DIFFRACTION OF LIGHT
Practical 12.
STUDY OF THE DIFFRACTION OF LIGHT BY THE SINGLE SLIT, DOUBLE SLIT, AND MULTIPLE SLITS

Equipment and accessories: a mercury lamp, a light filter, two lenses, an ocular micrometer, a set of plates with a different number of slits.

1 Introduction

Diffraction is a phenomenon in which the wave deviates from the rectilinear propagation. The effect is a general characteristic of wave phenomena occurring whenever a portion of the wavefront is obstructed in some way. If in the course of encountering an obstacle, *either transparent or opaque*, a region of the wavefront is altered in amplitude or phase, diffraction will occur. The various segments of the wavefront that propagate beyond the obstacle interfere, causing a characteristic energy-density distribution referred to as the *diffraction pattern*.

The **Fraunhofer** *or* **far-field** diffraction occurs when both the incoming and outgoing waves may be considered *plane*[1], which can be formulated mathematically as:

$$R \gg \frac{a^2}{\lambda}, \tag{1}$$

where a is the characteristic size of the obstacle, λ is the wavelength, R is the smaller of the two distances: from the light source S to the diffracting obstacle Σ and from the latter to the point of observation P, as depicted in Fig. 1. The diffraction patterns obtained with a single slit and a double slit are shown in Fig. 2. The principal minima and maxima of the diffraction pattern are given by:

$$\begin{cases} a \cdot sin(\theta) = \pm m \cdot \lambda, \quad m = \text{1,2... - } min \\ a \cdot sin(\theta) = 0, \pm(2m-1) \cdot \frac{\lambda}{2}, \quad m = \text{1,2... - } max \end{cases} \tag{2}$$

here a is the *width* of the single slit.

[1] On the other hand, when the curvature of the incoming and outgoing wavefronts is not negligible, the **Fresnel** *or* **near-field** diffraction is observed.

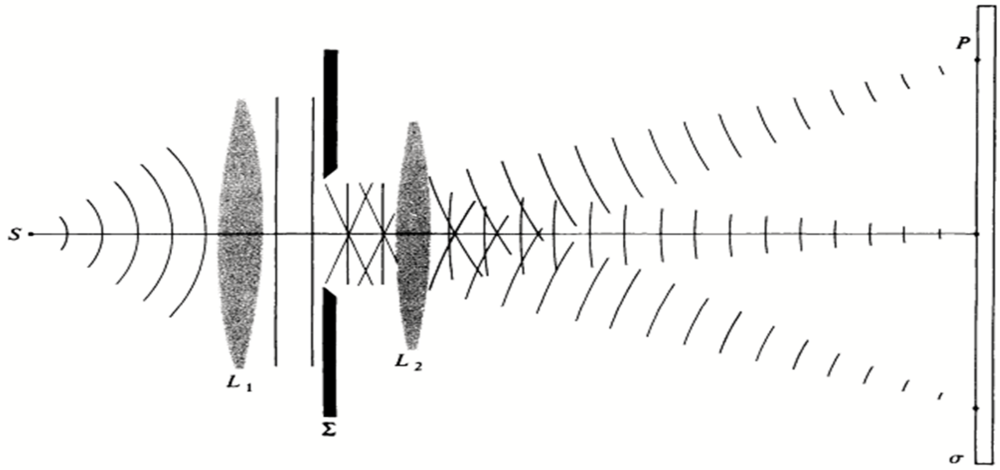

Figure 1: A practical realization of the Fraunhofer diffraction, where both S and P are effectively at infinity, which is achieved by positioning the light source S at the principal focus of lens L_1 and the plane of observation at the second focal plane of lens L_2.

