waves. It can be verified experimentally by covering the holes in Young's scheme with polaroids that convert natural light (incandescent lamps, gas-discharge lamps) into linearly polarized light of a given orientation.

In *Part IV* you study the effect of the degree of temporal coherence of radiation on the interference pattern. In the case of a real source, the interference pattern only will be observed if the optical path difference does not exceed the coherence length, L_c, of the radiation. As shown in Figure 3, if a glass plate of a thickness a and a refractive index n is placed into the path of one of the light beams, an optical path difference is changed by

$$\Delta = a(n-1). \tag{3}$$

In the case of a glass plate ($n \approx 1.5$), one obtains $\Delta = a(n-1) \approx 0.5a$.

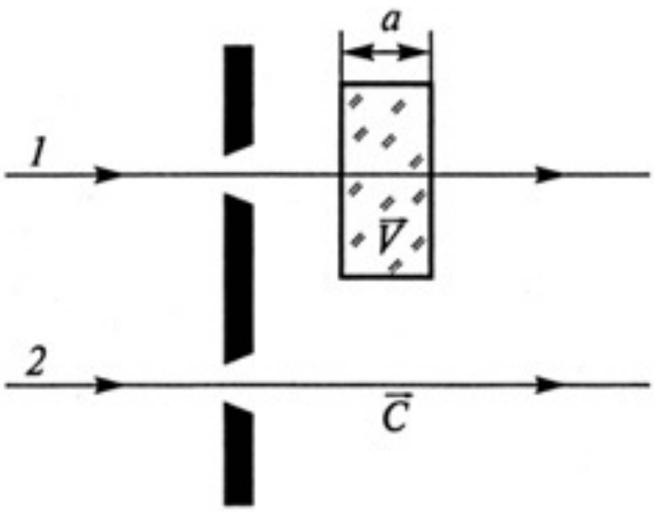

Figure 3: Study of the effect of temporal coherence on the interference pattern.

The interference picture disappears when $\Delta > L_c$, which gives a value of the coherence time as $\tau_c = L_c/c$. As $\tau_c \sim 1/\Delta\nu$, one can estimate the spectral range of the radiation $\Delta\nu$, or $\Delta\lambda$ of different sources of radiation.

The objective of Practical 7: study of the dependence of an interference pattern on the parameters of the setup; estimate the degree of spatial and temporal coherence of radiation produced by different light sources.

2 The experimental setup

Instruments: an incandescent lamp, a mercury lamp, glass filters, a diaphragm, lens, different double slits objects, glass plates, an eyepiece micrometer, an optical bench, polaroids.

The experimental setup is presented in Figure 4. The light from an incandescent lamp or a mercury lamp (1) falls on the slit (2). The width of the slit b determines the size of the source and can be measured with a precision of 0.005 mm. To reduce the spectral range of the radiation between the source slit (2) and two slits (5), a glass filter (8) is placed. Two slits (5) are prepared in a photographic plate. The distance between the slits is indicated on the frame of the photographic plate. In front of the slits a Lens (4) is placed. The Lens (4) converges the light beams from the two slots to the observation point (6), located at a distance L from the slits. You should be able to observe the interference pattern by means of an eyepiece micrometer (7) with a precision of 0.01 mm. The slits objects, glass plates and polaroids are installed on an optical bench. The distance from the slit source to two slits l and from the slits to the observation point L is measured with an ordinary ruler.

2.1 Ocular micrometer

An ocular micrometer is a glass disk that fits in a microscope eyepiece and has a ruled scale, which is used to measure the size of magnified objects (Fig. 5). The physical length of the marks on the scale depends on the degree of magnification. In this Practical a scale of a fixed glass plate consists of divisions which are equal to 1 mm. In the same plane there is a second glass plate (movable) with the cross K and the tics P. Rotating the micrometer screw, you can move the cross and the ticks

