First name .... Date ....

Last name .... Degree program name ....

Exercise 369

Measurement of the wavelength with an application of a diffraction grating spectrometer.

Wavelength of monochrome light	[nm]	

I. Determining a grating constant d

Deflection angle, [rad]			Grating constant
on the right α_1	on the left α_2	$\frac{\alpha_2 - \alpha_1}{2}$	d, [nm]

II Determination of the wavelength of light

The colour of the line spectral	Deflection angle [rad]			Wavelength λ, [nm]	$\Delta\lambda_{tab} = \lvert\lambda - \lambda_{tab}\rvert$	$\frac{\Delta\lambda_{tab}}{\lambda_{tab}} \cdot 100\%$
	on the right α_1	on the left α_2	$\frac{\alpha_2 - \alpha_1}{2}$			

Wavelengths of radiation emitted by mercury excited to glow:

colour	yellow 1	yellow 2	green	blue-green	blue	violet 1	violet 2
λ, [nm]	579,0	577,0	546,1	491,6	435,8	407,8	404,7

Exercise 369. Measurement of the wavelength with an application of a diffraction grating spectrometer.

PURPOSE

The purpose of the exercise is to analyse the radiation emitted by excited mercury and to determine the wavelengths of different colours of light using a grating spectrometer.

THEORY

Visible light is electromagnetic radiation (electromagnetic field disturbance propagating in space) to which the human eye reacts. The wavelength range of this radiation is (in vacuum) from $3{,}8\cdot10^{-7}$ m (beginning of the violet spectrum, frequency approx. $8\cdot10^{14}$ Hz) to $7{,}7\cdot10^{-7}$m (end of the red spectrum, frequency approx. $4\cdot10^{14}$ Hz). In general, light also includes infrared and ultraviolet radiation. To recall, the wavelength λ is equal to the distance between the points in space at which the wave is in the same phase (in the case of electromagnetic waves, this means that the vectors of the electric $\vec{E}$ (or magnetic $\vec{H}$) field strength at points removed by the wavelength have the same direction, value, i.e. they are identical). The time T that a wave takes to travel a path equal to the wavelength is called the period of the wave:

$$\lambda = c\cdot T = c/f\ ,$$

where c —speed of light (in a vacuum 300 000 km/s), f —wave frequency (quantity defined by the number of wavelengths traveling along the path of the wave per unit time).

The perception of light phenomena is related to the change in the electric field. The change in the electric field intensity E over time, at a point distant by r from the light source, for a wave with frequency f can be represented by the equation:

$$E = E_0 \sin\left[2\pi f\left(t-\frac{r}{c}\right)+\delta\right],$$

where E_0 is the amplitude, and δ — the initial phase of the wave.

Light has a dual nature, wave-particle. It is assumed that light is a kind of stream of peculiar particles (corpuscles), called photons, which exhibit wave properties. The wave nature of light is indicated by phenomena such as *diffraction and interference of light rays.*

The phenomenon of diffraction and light interference can be observed using a diffraction grating. The simplest diffraction grating is a transparent glass plate with densely incised, equidistant scratches. Scratches play the role of shutters, and the spaces between them are slits. The distance between the slits is called the *diffraction grating constant d*. The diffraction grating is used for spectral analysis and light wavelength measurements.

The light passing through the diffraction grating deflects at the slits because according to the Huygens principle, each slit becomes a source of a new wave and sends rays in all directions. The phenomenon of wave deflection at the apertures or shutter edges (with dimensions comparable to the wavelength) is called *diffraction*, i.e. *deflecion of the rectilinear path of rays*. The deflected beams (possibly collected with a lens) falling in the same spot of the screen are subject to interference. *Wave interference* is called the overlap of waves of the same frequency, resulting in an amplification or attenuation of the resultant wave intensity . In those areas of the screen where the deflected rays meet in coherent phases, they are strengthened and bright interference fringes are formed.

