INTERFERENCE
Practical 8.
YOUNG'S EXPERIMENT WITH A LASER

Equipment and accessories: a helium-neon laser, an incandescent lamp, a red light filter, a 40× microlens, a lens with f=20 cm, an objective with f=10 cm, a table with frames for objects, glass plane-parallel plates, polarizers, a measuring microscope, an ocular micrometer, a set of objects slits, a set of pinholes).

1 Introduction

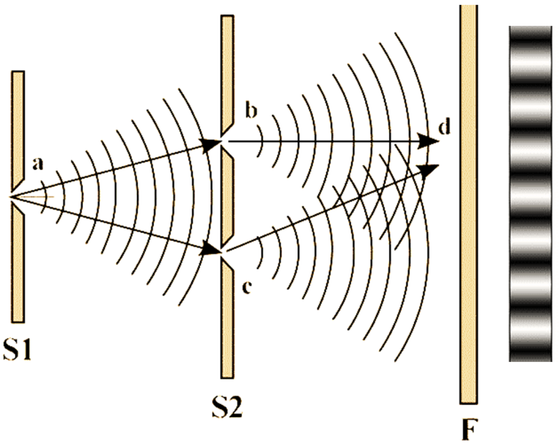

Figure 1: General setup of Thomas Young's Experiment.

Young's interference experiment, also called Young's double-slit interference, was the original version of the modern double-slit experiment. A general schematic of the double-slit interference experiment is shown in Fig. 1. The experiment was originally performed by Thomas Young in the beginning of the nineteenth century providing an immense support for the wave-nature theory of the light. Using an initial pinhole a as the primary light source, Young created a spatially coherent beam that could identically illuminate the two apertures b and c which are spaced apart by a gap d. As a result, a system of alternating bright and dark bands (referred to as the interference fringes) was observed on a screen F. Denoting the distance between the two coherent light sources and the screen as L, and separation between the bright (or dark) fringes on the screen as Δx, one finds that for a given wavelength of the light λ:

$$\Delta x = \frac{L\lambda}{d}. \tag{1}$$

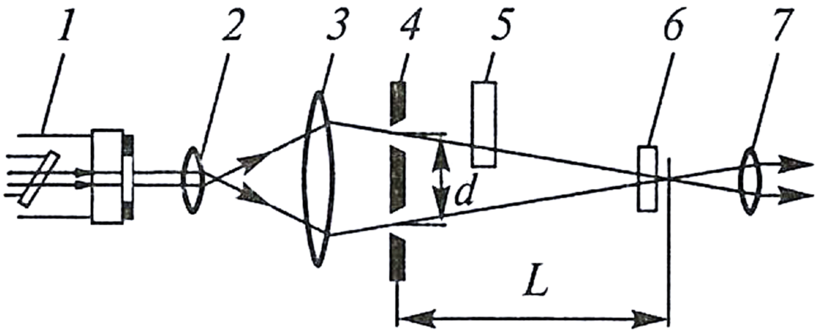

Figure 2: Experimental setup

The first part of the Practical involves calculation of the wavelength of the laser by measuring the distance between the interference fringes. In the second part of the Practical, the effect of the polarization of light waves on the result of their superposition is investigated. The third part is devoted to a comparative evaluation of the temporal coherence of radiation from various light sources: a filament lamp with a red filter and a helium-neon laser given that the average wavelength of the radiation from these sources is approximately the same.

2 Experimental setup

The experimental setup is assembled onto an optical bench and is depicted in Fig. 2. As the light source, a helium-neon laser ***1*** is used. The laser beam is widened by a lens-system which includes a micro-objective ***2*** providing 40× magnification and objective ***3*** an with a focal length *f = 110 mm* . Directly behind the lens is placed a table with a frame for objects ***4*** (which are pinholes in a foil or black paper). The table is followed by a pair of polarizers with the polarization angle adjustable by a rotating frame. A piece of glass ***5*** may be introduced into either of the two optical patches. The interference pattern is observed with the aid of an ocular equipped with a micrometer ***7***, which makes it possible to measure the necessary distances with an accuracy of 0.01 mm. Ocular micrometer is depicted in Fig. 3.

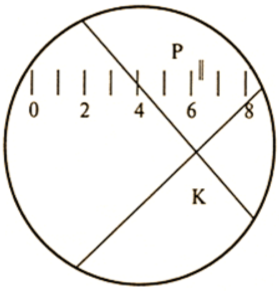

Figure 3: Ocular micrometer.

Ocular micrometer measures the size of the image of an object. In the focal plane of the eyepiece of the micrometer is located a fixed glass plate with a scale, each division of which is equal to 1 mm. In the same plane is placed a second - movable - glass plate with the cross K and the parallel risks P. With the rotation of the micrometer's thimble, the cross and the risks move in the field of view of the eyepiece relative to the fixed scale. One complete revolution of the thimble corresponds to rectilinear movement of 1 mm. One division on the circular scale on the thimble is 0.01 mm. Hence, the rectilinear displacement should be read using both scales.

