Laboratory work Nr 3.3

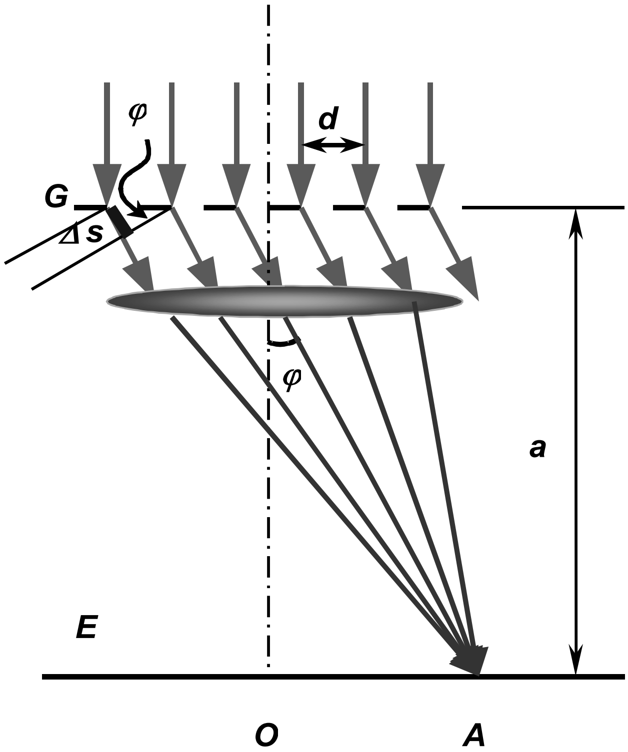


Fig.1. Light diffraction in a flat grating

Flat diffraction grating

Theoretical description

Flat diffraction grating is located in one plane, equal, parallel, equidistant (i.e., equally spaced) slit system. Distance d between equal points in the adjacent slits (for example, between the midpoints of the edges) is called *the grating constant*.

If on the grating G, perpendicular to its plane the parallel light beams are falling, than the main beam peaks emerging in directions for which the condition

$$d\sin\varphi = k\lambda \qquad (1)$$

is fulfilled.

Here $d\sin\varphi = \Delta s$ is the path difference for the beams passing through the adjacent slits and $k = 0; \pm 1; \pm 2; \ldots$ is a diffraction order. Equation (1) is true both for transmitted and reflected light. It is called the *grating equation*.

We can see, that diffraction maxima for different wavelengths can be observed in different directions (different values of φ), that is, if the incident light contains more than one wavelength, it will be spitted and beams with different λ will propagate in different directions. As a result, instead of one beam with multiple wavelengths there will be a spectrum, which is possible be observed on the screen, or by eyepiece. Therefore, diffraction gratings can be used for observation of optical spectra.

The angle between different wavelengths is defined by angular dispersion of the grating D:

$$\frac{d\varphi}{d\lambda} = D$$

By the derivation of (1) one can get:

$$D = \frac{k}{d\cos\varphi} \qquad (2)$$

Angular dispersion increases with decreasing of the lattice constant and with increasing of diffraction order k. In the frames of one order, if angle φ is small, the angular dispersion of the grating remains almost constant.

By taking into account equation (1), the equation for the angular dispersion can be rewritten also in form:

$$D = \frac{k}{d\sqrt{1-\left(\frac{k\lambda}{d}\right)^2}} \qquad (3)$$

where it is possible to observe the dependence of D on wavelength λ in the spectrum with order k.

Obviously, the angle of diffraction could not be more than 90° and $\sin\varphi$ more than one. Taking into account (1) we can see, that the maximal order of diffraction k_{max} for given wavelength λ, is defined by lattice constant,

