Student's name ____

Experiment O1

DETERMINATION OF WAVELENGTH BY DIFFRACTION GRATING

Objective: to investigate diffraction phenomena and determine the light wavelength with a diffraction grating.

1 EQUIPMENT:

1) optical bench with millimeter scale;
2) laser;
3) diffraction grating;
4) screen with millimeter scale.

2 THEORY

Diffraction is the phenomenon of light divergence from its initial line of travel. In general, diffraction occurs when waves pass through small openings, around obstacles, or past sharp edges, and penetrate into the shadow region. Waves of all kinds, including light and sound waves exhibit such property. The diffraction is always observed when obstacle's dimensions $\boldsymbol{a}$ are comparable with the wavelength λ (that is $\boldsymbol{a}\sim\lambda$). For visible light the wavelengths belong to interval 0.4÷0.7 μm, so for the diffraction to be observed, the obstacles must be of the same order.

One can explain the phenomenon of diffraction by Huygens-Fresnel principle which states that every point of the wave front is the source of secondary wave and oscillation is a result of interference of secondary points. To determine the diffraction pattern one has find interference maxima and minima by direct addition of secondary waves from all of the elements of wavefront, taking the amplitudes and phases into account.

Usually, diffraction is observed using the following layout. On the way of the light the opaque obstacle which obturates a part of wavefront is placed. Behind the obstacle a screen is installed. On the screen the diffraction pattern consisting of bright and dark fringes appears. One distinguishes two types of the phenomenon, Fraunhofer diffraction, which is realized in plane waves (parallel light beams) and Fresnel diffraction for spherical waves (divergent beams).

The diffraction grating, a useful device for analyzing light, consists of a large number of equally spaced parallel slits. A transmission grating can be made by cutting parallel lines on a glass plate with a precision ruling machine. The spaces between the lines are transparent to the light and hence act as separate slits. A reflection grating can be made by cutting parallel lines on the surface of a reflective material. The reflection of light from the spaces between the lines is specular, and the reflection from the lines cut into the material is diffuse. Thus, the spaces between the lines act as parallel sources of reflected light, like the slits in a transmission grating. Gratings that have many lines very close to each other can have very small slit spacings. For example, a grating ruled with 500 lines/mm has a slit spacing $\boldsymbol{d}$ = (1/500) mm = 2×10^{-3} mm. The best diffraction gratings have up to 1700 lines per 1 mm. For those gratings $\boldsymbol{d}\sim$0,6 μm.

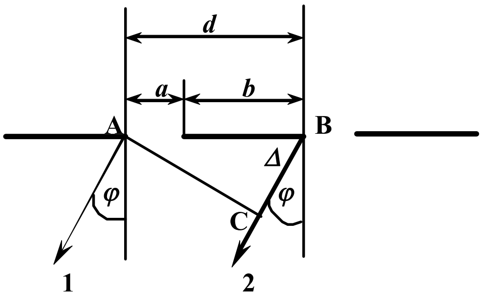


Figure O1.1

Let us derive the condition for diffraction maximum.

Consider an incident beam of the monochromatic light of wavelength λ, normal to the grating (fig. O1.1). In result of diffraction, light wave propagate in a variety of direction. We focus on the rays 1 and 2, at an angle φ to the grating. From ABC triangle one see, that the optical path difference of these rays is Δ=**BC**=$(a+b)\sin\varphi = d\sin\varphi$, where $(a+b)=d$ is the period of gratings. If the path difference equals integer number of wavelengths, $\Delta = k\lambda$, with k=0,1,2,..., then one observes maximum at angle φ.

Finally, the condition of the diffraction maximum for the diffraction grating (known as diffraction grating formula) is

$$\boxed{d\sin\varphi = k\lambda}, \qquad \text{(O1.1)}$$

here k=0,1,2,… is an order of diffraction, $0 \le \varphi \le \pi/2$.

At k=0 one has $\sin\varphi = 0$ what corresponds to the bright central maximum. Orders $k=\pm1$, ±2, ... correspond to the symmetrically placed lateral maxima. Thus, the diffraction pattern appears to be a set of maxima (bright spots), symmetrically distributed around the central maximum, separated by wide dark regions.

The largest order of diffraction maximum k_{max} is obtained at condition, that the angle of light deviation is $\varphi = \pi/2$, and $\sin\varphi = 1$. Then, from formula (O1.1)

$$k_{max} = \frac{d}{\lambda}. \qquad \text{(O1.2)}$$

Obviously, k_{max} has to be an integer, then the fractional part of k_{max}, calculated by formula (O1.2) is to be truncated. One can see that the number of the observed maxima is large for large d and small wavelength λ. The intensity of maxima decreases with increase of diffraction order k. The total number K of observable maxima (including the central one) is

$$K = 2k_{max} + 1. \qquad \text{(O1.3)}$$

It follows from the diffraction grating equation (O1.1) that, at fixed d and k, the angle φ at which a maximum is observed depends on the wavelength λ. Therefore, maxima of different colors (corresponding to different λ) appear to be shifted one with respect to another (except the central maximum). For white light incident of the grating, in all maxima except of the central one a spectrum (iridescent coloring) is observed. That is why diffraction gratings are used in spectral instruments instead of prism. Diffraction gratings ensure higher spectral resolution, that is, allows to resolve spectral lines with close values of λ. For diffraction gratings resolution power is $\frac{\lambda}{\delta\lambda} = kN$, where λ is wavelength, $\delta\lambda$ is difference of wavelengths for close spectral lines, k is the diffraction order (number of the diffraction maximum), N is total number of slits in the grating.