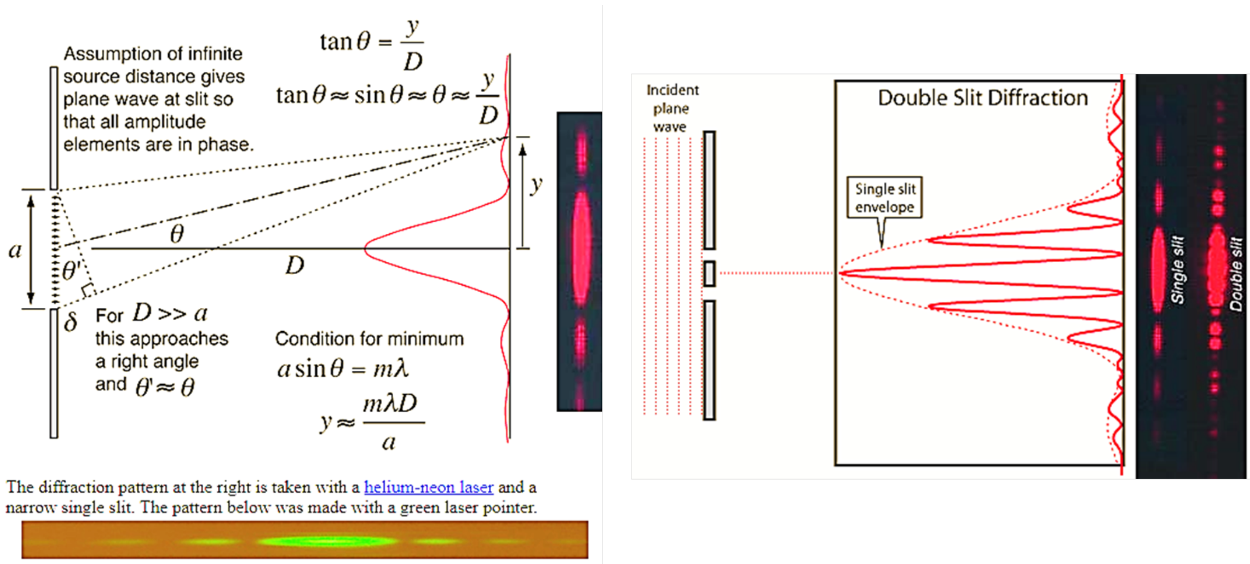

Figure 2: A diffraction pattern obtained with a single slit (left) and a double slit (right). Adopted from http://hyperphysics.phy-astr.gsu.edu/

With the use of the double slit, the intensity follows the so-called *single-slit envelope*, whereas newborn minima and maxima are formed due to the interference of the waves produced by the two slits. Recalling that for the interference maxima:

$$d \cdot sin(\phi) = \pm k\lambda, \tag{3}$$

where d is the distance between the two slits, and k - the interference order, one can find that in the double slit diffraction experiment the number of maxima and minima within the single-slit envelope, denoted as N_+ and N_-, are:

$$\begin{cases} N_+ = 2d/b + 1 \\ N_- = 2d/b \end{cases} . \tag{4}$$

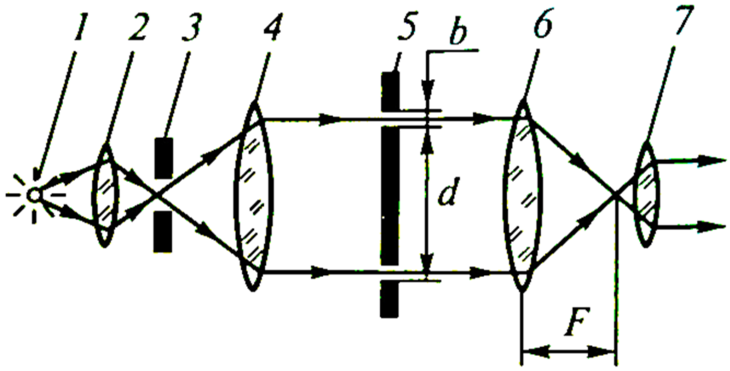

Figure 3: Experimental setup.

2 Experimental setup

A schematic of the experimental setup is shown in Fig. 3. Light emitted by the mercury lamp ***1*** is collected by the condenser ***2*** and directed to the slit ***3***, which is located at the focal plane of the objective ***4***. The plane wave formed (i.e., a parallel beam of rays) illuminates the object ***5*** - the two slits in the figure, each with the width b separated by the distance d. The objective lens ***6*** forms a diffraction pattern at a distance F (in the focal plane). The picture is observed through the ocular micrometer ***7***, which makes it possible to measure the required distances with an accuracy of 0.01 mm. In order to narrow the spectral interval of the mercury lamp, a light filter is used. The focal length of the objective is $F = 30\ cm$. The diffraction angles can be calculated from the distance Δx measured from the center of the diffraction pattern to the corresponding maximum (or minimum) and the focal length of the lens:

$$sin(\theta) \approx \Delta x/F. \tag{5}$$

3 Measurement and data processing

3.1 Task 1. Observation of the diffraction pattern using a single slit and calculation of the wavelength of the incident light

Place the diffracting obstacle - the single slit behind the lens at the narrowest point of the beam, and obtain a diffraction pattern. Calculate the wavelength of light, knowing the width of the slit b (it is indicated on the slit frame) and using (2) and (5).

To improve the measurement accuracy, measure the distance between the two minima of the corresponding order to the left and to the right of the center of the diffraction pattern rather than the distance between the center and one of the minima itself. Write down your data into a table. Perform the error analysis.

3.2 Task 2. Observation of the diffraction pattern using a double slit

The double slit is equipped with a special curtain, which allows one to alternately shut off the slits.

Observe the pictures using each slit independently, and then using the double slit. Having obtained the diffraction pattern using the double slit, calculate the number of minima and maxima arising in the region of the central maximum (the one due to diffraction pattern formed by the single slit). Make a conclusion about the relation between b and d for a given pair of slits (see eq. (4)).

Then calculate $2b/d$ by measuring b and d with a microscope, and compare the results obtained by direct measurement and observing the diffraction pattern. Write down your data into a table, including the values of b, d, $2 \cdot [d/b]_{meas}$ and $2 \cdot [d/b]_{calc}$.

3.3 Task 3. Observation of the diffraction pattern using multiple slits

Using a set of plates with multiple slits, obtain diffraction patterns for different number of slits N from 2 to 7. Write down in a table the number of additional maxima corresponding to the given number of slits N, and sketch the diffraction patterns observed.

4 Questions

1. What is the difference between the conditions for observing Fresnel diffraction and Fraunhofer diffraction?
2. What is the distribution of the light intensity in the diffraction pattern from a slit whose width b is equal to the wavelength of the radiation used?
3. How does the fraction of the energy pertaining to the main maxima change with the transition to a larger number of slits?
4. What diffraction pattern would be observed if the number of slits is large enough (of the order of hundreds)?
5. How will the diffraction patterns observed change if the light source is an incandescent lamp without a filter?