$$k_{max} = \left[\frac{d}{\lambda}\right] \qquad (4)$$

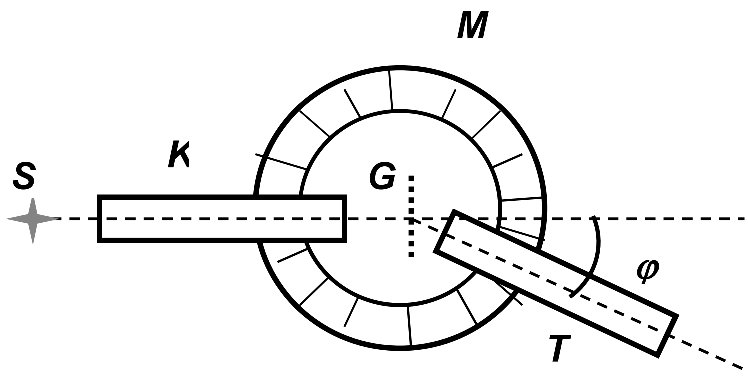
where k_{max} is the integral part of the relationship $k_{max} = \left[\frac{d}{\lambda}\right]$.

To resolve two wavelengths λ and $\lambda+\Delta\lambda$ not only dispersion is important, but also the shape of main diffraction maxima. These maxima become sharper with the increase of the total number of slits N in diffraction grating.

It is possible to approve, that the minimal $\Delta\lambda$, which could be resolved by the given diffraction grating is

$$\Delta\lambda = \frac{\lambda}{kN} \qquad (5)$$

Fig.2. The spectrometer with diffraction grating:



The quantity $R = \frac{\lambda}{\Delta\lambda}$ is called *the resolving power* of the grating. It depends on the order of diffraction k and the total number of slits N:

$$R = kN \qquad (6)$$

The total number of slits N in the grating can be calculated through the measuring of the width l of the grating:

$$N = \frac{l}{d} \tag{7}$$

If the angle of diffraction φ, the corresponding order k and the grating constant d are determined experimentally, then, by using equation (1) it is possible to calculate the wavelength of the diffracted light λ.

The experimental setup consists of a spectrometer (see Fig.2.) with the collimator *K*, diffraction grating *G*, spyglass *T* and measuring device *M* with vernier. The light from a source *S* illuminates the slit of collimator, which is placed in the focal plane of the collimator. Therefore light stars, coming through the one point of the slit, after the objective are parallel. These light beams illuminate the diffraction grating. Diffracted beams are observed by using spyglass and the angles of diffraction are measured by the device with vernier.

To the infinity focused spyglass gives the image of the observed point of the slit. The images of all points of the slit create the image of the slit - the line of the spectrum.

Procedure:

Switch on the source of the light and illuminate the slit of the collimator by placing of the source nearby the slit on the axis of the collimator. Zoom the lens of the spyglass in such a way, that the cross is clearly seen. To place the cross in the spyglass precisely against the zero order of the spectrum and define the corresponding point of reference. Then, the spyglass has to be shifted on the left and right side to the lines with known λ in the first order spectra and then corresponding diffraction angles φ are defined. By the further shifting the angles of diffraction are defined for the second and, if possible, for higher order spectra. According to the equation (1) the wavelength of the diffracted beam is

$$\lambda = \frac{d \sin \varphi}{k} \tag{8}$$

In such a way, to determine the wavelength λ of the light by using the diffraction grating with constant d the angle φ of the diffraction for spectrum with order k must be measured.

Possible appointments:

1. Determine the constant of the grating by using the light with known wavelength.

2. Determine the total number of slits and calculate the resolving power of the grating as well as the minimal $\Delta\lambda$, which can be resolved with the given grating in defined region of the spectrum.

3. Define the wavelength emitted by the source, if the grating with known d is given.

Protocol for laboratory work 3.3.

Diffraction grating

Students: 1.

2.

Appointments:

1. Determine the diffraction angles for all lines of first and second order (k= ±1; ±2) of given spectrum.

2. Determine the constant of the grating d and its absolute error by using the light with known wavelength.

3. Determine the total number of slits and calculate the resolving power of the grating as well as the minimal *Δλ*, which can be resolved with the given grating in defined region of the spectrum.

4. Define the wavelength emitted by the source, if the grating with known *d* is given.

Used measuring devices and set-up

Nr..	***Title***	***Measuring diapason***	***The value of smallest scale***
1.	Spectrometer		

Data tabele, width of the grating:

Nr.	Order of spectrum, k	Wavelength, nm	Angle of observation, degrees, minutes

Example of calculation:

d =