# *Fraunhofer diffraction at a slit*

<u>Experiment Objective:</u> Investigating the diffraction phenomena of a parallel light beam at diffraction at a slit.

<u>Tasks:</u>

- to acquire skills of the optical scheme for observing the diffraction of a He-Ne laser as a light source;
- to observe the diffraction pattern of a slit at different slit widths visually on the screen by the VideoCom system;
- to determine the slit width by the distance between the minima on the screen;
- to verify the linear dependence of the distance between the minima of the diffraction pattern of the inverse slit width by the VideoCom system;
- to measure the dependence of the distance to the n-th minimum of its order n.

<u>Optical elements and apparatus:</u>

- ✓ He-Ne laser (1);
- ✓ lens in frame, f = +5 mm (2);
- ✓ lens in frame, f = +50 mm (3);
- ✓ polarization filter (4)
- ✓ adjustable slit (5)
- ✓ lens in frame, f = +50 mm (6);
- ✓ VideoCom radiation-measuring instrument (7)
- ✓ PC (8)
- ✓ optical bench (9)
- ✓ optics riders (10)
- ✓ translucent screen (11)
- ✓ diaphragm with a fixed width slits (12)
- ✓ holder with spring clips (13)

Diffraction is a deviation from the laws of geometrical optics in wave propagation. It is one of the proofs of the wave character of light. Diffraction phenomena always occur when the free propagation of light is changed by obstacles such as iris diaphragms or slits. The deviation from the rectilinear propagation of light observed in this case is called diffraction.

When diffraction phenomena are studied, two types of experimental procedure are distinguished:

In the case of Fraunhofer diffraction, parallel wave fronts of the light are studied in front of the diffraction object and behind it. This corresponds to a light source which is at infinite distance from the diffraction object on one side and, on

the other side, a screen which, too, is at infinite distance from the diffraction object.

Experimentally, this is realised with the aid of converging lenses, which are placed in the ray path, e.g., between the light source and the diffraction object.

In the case of Fresnel diffraction, the light source and the screen are at a finite distance from the diffraction object. With increasing distances, the Fresnel diffraction patterns are increasingly similar to the Fraunhofer patterns. Calculating the diffraction patterns in easier in the case of Fraunhofer diffraction. Therefore the experiments described here are based on Fraunhofer's point of view.

Diffraction of the incoming parallel light at the slit aperture causes the light to propagate also in the geometrical shadow of the slit diaphragm (Fig.1). A pattern of bright and dark fringes is observed on the screen. The condition of being in a certain point of a minimum screen looks like:

$$b \sin \varphi = n\lambda, \qquad n = 1, 2, 3\ldots \tag{1}$$

where $d$ – slit width, $\varphi$ - direction in which the tracing point screen is observed, $\lambda$ – wavelength of the incident light, $n$ - the order of the minimum.
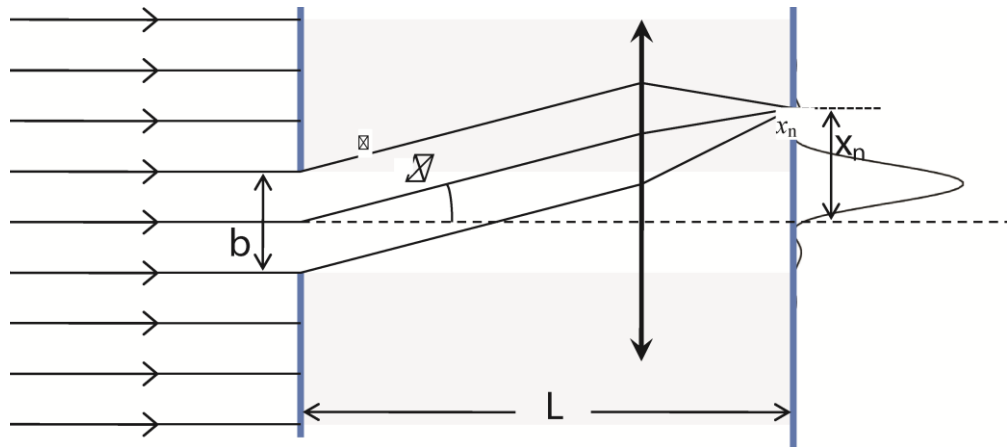


Fig.1. Schematic representation for the Fraunhofer diffraction of light at a slit.

For small diffraction angles $\varphi$ and a large screen distance $L$, we can use the approximation:

$$\sin \varphi \approx \varphi \approx \frac{x_n}{L} \tag{2}$$

Thus, from the condition (1):

$$b \frac{x_n}{L} = n\lambda \tag{3}$$

Thus, it is possible to determine the unknown slit spacing $b$ from a diffraction experiment with monochromatic light of known wavelength and the distance $L$.

