DIFFRACTION OF LIGHT
Practical 13.
Study of the Diffraction Grating

Equipment and accessories: a goniometer equipped with the objective and ocular tubes, a slit, a neon-glow lamp, a gas-discharge mercury lamp, an incandescent lamp, diffraction gratings, a dispersive prism.

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*. As the *diffraction angle* depends on the wavelength of the diffracted light beam, the spectral composition of the latter can be easily determined by measuring the diffraction angles of individual spectral components. In practice, a *diffraction grating* is used which is a repetitive array of diffracting elements, either apertures or obstacles, that has the effect of producing periodic alterations in the phase, amplitude, or both of an emergent wave. A periodically changing parameter can be, for example, the transparency (for an amplitude grating), or geometrical thickness or refractive index (for a phase grating). In Fig. 1(left panel) a laser beam diffracted by a transmissive diffraction grating is shown. Fig. 1(right panel) demonstrates how the spectral components of the light beam are separated depending on their wavelength. A large number of slits makes the intensity maxima very sharp and narrow, providing the high resolution for spectroscopic applications. The wavelength, diffraction grating period and diffraction angle are connected through the *grating equation*:

$$d \cdot sin(\alpha) = \pm m\lambda, \tag{1}$$

with m being the order of the diffraction spectra. There is no spectral dispersion at the central diffraction maximum ($m = 0$), and a mixture of all the components is observed.

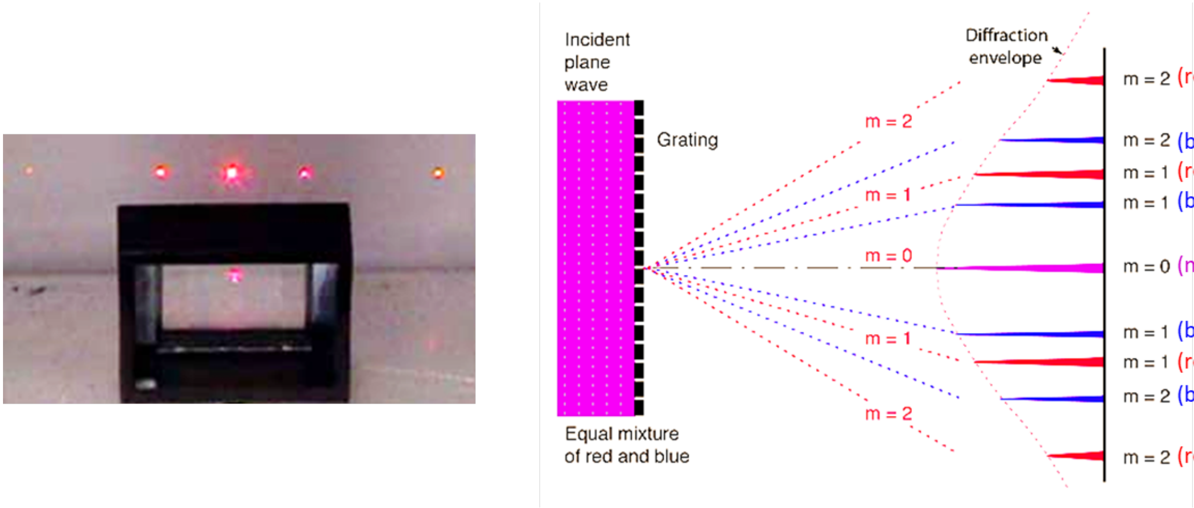

Figure 1: Left: The helium-neon laser beam diffracted by a transmissive diffraction grating. Right: Dispersion of the spectral components by a transmissive diffraction grating. Adopted from http://hyperphysics.phy-astr.gsu.edu/

2 Experimental setup

A schematic of the experimental setup is depicted in Fig. 2. In this practical a transmission grating is used, which is a glass plate with a series of parallel lines produced by means of a ruling machine with a special diamond cutter. The dispersion angles are measured with the use of a *goniometer*. Referring to the right panel of Fig. 2, the goniometer consists of a telescope tube T, collimator C, and a table. The angular position of the telescope tube can be precisely measured with the angular scale equipped with a vernier. The collimator creates a parallel beam of light. It consists of an outer tube and an internal tube with an entrance slit S installed in the focal plane of the lens. A plane wave (a parallel beam) of light emerges from the collimator and irradiates the diffraction grating. The light beams are collected by the telescope objective lens Ob in the focal plane of which the actual images of the collimator slit are formed. In the field of view of the eyepiece, a cross-marker and the actual image of the slit (the diffraction maximum) are simultaneously visible.