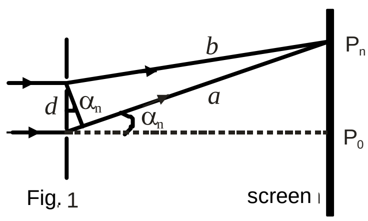


Fig. 1

The phase compatibility condition revels that the interfering rays $a - b = d\sin\alpha_n$ will amplify if the path difference of two adjacent rays, is equal to the total multiple of the incident light wavelength (Fig. 1):

$$d\sin\alpha_n = n\lambda, \qquad (1)$$

where d – distance between the slits (grating constant), α_n – deflection angle, n – the number of fringes per unit length (fringes order), λ – wavelength.

Equation (1) indicates that fringes corresponding to different wavelengths will be formed in different places on the screen. By measuring the deflection angle α_n for the n-order fringe, we can determine the wavelength if the grating constant is known.

The rays that meet at the same place of the screen in opposite phases will be mutually extinguished and a dark fringe will be visible on the screen. The condition for the diffraction minimum achievement is that the path difference of adjacent rays is equal to an odd multiple of half the wavelength:

$$d\sin\alpha_n = (2n+1)\frac{\lambda}{2}.$$

A clear diffraction image (sharp light and dark fringes) is obtained only when the grating constant is comparable to the wavelength of the deflected light. In typical diffraction gratings, the number of scratches per 1 mm ranges from about 1200 for ultraviolet to 300 for infrared.

I. Measuring setup

The diffraction grating allows to obtain more accurate λ wavelength measurements, if a spectrometer is used to measure the deflection angles. The scheme of the measuring system is shown in the figure.

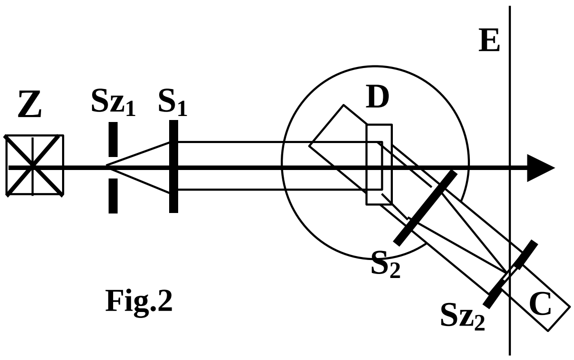


Fig.2

The light emitted by the source **Z** passes through the slit **Sz₁** in the screen, and falls on the lens **S₁**. Because the slit is located in the focal plane of the lens, the light beam becomes approximately parallel as it passes through the lens **S₁**. This beam reaches the diffraction grating **D**, located in the center of the rotating spectrometer stage. On the screen **E** positioned behind the grating, you can see a series of colored fringes on the right and left sides of the slit. The elements **Z**, **Sz₁**, **S₁**, **D** are fixedly attached to the base. The lens **S₂** is placed behind the diffraction grating on a movable arm; in the focal plane of this lens there is a slit **Sz₂**, and directly behind the slit is a light sensor **C**. The lens **S₂** focuses light on the slit **Sz₂**.

II. Determination of the grating constant *d*

The grating constant is determined by measuring the deflection angles for a monochromatic light source with known wavelength - λ . It may be a laser beam.

We read the deflection angles of the spectral lines for the first order. We calculate the sine of the deflection angle and, based on the formula (1) we calculate the grating constant d:

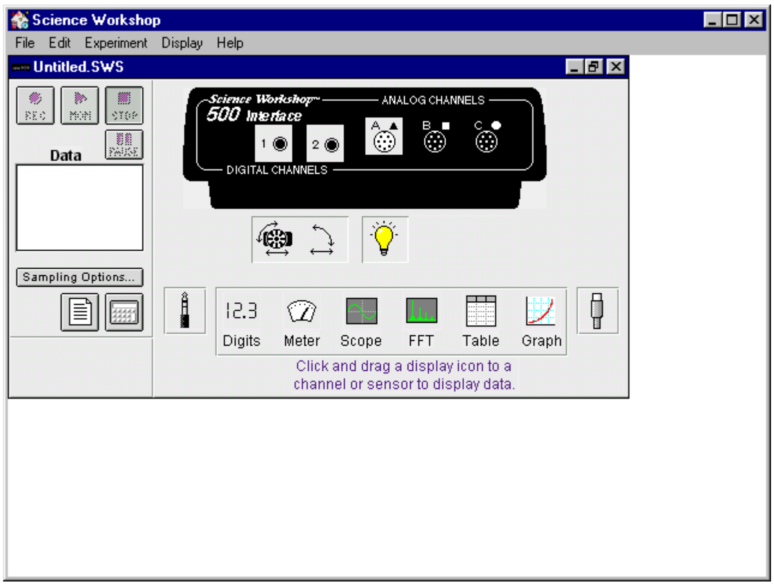
$$d = \lambda / \sin\alpha . \qquad (2)$$