If the slit width can be changed the plot of the reciprocal distance between two clearly expressed minima of the same order $2*x_n$ of slit width $1/b$ will be a straight line.

Procedure:

*Exercise 1. Assembly installation for observing diffraction at a slit. The observation of diffraction patterns at a slit with various slit spacing by VideoCom system.*

Assemble the installation which is shown in Fig. 2.



Fig.2. Experimental setup for observing diffraction at a slit by VideoCom system.

**Safety notes**
**The He-Ne laser meets the requirements according to class 2 of EN 60825-1 "Safety of laser equipment". If the corresponding notes of the instruction sheet are observed, experimenting with the He-Ne laser is safe. Never look into the direct or reflected laser beam. No observer must feel dazzled.**

All optical elements must be installed at the same height.

Using a rider (10), mount the He-Ne laser (1) to the optical bench (9). Place the adjustable slit (5) on the optical bench at a distance of approx. 50 cm from the laser. Direct laser parallel to the optical bench. Switch it on by turning the key to "1" on the back of the laser. Adjust the height of the laser so that the laser beam passes the middle of the diaphragm.

Place the spherical lens (2) with the focal length f = +5 mm in front of the laser at a distance of approx. 1 cm (the laser light has to cover the diaphragm).

Position the lens (3) with the focal length f = +100 mm behind the spherical lens (2) at a distance of approx. 10-11 mm, and displace it along the optical bench (9) towards the spherical lens (3) until the laser beam is imaged sharply on the screen. Displace the converging lens (3) on the optical bench somewhat further

towards the spherical lens (2) until the diameter of the laser beam on the screen is approx. 6 mm (now the laser beam should have a constant circular profile along the optical axis). In order to check whether the beam diameter of the laser is constant between the lens and the screen, hold a sheet of paper in the ray path and follow the profile of the laser beam along the optical axis.

Move the diaphragm with the slit closer to the laser. The distance between the laser and the diaphragm should be 35 cm. Make sure that the laser beam is still in the center of the slit.

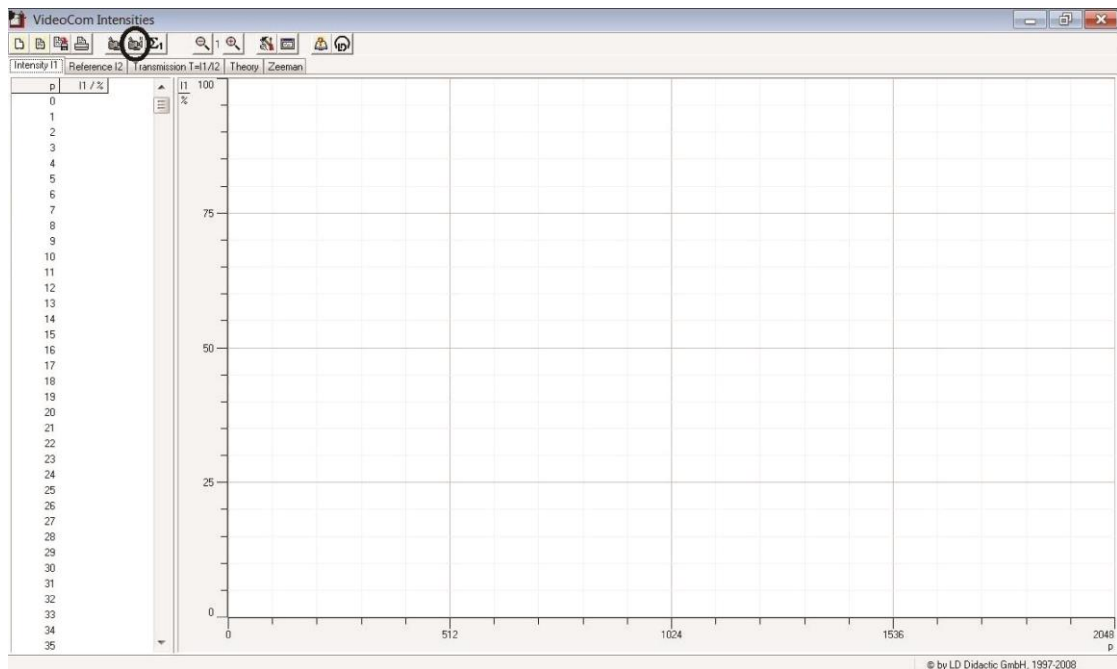Put the polarization filter (4) between the converging lens (3) and the adjustable slit (5).



Fig.3. VideoCom Intensities program window. Button to start measuring at 2048 pixels is marked. Pixels plotted on the X axis, incident light intensity in % plotted on the Y-axis.

At the opposite end of the optical bench set radiation detector VideoCom 7

Mount the VideoCom radiation-measuring instrument (7) to the end of the optical bench opposite the laser.