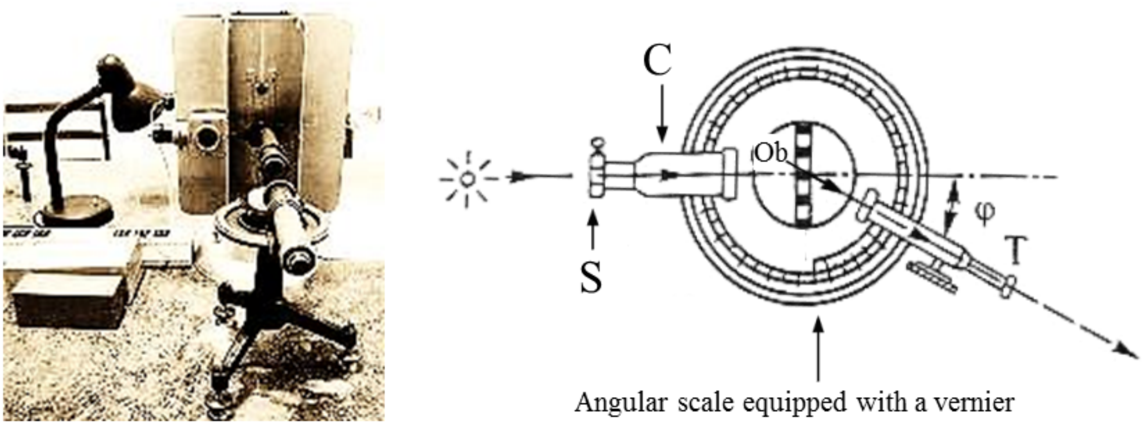

Figure 2: Left: a photograph of the experimental setup. Right: a schematic of the goniometer.

3 Measurement and data processing

3.1 Task 1. Determination of the diffraction grating period with the use of a monochromatic light source

In this task, a well-known line of the neon spectrum (yellow line, $\lambda = 585\ nm$) is used to determine the grating period. The diffraction grating should be placed on the goniometer table so that its lines are vertical and the beam of light emerging from the collimator is normal to the grating. Rotate the telescope until the eyepiece marker is aligned with the first left image of the slit 1^{st} order maximum), note the angular position α_{left}. Rotate the telescope until the marker is aligned with the first right image of the slit and also note the angular position α_{right}. Using these values, find the diffraction angle ϕ. Repeat the measurement but now measure the diffraction angle of the second diffraction maximum, $m = 2$. Using formula (1), calculate the grating period d. Write down your results into a table. Estimate the measurement error.

3.2 Task 2. Study of the mercury lamp spectrum

In this task, the brightest lines in the mercury emission spectrum are measured. Point the goniometer to the mercury lamp and obtain a sharp image of the slit. In the same way as in Task 1, measure the angles of deviation for all visible lines of the mercury spectrum (for the 1^{st} and 2^{nd} orders of the spectrum). Calculate the wavelengths of the observed lines of the mercury spectrum. Write down the measured and calculated parameters into a table.

3.3 Task 3. Determination of the diffraction grating angular dispersion

Determine the difference in the deviation angles for the blue and violet lines in the spectra of the 1^{st} ($\Delta\phi_1$) and 2^{nd} ($\Delta\phi_2$) orders. Knowing the difference $\Delta\lambda = \lambda_b - \lambda_v$, calculate the angular dispersion of the grating for the spectra of the first and second orders as $D = \Delta\phi/\Delta\lambda$.

Using a piece of paper shield the side part and later the top part of the grating. Observe the changes introduced to the observed spectra. Make a sketch of the observed pictures. Find out if the angular dispersion of the shielded grating has changed.

3.4 Task 4. Observation of the emission spectrum of a heated body

Illuminate the goniometer slit with the light emitted by the incandescent lamp. Observe the spectra of the 1^{st} and 2^{nd} orders using the diffraction grating. Place a prism instead of the diffraction grating on the goniometer table, obtain a dispersive spectrum of the incandescent lamp, and compare it with the diffraction spectrum. Draw the spectra observed into the notebook using coloured pencils.

4 Questions

1. What kind of diffraction is observed in the practical: Fresnel diffraction or Fraunhofer diffraction?
2. Using the rules of geometric optics, construct the ray path in the goniometer (in the presence of a diffraction grating) from the light source to the eye for the maxima of the 0^{th} and 1^{st} orders.
3. How is the position of the main maxima calculated if a parallel beam of light illuminates the grating at an angle $\alpha \neq 0$?
4. How can a "rough" ($d \approx 1\ mm$) diffraction grating be used to observe diffraction of light?
5. How will the diffraction pattern change if the width of the slit is changed without changing the grating period (the light source yields a line spectrum)?
6. What is the significance of the spatial coherence of radiation for the observation of interference patterns?
7. How will the diffraction patterns obtained from gratings with different periods differ, but with the same number of lines per millimetre?