III. Determination of the wavelength of light λ

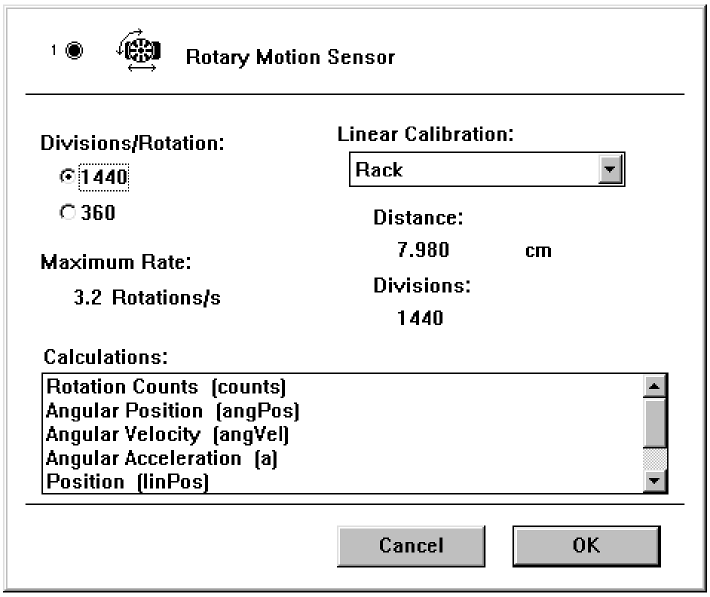
We place a mercury lamp behind the slit of the screen. We note the angular positions of the spectral lines of different colours in the spectrum of the first order, we find the sine of the angle of deflection and the wavelength: $\lambda = d\sin\alpha$. (3)

Program windows for exercise 369

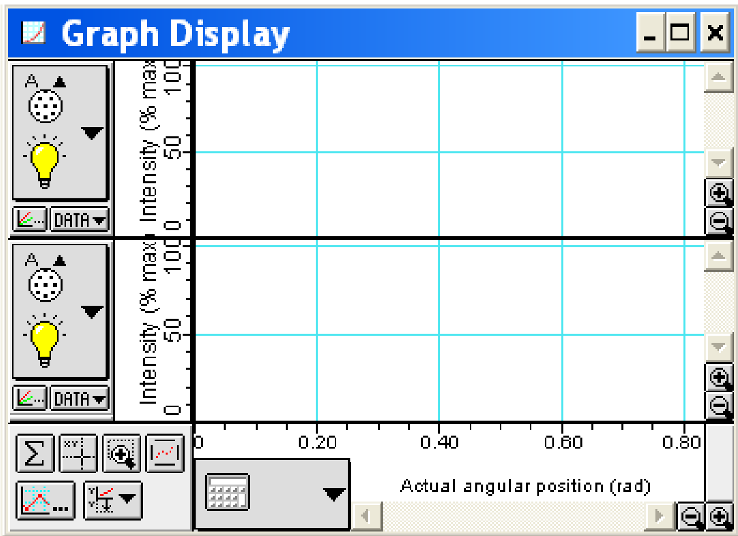
Basic window „**P67_INTER.SWS**” — includes control buttons.



Auxiliary window
«Rotary motion sensor».



„**Light Intensity vs Actual angular position**” window — shows a graph of the dependence of light intensity vs. position.



