463. Determining wavelength of spectral emission lines using a reflection diffraction grating

Tasks to solve

- Studying the Fraunhofer diffraction
- Measuring the positions of diffraction maxima
- Determining wavelength of spectral lines

Description of the experiment

This work uses a phase reflection diffraction grating. Grating of this kind are made as follows: a thin layer of a soft metal is deposited in vacuum from metal vapour onto a glass plate. Then grooves with a saw-shape profile are formed in this layer using a special diamond tool. This profile allows concentrating the maximum of light energy not in the zero-order spectrum, as usual diffraction gratings do, but in a spectrum of any given order.

The diffraction pattern produced by the grating is a combination of two patterns: diffraction on an individual reflecting element and interference from *N* reflecting elements.

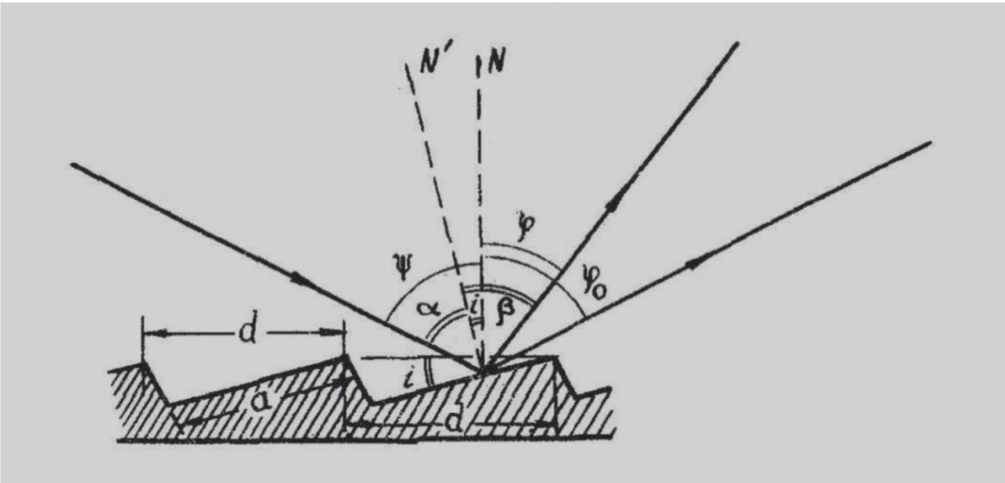

Figure 1. Reflection diffraction grating (schematic cross-section).

Let a plane wave is incident on the plane of the grating at a certain angle ψ. The scheme is shown in Fig. 1, where N is the normal to the grating plane, N′ is the normal to the reflecting elements, ψ is the angle of incidence and φ is the diffraction angle, i is the angle of the grating's profile, α is the angle of incidence with respect to an individual mirror element and β is the diffraction angle from a reflecting element, a is the width of the mirror element, and d is the grating period.

The angles are counted from the normal to the grating plane. The counting direction clockwise from the normal is assumed positive (in our scheme, φ and φ_0 are positive, and ψ and i are negative). Orders of the spectra which appear clockwise with respect to the zero order spectrum are also assumed positive. Evidently, the zero-order maximum is observed in the direction $\varphi_0 = \psi$.

The direction of the zero-order diffraction maximum from a single mirror element appears at the angle $\beta = -\alpha$. To attain the light energy concentration in a desired order, it is necessary that the maximum of a mirror element corresponding to the proper reflection coincides with the given maximum of the grating. This condition is fulfilled when both equations

$$d(\sin\psi + \sin\varphi_n) = m\lambda_n\,,\ \psi + \varphi_n = i$$

are true simultaneously.

These conditions are strictly fulfilled only for a single value of the wavelength when i, d, φ, ψ, m are fixed. However, the spectral energy distribution from a single reflecting element slowly decreases from the center toward the edge, and hence the energy will be concentrated also for other wavelengths close to λ_n.