In this laboratory experiment the diffraction grating is used for determination of the light wavelength.

The experimental apparatus is shown in Fig. O1.2. Along the optical bench **OB** in positions P_1, P_2 and P_3 the laser **L**, diffraction grating **DG** and screen **S** are installed, respectively. Both the optical bench **OB** and the screen **S are** provided with millimeter scales for measuring distances between DG and S and between diffraction maxima.

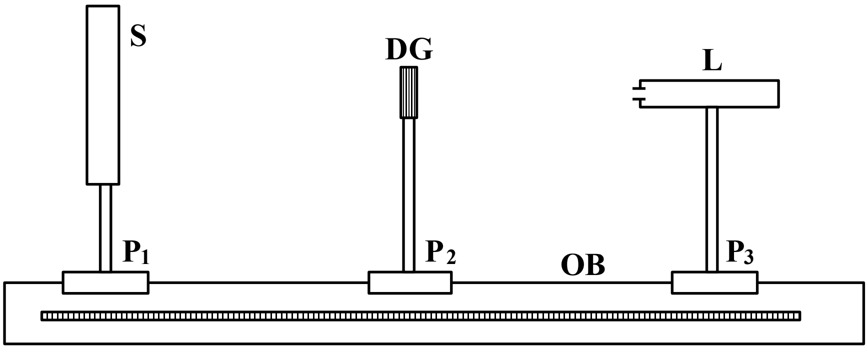
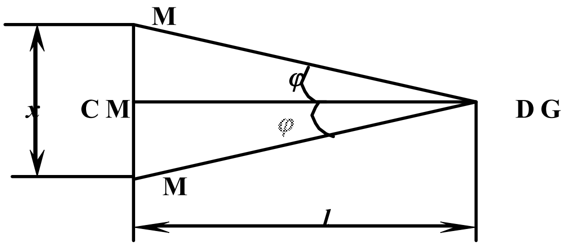


Figure O1.2

A beam of monochromatic light from laser **L** experiences the diffraction on grating **DG** and a set of light spots (diffraction maxima of different orders) are observed on screen **S**.



F igur e O 1.3

In Fig. O1.3, rays which produce symmetrically distributed maxima **M** on screen **S**, are shown. It is easy to see that

$$tg\varphi = \frac{x}{2l},$$

where ***x*** is distance between left and right maxima of the same order ***k***, symmetrical with respect to the central maximum **CM**., ***l*** is distance between **DG** and **S**. In practice, the angle φ is small, so $tg\varphi \approx sin\varphi$, and

$$sin\,\varphi = \frac{x}{2l}.$$

If the number of slits ***n*** per unit length is specified on the grating holder, then the grating constant equals

$$d = \frac{1}{n}.$$

By substitution of the above expression into formula (O1.1) one obtains the computation formula

$$\boxed{\lambda = \frac{xd}{2kl}}, \qquad \text{(O1.4)}$$

where λ is the wavelength, ***x*** is the distance between left and right maxima of the same order, ***k*** is the order of the diffraction maximum, ***l*** is distance between the grating and screen.

3 **PROCEDURE AND ANALYSIS**

1. Turn on the laser and direct the laser beam onto diffraction grating with known number of slits ***n*** per millimeter and calculate ***d=1/n***.
2. Adjust the diffraction pattern. Make it symmetrical with respect to the center of screen, installed on a distance ***l*** from the grating.
3. By a millimeter scale on the screen, measure the distance ***x*** between left and right maxima of the same order ***k***.
4. Calculate wavelength λ by formula (2.4).
5. Repeat the experiment for two different values of ***k*** and ***l***.
6. Calculate mean value of λ.

7. Estimate absolute and relative errors and compare the obtained result with table data for the light source used in experiment.
8. Fill the table O1.1 with the results of measurements and calculations.

Table O1.1

	d, 10^{-3} m	***k*** -	***l***, 10^{-3}, m	***x***, 10^{-3} м	λ, 10^{-9} m	$\Delta\lambda$, 10^{-9}, m	ε, %
1							
2							
3							
Mean value							

9. Represent the final result as

$$\lambda = (\lambda_{mean} \pm \Delta\lambda_{mean}) \text{ nm.}$$

4 CONTROL QUESTIONS

1. What is diffraction of light? What types of diffraction can be realized?
2. What is the diffraction grating? What are principal characterictics of a diffraction grating?
3. Write and explain diffraction grating formula.
4. What is difference of diffraction pattern for monochromatic light and white light?
5. Why a laser is used in this experiment as a source of light?