REQUIRED EQUIPMENT	• Spectrometer system
• Interface „Science Workshop 500”	• Mercury lamp
• Rotary motion sensor	• Laser
• Light sensor	

Attention! LASER LIGHT SOURCE IS USED IN THIS EXERCISE. DO NOT POINT THE LASER IN THE FACE DIRECTION! RISKS EYE DAMAGE!

In the first part of the exercise, the radiation intensity of the laser light will be measured after it passes through the diffraction grating, and in the second part, the radiation intensity of the mercury lamp will be measured after it passing through the diffraction grating. The relative positions of the interference phenomenon will be measured using a rotating motion sensor.

The *Science Workshop* software enables the presentation of graphs of the intensity of light radiation as a function of position.

Preparation of the measuring system

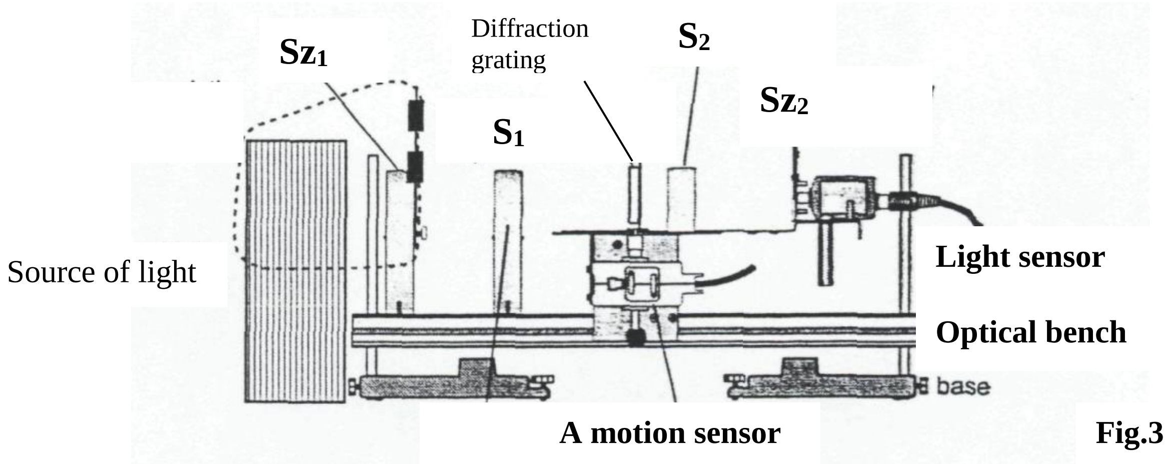


Fig.3

1. The best measurement results can be obtained by selecting the slit nr 2 from the **Sz₁** slits set –, and nr 1 from **Sz₂** slits. Check the slits settings.
2. Check if **S₁** lens is 10 cm from the **Sz₁** slit (the focal length of the **S₁** lens is 10 cm).
3. Check that the **S₂** lens is at a distance of 10 cm from the **Sz₂** slit (the focal length of the **S₂** lens is also 10 cm). The distance of this lens should be selected to obtain sharp fringes on the screen.
4. Check that the diffraction grating **D** placed on the spectrometer table is turned with the glass side towards the light source.
5. Connect the pins of the rotary motion sensor to the digital inputs **1** i **2** (digital channels 1 & 2) of the interface. Connect the yellow plug into input **1** and the black plug into input **2**.
6. Connect the light sensor to the analog channel **A** of the interface.

Preparation of computer

1. Turn on the interface and the computer. The interface switch is on its rear wall - the interface should be turned on before starting the computer (indicated by the green light).
2. Start the *Windows* operating system and „*Science Workshop*”software. Open (File ⇒ Open) in the *Library\Physics* directory the **P67_INTER.SWS** document. We will see on the screen (after closing the Experiment Notes window) the P67_INTER base window and the Light Intensity vs Actual Angular Position plot window, showing the dependence of the light intensity vs. position.