Experimental setup

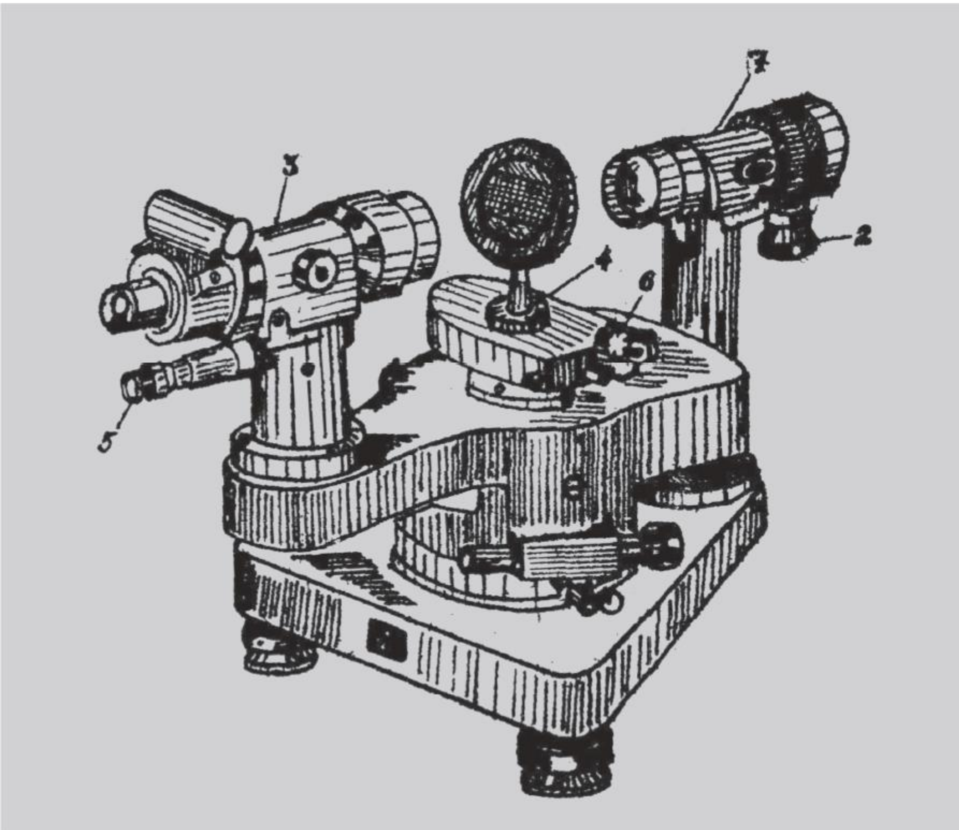

Figure 2. Goniometer.

The grating used in this work is a replica having 600 grooves per millimeter and the blazing angle (i) of 12°; this allows concentrating light in the first-order spectrum when the angle of incidence is near 43°. The grating is placed on a goniometer; its scheme is shown in Fig. 2.
The goniometer consists of a fixed collimator tube; a gap is placed in the focal plane of the collimator's objective lens 7. The gap width is controlled by the screw 2. The observing tube 3 is movable; by rotating it around the vertical axis, spectra of different orders can be observed. The diffraction grating is put on the table 4 with a limb on it. The optical tool 5 allows measuring the rotation angle of the tube with the accuracy of 1″.
The observing tube is equipped with an autocollimation Gauss ocular (Fig. 3). Light from a lamp 1 goes through a mat plate 2, reflects from a parallel-sided plate 3, then goes through a plate 4 with a cross-hair drawn on it (the plate 4 is placed near the focal plane of the ocular 5), and finally exits from the tube's objective lens and falls onto the mirror surface of an object located on the goniometer's table.

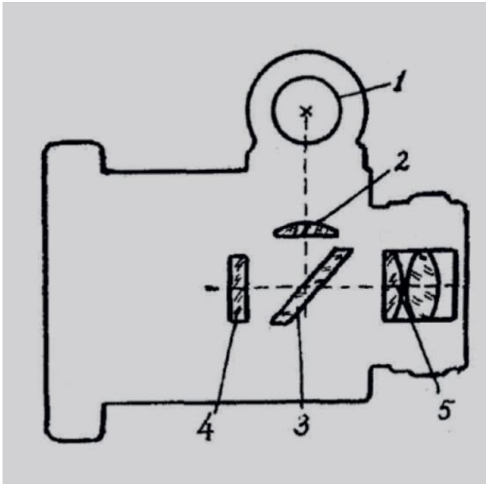

Figure 3. Ocular.

The tube is matched to the infinite distance if the cross-hair and its image are both seen at the same time through the eye-glass 5. In this case, indeed, the planes of the cross-hair and its image coincide, which means that both these planes coincide with the focal plane of the tube's objective lens. The reflecting surface of the object should be strictly perpendicular to the optical axis of the tube.

Algorithm of measurements

1. Turn on the lamp and illumination of the goniometer.
2. Tune the observing tube to the infinite distance and find the direction of the grating plane. To do this, orient the observing tube at an angle somewhat larger than 90° relative to the collimator, loosen the clamp 6 (Fig. 2) and rotate the grating (the table) until a light cross-hair appears in the field of vision. Then fix the grating with the clamp. Achieve a fine image of the light cross-hair by regulating the focus of the observing tube. By hand or using the micrometric wheel superpose the light cross-hair with the cross-hair in the ocular. Take the reading γ_N from the limb gauge. This reading gives the direction of the normal with respect to the grating plane. Since the limb rotates together with the grating, this value remains the same at any position of the table. At the same time,

the procedure described above tunes the observing tube at the infinity.

3. Tune the collimator to the infinite distance and adjust the gap width. To do this, keep the observing tube untouched in the position found at the step 2; loosen the clamping screw 6 (Fig. 2), and rotate the grating until the zero-order maximum appears in the field of vision of the observing tube. After that, tighten up the clamp 6 again. By regulating the focus of the collimator, make a fine image of the zero-order maximum.
   Make the gap 2 as narrow as possible using the screw 2, so that its image is a thin but still bright enough line.
4. Superpose the vertical line of the ocular's cross-hair with the image of the zero-order maximum, and take the corresponding reading γ_0. Slowly and accurately rotate the tube to the left (so that the angle between the collimator and observing tube decreases); find the first spectral line in the first-order maximum, superpose it with the cross-hair and take again the reading γ_1. The line may look blurred due to chromatic aberration; in this case adjust the focus. Repeat this operation with all lines seen in the first-order spectrum. Based on a set of your readings, calculate:
   $|\psi| = |\gamma_N - \gamma_0|$,
   $|\varphi_1| = |\gamma_N - \gamma_1|$,
   $|\varphi_2| = |\gamma_N - \gamma_2|$
   …
   $|\varphi_n| = |\gamma_N - \gamma_n|$.

Knowing that the grating has 600 grooves per 1 mm and allowing for the sign rule, determine the wavelengths of all observed spectral lines using the formula

$$d(\sin\psi - \sin\varphi_n) = \lambda_n . \qquad (1)$$