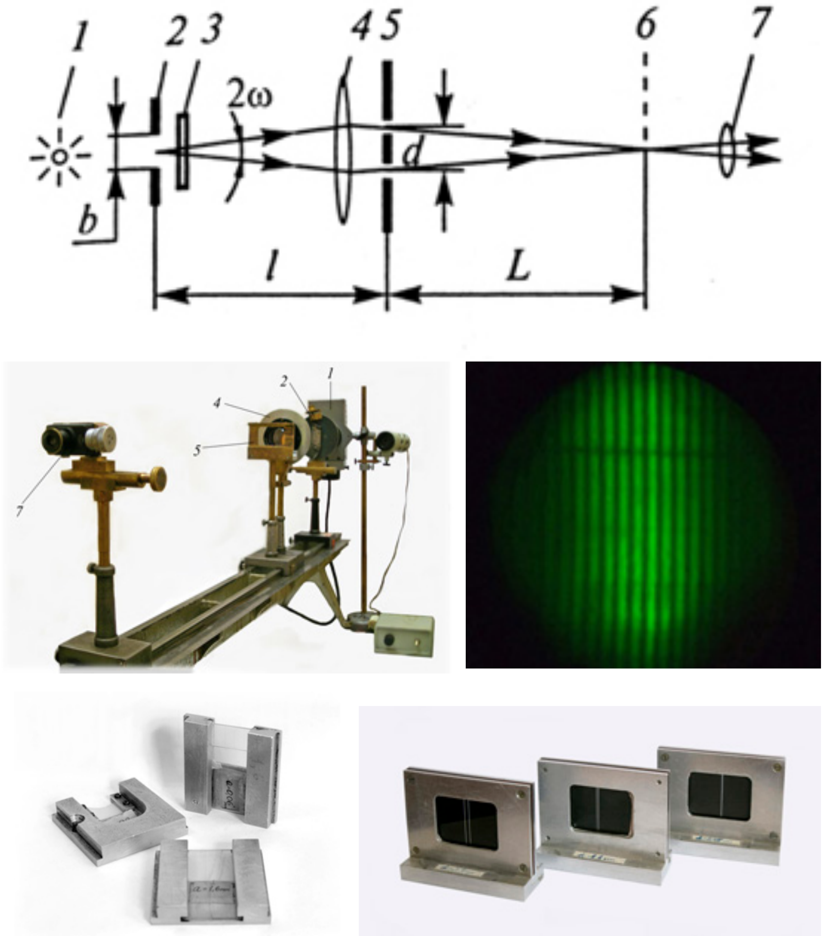

Figure 4: A schematic of the experimental setup.

relative to the fixed scale in the field of view of the eyepiece.

One complete turn of the micrometer screw is 1 mm. When you rotate the screw drum through one complete turn, the cross and the tics in the field of view of the eyepiece will move by one scale division, 1 mm. For counting the hundredths of a millimeter, the scale of the micrometer screw must be used. One division on the micrometer scale corresponds to 0.01 mm.

As an example, assume that the tics in the field of view are located between the 6th and 7th scale divisions of the ocular micrometer and the micrometer screw scale correponds to 21 divisions on the scale. In this case, the total reading is $6 + 0.21 = 6.21$ mm.

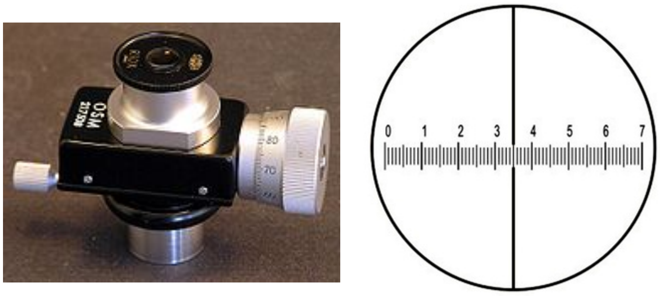

Figure 5: A schematic of an ocular micrometer.

3 Measurements and data processing

3.1 Study of the dependence of the interference pattern on the parameters of the optical setup and determination of the radiation wavelength.

Put the incandescent lamp in front of the source slit so that there is a bright image of the filament in the plane of the slit. With a source slit of a width of ~ 0.5mm and the lens, obtain an image of the slit on an auxiliary screen (for example, a sheet of white paper). Place the eyepiece micrometer at this point. You need to obtain a contrasting and bright image of the slit.