- The P67_INTER base window is in a collapsed form. The full form can be restored - as with any window in the *Windows* program. After expanding this window, we can see the interface with lighted digital inputs **1** and **2** and analog input **A**.
- If the digital inputs are not lighted, grab the digital plug icon with your mouse and drag it to channel **1.** A list of possible sensors will appear on the screen - find and select a rotation sensor (Rotary Motion Sensor), and confirm your selection by pressing OK. Similarly, after sliding the analog plug icon over channel **A**, select the light sensor (Light Sensor) from the list.
- If the plot window does not appear, grab the plot icon (Graph) located at the bottom of the P67_INTER window and drag it to channel **A** of the interface icon. Next to the vertical and horizontal axes are large frame-shaped buttons - these are the input menu buttons for the respective axis. Select Analog A ⇒ Intensity for the vertical axis and calculations ⇒ Actual Angular Position for the horizontal axis.

3. In the basic window, press the Sampling Options button and set the measurement frequency with the slider (Periodic Samples) at 20 Hz (Fast). Press OK.

The resolution in the motion sensor window should be set to 1440 Divisions/Rotation.

- If the digital inputs are not lighted, grab the digital plug icon with the mouse and drag it to channel **1**. A list of possible sensors will appear on the screen - find and select a rotation sensor (Rotary Motion Sensor), and confirm your selection by pressing OK. Likewise, after sliding the analog plug icon over the channel **A**, select a light (Light Sensor) sensor from the list.

Course and record of measurements

IV. Determination of the grating constant *d*

1. Turn on the laser light source
2. Align the laser at the $\mathbf{S_1}$ slit height. You should see single red bars on the **E** screen.
3. Set the light sensor GAIN switch to position 10.

The spectrum of the 1-order

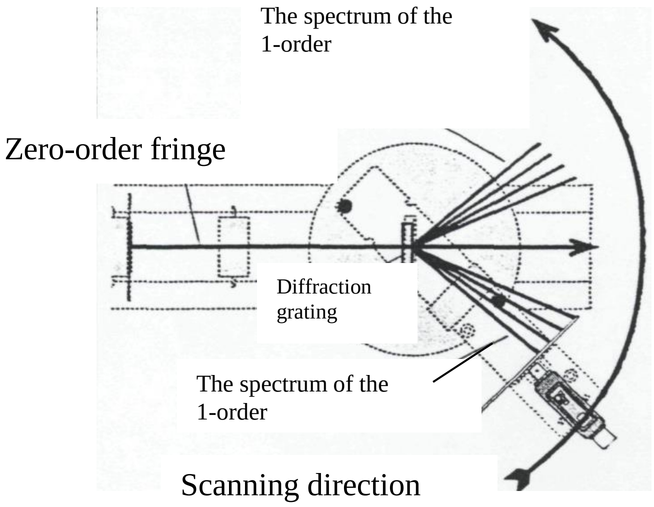


Fig.4

4. Move the light sensor arm away from the image of the first-order bands.
5. To start the measurement, press the REC button.

6. Move the light sensor knob slowly and smoothly in the direction of the central fringe visible on the screen up to the first-order fringe visible on the other side of the screen.
7. Observe the change in light intensity as a function of the position in the graph window and adjust the speed of movement of the light sensor arm to obtain a relatively continuous set of measurement points.
8. After completing the measurements, press the STOP button.

V. Determination of the λ wavelength of light

1. Position the mercury lamp in front of the slit to see a sharp image of the colored fringes of the mercury spectrum on the E screen.
2. To measure the positions of the most intense lines, set the light sensor GAIN switch to position 10.
3. Move the light sensor arm away from the image of the first-order fringes.
4. To start measuring, press the REC button.
5. Move the light sensor arm slowly and smoothly in the direction of the central fringe visible on the screen up to the first-order fringe visible on the other side of the screen.
6. Observe the change of light intensity as a function of the position in the graph window and select the speed of movement of the light sensor arm to obtain a relatively continuous set of measurement points
7. After completing the measurements, press the STOP button.
8. To measure the positions of the less intense and weakest lines in the spectrum, set the light sensor GAIN switch to 100.
9. Repeat steps 3, 4, 5, 6, 7.