To reduce the brightness of the observed patterns, an additional polarizer ***6*** is placed in front of the ocular micrometer. (The minimum of light transmission corresponds to the lower position of the red dot on the frame).

For the third part of the practical, an auxiliary setup assembled on the same table is used. It includes an incandescent lamp, a red filter, a slit, an objective, a table with a frame for objects and an ocular micrometer.

Attention! When working with a laser, the following precautions should be taken:

1. Do not turn the laser *on* or *off* by yourself. **The laser is always on!**
2. Never look at the laser beam by a naked eye as it may be extremely dangerous for the eye.
3. Before you start the observations with the ocular micrometer make sure that the pinholes are installed into the laser beam and that the intensity of light transmitted by the polarizer ***6*** is minimal (using a sheet of paper placed in front of the ocular).
4. Before removing the object ***4*** or altering its position, make sure that no one is looking into the micrometer eyepiece.

3 Measurement and data processing

3.1 Task 1. Determination of the laser wavelength

1. Check on the setup. Observe a bright and uniformly illuminated circle with a diameter of ~ 20 mm using a piece of paper placed behind the lens ***3***. Moving the paper away from the lens, make sure that the light beam converges to a point approximately in the focal plane of the ocular.
2. Using a microscope, measure the distance d between the pinholes.
3. Insert the object into the frame ***4*** and make sure that the position of the polarizer ***6*** corresponds to the minimum of light transmission. Observe the interference pattern. If the brightness of the picture is insufficient, increase it rotating the polarizer.
4. Measure (for the selected pair of pinholes, e.g., object *#1*) the distance between the interference fringes Δx and the distance from the pinholes to the observation point L which is the ocular micrometer frame facing the light. In order to improve accuracy of the measurement, measure the width of N = *10, 20, 30* fringes and then calculate Δx. Repeat the measurements by placing the micrometer at a different distance from the object.
5. Perform similar measurements by taking another pair of pinholes (object *#2*) with a different distance between them.
6. Knowing *d, L*, and Δx, calculate the wavelength of the laser for all cases. Tabulate the measurement results. Estimate the measurement error $\Delta\lambda$.

3.2 Task 2. Investigation of the wave superposition depending on their relative polarization angle

Use a pair of pinholes separated by ∼10 mm. Set a pair of polarizers onto the optical bench after following the pinholes so that the light beams emerging from the pinholes pass through different polarizers. Rotating their frames, observe the change in the intensity of the beams, find the position in which the beam intensities are maximal (the polarizers' axes are parallel to the direction of the electric field of the laser beam). After this, it is useful to verify that the laser radiation is linearly polarized: when the polarizers are rotated by 90°, the intensity of the beams should become minimal.

Attention! For all further observations, the installed pinholes **MUST NOT** be removed from the optical bench!

Rotating the polarizers (one clockwise and the other counter-clockwise), note the difference in the pattern for cases where the angle between the polarizers' axes is 0°, 30°, 50°, and 90°. Investigate the observed pattern dependence on the orientation of the third polarizer placed in front of the eyepiece.

3.3 Task 3. Study of the temporal coherence of light irradiated by different sources

Turn on the incandescent lamp and observe the interference of the radiation transmitted by the red filter. Here, the Young scheme with the two slits is implemented because of a comparatively low brightness of the source. Nevertheless, this does not alter the experiment principally. In the path of light after the slots, place the thinnest glass plate. Overlapping one slit first, and then both, observe the changes in the interference pattern.

Knowing the thickness and refractive index of the plate, and taking into account that the optical path length (OPL) or optical distance is the product of the geometric path, and the index of refraction of the medium (i.e., $OPL = \ell_{geom} \cdot n$), estimate the coherence length of the radiation transmitted by the red filter.

Perform similar operations using the former setup. Use glass plates of different thicknesses (up to 40 mm). Estimate the coherence length of the laser radiation and compare the result with that of the incandescent lamp. Compute the temporal coherence for both of the sources.

4 Questions

1. What kind of interference pattern will there be from two coherent point sources if one observes it on a screen whose plane is perpendicular to the line connecting the sources?
2. What will be the picture if the plane of the screen is parallel to this line?
3. Estimate the size of the source, which makes it possible to observe the interference pattern from two holes spaced 20 mm apart and located 10 cm from the source.
4. Is it possible to observe the interference of laser radiation by applying a plane-parallel plate several centimeters thick?
5. Estimate the coherence length of the laser radiation if the obtained interference pattern ceases to be clearly visible when the path difference of the interfering beams reaches 10 m.
6. Is it possible, using the radiation of a heated body, to achieve the same degree of spatial coherence as in the case of laser radiation?