Install a filter behind the source slit, and observe the interference pattern behind the lens and a frame with two slits. If the contrast of the picture is not good enough, adjust the brightness and contrast of the picture by reducing the width of the source slit.

Measure the fringe width Δx and the distance L. For better accuracy, measure the width of several fringes and divide the result by their number. Perform similar measurements using another pair of slits ($d_2 > d_1$), and then change the distance L. *Why does the change of the two slits need to be accompanied by a change of the position of the Lens (4)?*.

Task 1.

Calculate the mean value of the wavelength of the radiation transmitted through the filter in all cases. The results of the measurements and calculations must be presented in a table. The table must contain readings of the micrometer, the calculated values of Δx and λ for different values of L and d. You should also estimate the measurements errors Δx, d, L and $\Delta\lambda$.

3.2 Study of the influence of spatial coherence on the interference pattern.

To perform this part of Practical 7, you need to know the parameters that affect the degree of spatial coherence, i.e. the width of the source slit b and the interference aperture 2ω. The width of the slit can be measured with a scale on the slit frame. The interference aperture can be determined from the distance between the source slit and two slits l (see Figure 4) and the distance between the slits d. If $d \ll l$, one can take $sin\ \omega \approx \omega \approx d/2l$.

You should perform the measurements according to the following procedure. Obtain a clear interference pattern with an object with a small (0.5 mm) gap between two slits. The distance l should be of the order of 30 cm. Measure the values of l, b and d. Tracing the change in the form of the interference pattern, increase the width of the slit to the value at which the picture disappears completely. Record the corresponding gap width b. Move aside the frame with two slits from the source, it will result in increase of the spatial coherence of the radiation incoming on the slit. Observe the changes in the picture and write down the position of the object (a new distance l), at which the picture becomes clearly visible. After that, without changing the width of the source slit b, increase the distance between two slits d and again make the picture disappear.

Task 2.

Write down all the measurements of l, d and b in the table and calculate for each case $b\ sin\ \omega \approx bd/2l$. Compare the obtained values of $b\ sin\ \omega$ with the previously calculated value $\lambda/4$ and formulate the criterion of observing the interference pattern in the experiment.

3.3 Study of the influence of the polarization on the interference pattern.

For this task you need an object with a large enough distance between the two slits ($d \sim 3$ mm). Obtain a clear visible interference pattern as in the previous tasks. Insert the polaroids into the frame of the object table. The orientation of the polaroid axes is indicated on the frame.

Task 3.

Closing the slits with the polaroids (first close slits with differently oriented polaroids, and then both slits with one polaroid), observe the change in the picture. Record the results for cases with different polaroid orientations.

3.4 Estimation of the degree of the temporal coherence of the radiation from various light sources.

In this experiment, the same optical setup is used as in the previous task, but instead of the polaroids, the slits (first one slit and then both slits) are covered with a glass plate of a known thicknesses.

Task 4.

Find the thickness of the plate at which the interference pattern disappears, and estimate the coherence length of the incandescent light with a green filter.

Task 5.

Replace the incandescent lamp by the mercury lamp with a filter centered at $\lambda = 546$ nm. Repeat the same procedure as in Task 4, estimate the coherence length of the mercury lamp.

4 Questions

1) How will you achieve the necessary degree of spatial and temporal coherence in the following interference schemes: (a) Fresnel's double mirrors (b) Fresnel's double lens (c) Newton's rings (d) a plane-parallel plate (e) Michelson's interferometer?

2) Is it possible to change the degree of spatial coherence of radiation without changing its spectral range?

3) Why are rainbow rings visible only in the case of very thin films (for example, gasoline on water)?

4) Are there radiation sources with a coherence length of a few kilometers?

5) Estimate the coherence length of the radiation produced by a radio source if its relative frequency stability is $\Delta\nu/\nu \approx 10^{-6}$, and $\lambda = 30$ m.

6) State possible reasons of the observed difference in the coherence lengths of two sources.