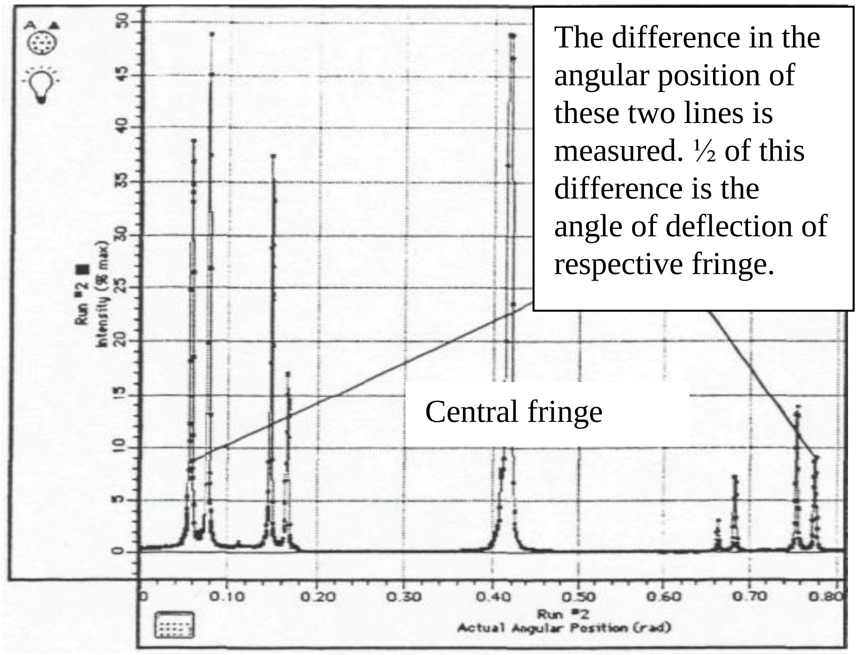
Data analysis

VI. Determination of the diffraction grating constant d

In order to determine the diffraction grating constant, we need to know the deflection angle of the red fringes visible in the laser light spectrum. This angle is equal to half the difference of the angular positions of the lines on both sides of the central fringe. To determine the angular positions of the spectral lines, we use the precision cursor in the graph window.

1. Press the precision cursor 

button in the lower left corner of the graph. Move the cursor to the plot area. The cursor changes to a cross of spider threads. The x and y coordinates of the cursor position are displayed next to the horizontal and vertical axes. Move the cursor on the graph to the middle of the maximum on the right side and read the coordinate of the α_1 position.
2. Then move the precision cursor to the center of the maximum on the left side and read the position coordinate again for α_2.
3. Calculate the α angle of deflection: $\alpha = \dfrac{\alpha_2 - \alpha_1}{2}$.
4. Read the wavelength of the laser light on the laser housing.
5. Calculate the grating constant using the formula: $d = \dfrac{\lambda_s}{\sin \alpha}$



Calculation of the uncertainties

VII. Determination of the wavelength of light λ

1. To determine the wavelength of the light for a given colour, the fringe angular position of a given colour should be determined. For this purpose, we use a precision cursor. Measure the difference in the angular position of two lines for the same colour, ½ of this difference is the deflection angle of a given fringe. Follow the steps described in paragraph V, points 1,2,3.
2. Calculate the light wavelength of a respective colour using the formula: $\lambda = d \sin \alpha$.
3. Compare the calculated wavelength for a respective colour with the table value given in the table under the table with the measurement results. Calculate the absolute error $\Delta\lambda_{tab}$,

$$\Delta\lambda_{tab} = |\lambda - \lambda_{tab}|.$$

   and the relative percentage error:

$$B_p = \frac{\Delta\lambda_{tab}}{\lambda_{tab}} \cdot 100\% .$$

4. In the graph windows, select the parameters to make the graphs look most favorable, then save the file on a floppy disk (Save As option from the File menu) and print the graphs on a computer connected to the printer ("Print Active Display" option from the File menu).