The closest to the body of the VideoCom radiation-measuring instrument scale on the lens corresponds to the width of the aperture of the lens, it should be set to 1.5, which corresponds to the maximum width of the aperture. The second scale should be set to ∞. Connect the VideoCom radiation-measuring instrument to the PC (8) by USB connector. Run the program «VideoCom Intensities» on the computer. Use the scale on the back side of the diaphragm with a slit (5) to set the slit width of 0.6 mm. The «VideoCom Intensities» program window is shown in Fig. 3. Press the corresponding key, or press F9 on the keyboard to start a measurement in the program. The same keys stop the measurement.

If the experimental setup installed correctly a narrow intense signal in the central range of the scale of the program should be observed (the intensity of the incident light on the receiver can be regulated by turning the polarizer, wherein 0 corresponds to the position of the maximum intensity, 90 - light does not pass). When the polarizer is fully opened (position 0) the intensity of the observed signal must be > 100.

Received the an intense signal from the receiver to add an extra lens (6) with the focal length f = +50 mm in front of the VideoCom objective. At the same time partially rotate the polarizer (~ 45°). The lens must be set so that the ring around the lens is aligned with the outer casing the objective. Running the measurement in the «VideoCom Intensities» program and adjusting the intensity of radiation by a polarizer, get on the computer screen diffraction pattern from a slit. An intense maximum in the center and a few higher-order peaks with lower intensities on both sides of it should be observed.

Change the width of the slit (0.2 mm, 0.4 mm, 0.6 mm, 0.8 mm) to obtain the diffraction patterns for the different widths of the slit on the computer screen. Measure the distance in pixels between the two second minima for each fixed-width (allowed to measure the distance between the third minima, but for all the slit widths used minimum order must be the same). Press the key combination Alt + Z and highlight the desired area with the mouse if you need to expand a part of the program window. Reverse scaling - Alt + O.

Record the results in the table:

| slit spacing, $b$/mm | The distance between the first minima, $2x_n$/ pixel |
|---|---|
|  |  |

Plot the distance between the minima of the inverse slit width $x_n = f(1/b)$.

*Exercise 2. Determination of the dependence of the distance to the minimum from its order.*

Experimental setup is the same as in Exercise 1.

Set the slit width of 0.6 mm using a scale on the rear surface of the diaphragm with an adjustable slit. Get a clear picture of the diffraction pattern on a computer screen. Stretch the required area of the image on the screen. Measure the distance in pixels between the minima n = 1, 2, 3, … while it is possible but not less than 3 points. To determine the distance between the minima of the n = 3 and more the intensity of incident light can be increased by turning the polarizer in corresponding side.

Record the results in the table:

| The order of the minimum, $n$ | The distance between the $n$ minima, $2x_n$/ pixel | $x_n/n$ ratio, (mm/pixel) |
|---|---|---|
|  |  |  |

*Exercise 3. Determination of the slit width from the diffraction pattern.*

In this exercise, the diffraction pattern from the slit is observed visually on a translucent screen. For this purpose, the polarizer (4), lens (6), VideoCom radiation-measuring instrument (7) should be removed from the optical bench (10). Then replace the diaphragm with an adjustable slit (5) by the holder with spring clips (13) and insert the diaphragm with a fixed width slits (12) in the holder with spring clips. Using a rider (10) mount the translucent screen at the end of the optical bench.

Experimental setup is shown in the Fig.4.



Fig. 4. Experimental setup for observing diffraction at a slit on the translucent screen. $L_1$ and $L_2$ are lenses with the focal length f = +5 mm and f = +50 mm. H - diaphragm with 3 fixed width slits which is inserted in a holder with spring clips, S - translucent screen.

Carefully (do not touch your fingers the transparent part of the diaphragm with a fixed width slits (12)) move the diaphragm in the spring holder so that the laser beam passes completely for one of the slit on the diaphragm. A diffraction pattern of fringes appears on the screen. Consistently observe the diffraction pattern on the screen from all three slits. If necessary, the laser beam intensity can be temporarily increased by pressing the button on the end of a flexible shaft, exiting the top of the housing a helium-neon laser. In this case the gray filter that covers the outlet of the laser is shifted. Put a sheet of paper on the screen and mark using a soft pencil the locations of the first minimum of the diffraction pattern for all three slits. Turn off the laser by turning the key to "0". Measure the obtained distance $2x_{1i}$ with a ruler. Record the results. Also it is necessary to measure the distance $L$ between the slit and the a translucent screen to determine the slit width. Considering the wavelength of helium-neon laser is 632.8 nm determine the slit with of slit $i$, where $i = 1, 2, 3$ in formula:

$$b_i = \frac{L\lambda}{x_{1i}} \qquad (4)$$

Record the obtained values.