# Practical 11
# DIFFRACTION OF LASER RADIATION

## 1 Introduction

The high degree of coherence of laser radiation gives us an excellent opportunity to study diffraction phenomena. The results of experiments with lasers are very clear and easily reproducible. In this case it is easy to overcome the limitations related to the size of the source, the size of the diffraction object in comparison with the distances at which a diffraction pattern can be observed.

In the case of diffraction of a plane wave on a single slit of width $b$ (Fraunhofer diffraction), interference (diffraction) minima are observed in directions determined by the condition

$$sin\ \phi_{min} = \lambda/b; 2\lambda/b; .. \tag{1}$$

In Fig. 1, the dashed line shows the intensity distribution in diffraction at one slit for the central part of the picture (between the minima of the first and the minus first order).

The intensity distribution in diffraction on two parallel slits of width $b$ with centers located at a distance $d$, is presented in Fig. 1 by a solid line.

The maxima of diffraction on two slits are observed along the directions determined by the distance between the slits:

$$sin\ \phi_{max} = \lambda/d; 2\lambda/d; .. \tag{2}$$

The number of minima $M$, that cover the central maximum of diffraction on one slit, is equal to

$$M = 2[d/b]. \tag{3}$$

The number of maxima observed in the region of this central maximum exceeds the number of minima:

$$L = M + 1 = 2[d/b] + 1. \tag{4}$$

In the case of diffraction by three or a greater number of slits (at constant $d$), the position of the maxima determined by expression 2 remains unchanged, so they are called the main maxima. An increase in the number of slits results in the appearance of additional maxima and minima between the main maxima. The number of maxima increases in proportion to the number of slits $N$.

Practical 11, *Part I* proposes the study of diffraction of laser radiation by objects of simple forms (a slit, a circular hole, etc.). In *Part II*, you will observe a change in the number of additional maxima, as well as the width and intensity of the main maxima with an increase in the number of slits. The final experiment is the observation of a diffraction pattern by a diffraction grating.

*The objective of Practical 11*: Observation of diffraction of laser radiation by objects of the simplest configurations.

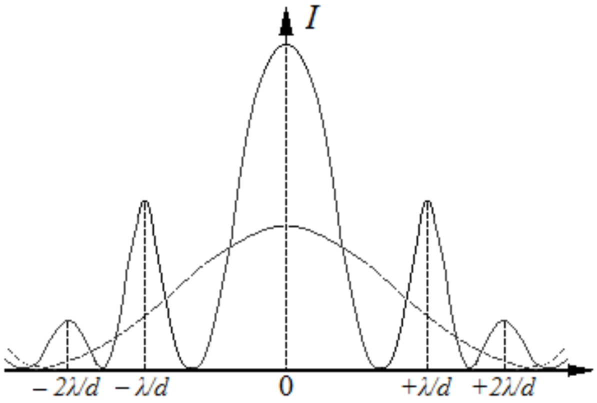

Figure 1: Diffraction pattern produced by two slits (dashed line). The solid line corresponds to the intensity distribution in diffraction on two parallel slits of width $b$ with centers located at a distancw $d$.

## 2 The experimental setup

*Instruments*: For *Part I* - a helium-neon laser, concave lenses, a set of different objects for observing diffraction. For *Part II* - a collimator, a cylindrical lens, an objective, a telescope, a polaroid, an ocular micrometer, a set of various objects.

A schematic of the experimental setup used in *Part I* is shown in Figure 2. The helium-neon laser is used as a source. To observe Fraunhofer diffraction, the laser beam is used without any additional transformation. To observe Fresnel diffraction, the beam is made divergent by means of the Lens 2. Diffraction patterns are observed on the Screen 4. The Lenses, the Screen and the Holder 3 for diffraction objects are installed on the optical bench in rheaters. The rheaters can be moved along the optical bench for achieving the best observation conditions.

A schematic of the experimental setup used in *Part II* is shown

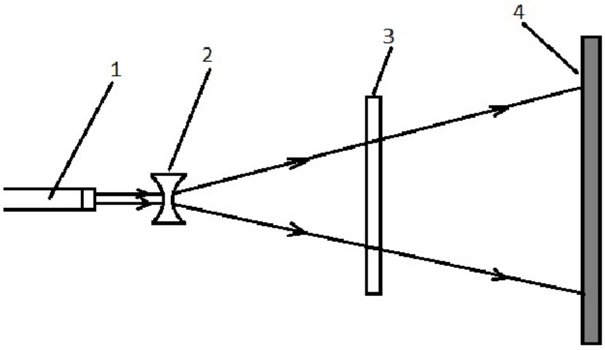

Figure 2: A schematic of the experimental setup for observation of diffraction of simple objects.

