Fraunhofer diffraction at one- and two- dimensional gratings

Experiment Objective: Investigating the diffraction phenomena of a parallel light beam at a periodic structure.

Tasks:

- to observe the diffraction pattern at a one-dimensional grating with different numbers of lines per cm visually on the screen;
- to observe the diffraction pattern at a two-dimensional grating visually on the screen;
- to measure the distance between the maxima in the diffraction pattern of one-dimensional grating and determine a slit spacing d (g - a notation on the slit);
- to determine a wavelength of a helium-neon laser from the diffraction pattern of two-dimensional diffraction grating.

Optical elements and apparatus:

- ✓ He-Ne laser (1);
- ✓ holder with spring clips (2)
- ✓ diaphragm with 3 one-dimensional gratings 469 87 (3)
- ✓ diaphragm with 2 two-dimensional gratings 469 88 (4)
- ✓ optical bench (5)
- ✓ optics riders (6)
- ✓ translucent screen (7)
- ✓ sled tripod (8)

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.

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.

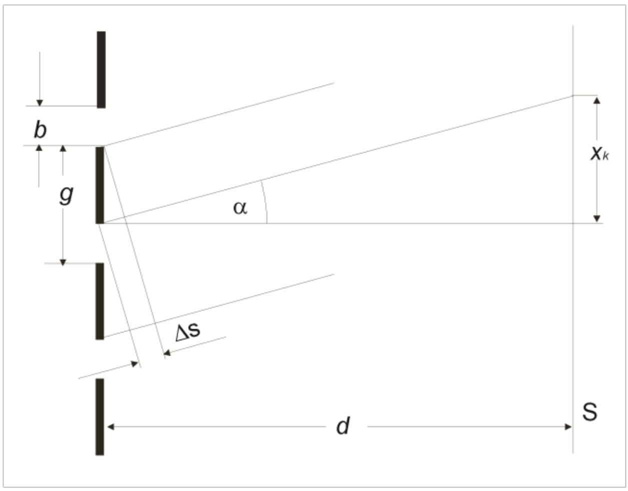

Fig.1. Geometrical relations in the diffraction of light at a groove grating. *b* - slit width, *d* - slit spacing, *L* - distance between the screen S and the slit, x_n - distance of the n-th intensity maximum from the centre.

Due to the diffraction of the incoming parallel light at the grating with a period *d* (see Fig.1), the light propagates into the geometrical shadow area. A pattern of bright and dark fringes is observed on the screen. Maximum condition at a certain point the screen remote from the center by a distance x_n is:

$$n\frac{\lambda}{d} = \frac{x_n}{L} = 1,2,3\ ... \qquad (1)$$

where λ – wavelength of the incident light, *n* - the order of the maximum. Here we supposed that $L >> d$.

Thus, knowing the wavelength of the light source and the distance *L*, from the diffraction pattern observed at a slit, an unknown slit spacing *d* can be determined. If the slit spacing is known it is possible to determine a wavelength of the light source from the diffraction pattern on the screen.

In an arrangement of N slits of width *b* and spacing *d*, the intensity distribution on the screen is given by:

$$I(\alpha) = \frac{\sin^2\left(\frac{\phi}{2}\right)}{\left(\frac{\phi}{2}\right)^2} \cdot \frac{\sin^2\left(\frac{N}{2}\varphi\right)}{\sin^2\left(\frac{\varphi}{2}\right)}, \qquad (2)$$

where $\phi = \frac{2\pi}{\lambda} b \sin\alpha$ and $\varphi = \frac{2\pi}{\lambda} d \sin\alpha$.

The second factor on the right-hand side of equation (2) describes a periodic sequence of intensity maxima and intensity minima which would be observed in the case of diffraction at an arrangement of N equally spaced, infinitely narrow slits. The first factor on the right-hand side of equation (2) describes the influence of the finite slit width *b*. This factor corresponds to the “envelope” of the diffraction pattern and is equal to the diffraction function of a single slit of width *b*.

The superposition of two groove gratings at an angle of 90° results in a crossed grating. The diffraction pattern can also be described with equation (2), whereby the relation has now to be applied for either of the two perpendicular components according to the superposition principle.

Procedure:

Exercise 1. Assembly installation for the diffraction observation at a periodic structures. The observation of diffraction patterns at a one-dimensional gratings with various slit spacing.

Assemble the installation which is schematically shown in Fig. 2.

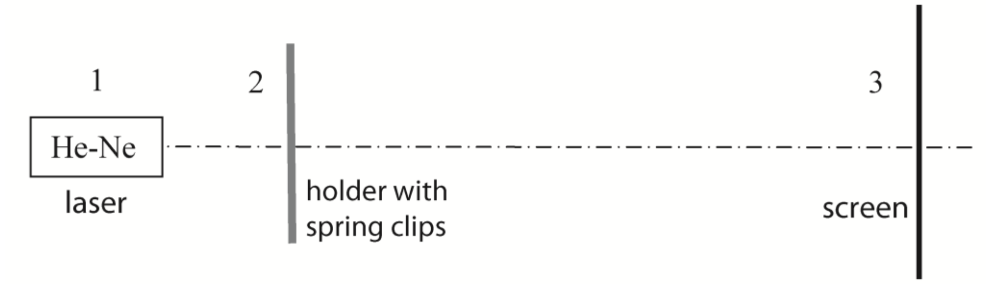

Fig.2. Experimental setup for observing diffraction at a periodic structures.

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.

Using a rider, mount the He-Ne laser (1) to the end of the optical bench. Set up the holder with spring clips (without the diaphragm with gratings) at a distance of approx. 20 cm from the laser. Using a sled tripod, set up the screen (7) with at a distance of approx. 170 cm from the holder with spring clips. Direct the laser towards the screen, and switch it on by turning the key to "1" on the back of the laser. Adjust the elements of the optical system so that the laser beam passes the center of the screen.

Place the diaphragm with 3 one-dimensional gratings into the holder with spring clips. Carefully (do not touch your fingers the transparent part of the grating) move the plate in the spring holder so that the laser beam passes completely for one of the bars on the diaphragm. Consistently observe the diffraction pattern on the screen from all three gratings. 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. In order to determine the distances between the intensity maxima, put a sheet of paper on the screen and mark the locations of maximum light intensity using a soft pencil.

Attention! During the measurements the distance between the grating and the translucent screen should be constant!

Measure the distance *L* between the grating and the screen by measuring ruler or steel tape measure. Considering the wavelength of helium-neon laser is 633 nm determine the periods for the three gratings. Record the results in the table:

The distance between the maxima, x_n/mm	slit spacing, d/mm

<u>Exercise 2.</u> Determination of the wavelength of a helium-neon laser from the diffraction pattern at a two-dimensional diffraction grating.

Change the diaphragm with 3 one-dimensional gratings to diaphragm with 2 two-dimensional gratings in a holder with spring clips. Observe the diffraction patterns on the screen at the both two-dimensional gratings. For each two-dimensional grating determine the distances between the intensity maxima (put a sheet of paper on the screen and mark the locations of maximum light intensity using a soft pencil *same as in Exercise 1*). Measure the distance *L* between the grating and the screen by measuring ruler or steel tape measure.

For the grating with a slit spacing $d = 0.25$ mm determine the laser radiation wavelength λ according to the formula (1).