in Figure 3. A laser beam with a collimator 2 (a telescope is set to infinity) is converted into a wide parallel beam. To investigate diffraction phenomena at slit-type objects, you should use a cylindrical lens 3 and an objective 4. It allows to obtain a ”narrow” light source parallel to the slit. After the Collimator 2, the plane front of light waves is transformed by the Lens 3 into a cylindrical one. In the focal plane of this lens, the light beam is compressed into a narrow vertical strip, which serves as a source. It is useful to verify the conversion of the light beam by moving a sheet of white paper between Lens 8 and Lens 4. Using a cylindrical lens allows you to dispense with a real slit diaphragm. Behind the cylindrical lens 8, you should place Lens 4 at a distance equal to the sum of the focal lengths of the lens and the objective (the positions on the bench of the lenses are fixed). At some distance from Lens 4 the beam is converged into a narrow horizontal strip. Here, you should place the diffraction object 5. Since in this position a small area of the slit or grating is illuminated and the object defects do not affect on the quality of the diffraction pattern.

A diffraction pattern is observed in the telescope $b$ with an eye-

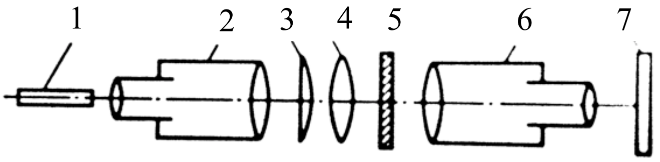

Figure 3: The experimental setup for observation of Fraunhofer diffraction on two or more slits.

piece micrometer. For example, you can obtain the diffraction pattern from the slit (or from the grating) in the field of view of the tube by measuring the distances between the maxima. If you know the focal length of the tube objective and the width of the slit (or the grating period), you can determine the wavelength of the light.

To reduce the intensity of linearly polarized laser radiation, you should use the polaroid 7 fixed on the eyepiece of the telescope 6. It is forbidden to start observations in the telescope without checking first that the polaroid is installed at an angle that ensures the minimum of light passing. When changing of a diffraction object, you should temporarily stop observations in the telescope. Before observations with a new object, you should again check the polaroid setting for minimum illumination.

The laser can only be switched on and off by a lab assistant or a teacher.

# 3 Measurements and data processing

## 3.1 Diffraction by objects of simple forms.

### Task 1. Observation of Fraunhofer diffraction patterns produced by a slit.

Obtain on the screen a diffraction pattern from the slit. You should remove the diverging Lens 2, place the slit in $30 - 40$ cm from the source, and set the screen at the end of the bench. Changing the width of the slit, observe the changes in the diffraction pattern. Draw features of the pattern for wide and narrow slits and indicate how the width of the slit affects the distance between the diffraction peaks.

### Task 2. Study and description of diffraction patterns produced by diffraction gratings.

Obtain a diffraction pattern from a one-dimensional diffraction grating. The configuration of the optical set-up is the same as in Task 1. Observe diffraction patterns for the vertical and horizontal arrangements of the grating. Then obtain a diffraction pattern for a two-dimensional grating.

Calculate the periods of the two-dimensional grating in horizontal $d_1$ and vertical $d_2$ directions. To do that, use the relations $d_1 \ sin\phi_1 = m_1\lambda_1$ and $d_2 \ sin\phi_2 = m_2\lambda_2$ , which determine the directions along which the principal maxima are observed. Here, $m_1$ and $m_2$ are integers that determine the order of the maximum. Determine the values of $\lambda_1$ and $\lambda_2$ from the relations $sin\phi_1 \approx \Delta x/L$ and $sin\phi_2 \approx \Delta y/L$, where $\Delta x$ is the distance from the zeroth-order maximum to the maximum of the order $m_1$ in the horizontal direction, $\Delta y$ is the corresponding distance from the zeroth-order maximum up to a maximum of the order $m_2$ in the vertical direction, $L$ is the distance from the grating to the screen, and $\lambda$ the wavelength of the laser radiation ($\lambda = 633$ nm).

The results of your measurements and calculations ($L$, $\Delta x$, $\Delta y$, $m_1$, $m_2$, $d_1$ and $d_2$) should be written down into a Table.

**Task 3. Observation of Fresnel diffraction patterns from different obstacles in a slightly divergent beam.**

Using the Lens 1, obtain on the screen a diffraction pattern from a circular obstacle, the steel ball of a diameter of $4 \sim 6$ mm.

Moving the object between the screen and the lens, observe the changes in the pattern and draw a picture after a light spot appears in the center of the shadow, the so-called Poisson spot.

Obtain a diffraction pattern from a narrow long strip (a wire, or a pin, etc). Draw pictures of the diffraction patterns for the cases when the diffraction object is (a) near the screen (b) near the lens (c) at some middle position.

**Task 4. Observation of Fresnel diffraction patterns produced a circular hole in a divergent beam.**

To obtain a diffraction pattern produced by the circular hole, use the Lens 2 that provides a greater beam divergence than the Lens 1. Moving the hole relative to the Lens, obtain the diffraction pattern corresponding to two, three, four, five and six (or more, if possible) Fresnel zones that are cut out of the wavefront by the hole.

## 3.2 Diffraction by slits.

### Task 5. Study of diffraction pattern by one slit and determination the light wavelength.

Place the diffraction object (slit) behind the lens at the narrowest point of the beam. Obtain the diffraction pattern produced by one slit and calculate the light wavelength, knowing the width of the slit $b$ (it is indicated in the specifications).

For calculalions use the minima condition for diffraction by one slit (Eq. 1), assuming that $sin\phi_m \approx x/f$, where $f$ is the focal length of the telescope (in this Practical $f = 40$ cm), $\Delta x$ is the distance from the center of the diffraction picture to a minimum of the m-th order. You should determine $\Delta x$ by means of the ocular micrometer.

The measurements will be more accurate if you determine $2\Delta x$, the distance between two minima of the same order to the left and to the right of the center of the picture, instead of $\Delta x$.

Record the results of measurements and calculations in a Table ($2\Delta x$, $f$, $sin\phi_m$, $\lambda$).

### Task 6. Study of diffraction pattern produced by two slits.

A plate with two slits is equipped with a special curtain, which allows cover the slits separatly.

Observe the pictures from each slit separately, and then from both slits together. For the diffraction pattern produced by the two slits, calculate the number of minima and maxima arising in the region of the central maximum due to diffraction by one slit, and make a conclusion about the relation between $b$ and $d$ for a given slits (see relations (3) and (4)).

Then calculate $2b/d$ by measuring $b$ and $d$ with the ocular. Compare the results obtained by direct measurement, $2[d/b]_{meas}$, and from the diffraction pattern, $2[d/b]_{dif}$.

Record the results of measurements and calculations in a Table ($b$, $d$, $2[d/b]_{meas}$, $2[d/b]_{dif}$).

### Task 7. Study of diffraction pattern by several slits.

Using a set of plates with several slits, obtain diffraction patterns produced by $N$ slits ($N$ changes from 2 to 9). Note that the number of additional maxima corresponding to the given number of slits $N$.

Put down the results of your measurements and calculations in to a Table. Draw different diffraction patterns from 2, 3, 4 and 5 slits.

In the report, indicate how the number of additional maxima and minima depends on the number of slits, and whether the position of the main maxima changes when moving to a larger number of slits. It can be determined by marking the maximum position by means of the cross threads in the field of view of the ocular micrometer.

### Task 8. Study of diffraction pattern produced by the diffraction grating as the number of slits changes.

Install a diffraction grating between the lens and the tube. Also set just before the grating a sliding slot. Obtain a picture from the diffraction grating (with the gap of the sliding slot being maximally extended). By reducing the effective number of grating slots with the help of a sliding slit, observe changes in the diffraction pattern. Find out how the distance between the main maxima, their sharpness, and the ratio between the intensities of the main and additional maxima change with an increasing number of slits.

### Task 9. Study of diffraction pattern from produced by a rectangular and circular holes.

To obtain a diffraction pattern by a rectangular hole, a source in the form of a gap is non-effective. You should remove the cylindrical lens 8 and the objective lens 4 from the bench.

Obtain diffraction patterns by the square with a side $a$, by the square with a side $b$ and by the rectangular hole with sides $a$ and $b$.

Draw all three diffraction patterns. Find out the dependence of the diffraction pattern on the rectangle orientation.

Obtain and draw a picture of the diffraction pattern by a circular hole. Note how the observed pattern differs from the diffraction patterns by the circular aperture observed with the use of Fresnel method.

## 4 Questions

1) Formulate the Huygens-Fresnel principle.

2) What is the difference between the conditions of observation of Fresnel diffraction and Fraunhofer diffraction?

3) What is the significance of the degree of coherence of the light used to observe diffraction patterns?

4) Why is it expedient to use laser radiation for observation of diffraction produced by two or several slits?

5) Why is it expedient to use a diverging lens of a small optical power for observation a diffraction pattern produced by a round object (ball)?

6) How is the beam of laser radiation formed between the collimator and the telescope in the experimental setup?

7) Draw the path of the rays in the vertical and horizontal cross-section of the beam.

8) How will the observed pattern change if a slit or a grating (in Tasks 5-7) is moved across the beam?