“D I F F R A C T I O N”

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Theoretical Introduction

Experiment “D I F F R A C T I O N”

Light has a dual nature: it is both a collection of particles, photons, emitted from a source and moving along straight lines, and also a wave subject to all wave phenomena, such as diffraction, interference and polarization.

In the second approach, light is an electromagnetic transverse wave propagating through space at a very high speed. When it encounters an obstacle, light bends, that is, it undergoes diffraction, and changes its direction of propagation. This phenomenon can be explained, for example, based on Huygens’ principle.

After passing through one narrow slit, light propagating in a straight line, as a plane wave, changes into a spherical wave propagating in all directions. When there are many slits, partial waves diffracted at different angles overlap, interfere with each other and form an image consisting of reinforcements and cancellations, so-called interference fringes, according to the equation:

$$d \cdot \sin\alpha = n \cdot \lambda$$

where:
d – diffraction grating constant, the distance between the slits of the grating (in metres),
α – angle of wave diffraction,
n – fringe order number,
λ – wavelength of light.

A system of many slits cut in an opaque screen forms a so-called diffraction grating. If a beam of rays with wavelength λfalls perpendicularly on the grating, the light is diffracted in such a way that diffraction images may be formed only in certain directions - those for which the path differences of rays emerging from two adjacent slits are equal to integer multiples of λ.
An interference fringe is formed when the optical path difference of light waves is equal to zero, central fringe, or is equal to the wavelength, first fringe, or to its multiple, nth fringe.

For the first fringe:

$$d \cdot \frac{a + \frac{d}{2}}{\sqrt{l^2 + \left(a + \frac{d}{2}\right)^2}} = 1 \cdot \lambda$$

Since *d* is of the order of 10^{-5}, while a is of the order of 10^{-1}, the terms *„d/2”* may be neglected and we obtain:

$$d \cdot \frac{a}{\sqrt{l^2+a^2}} = \lambda \text{ lub } ad = \lambda\sqrt{l^2 + a^2}$$

Laser light has all the features necessary to observe the phenomena of diffraction and wave interference. It is highly collimated, monochromatic and coherent in time and space.

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Preparation Questions:

1. What is wave-particle duality?
2. Give examples of physical phenomena in which light, as an electromagnetic wave, shows its wave nature and phenomena in which it shows its particle nature.
3. What is diffraction of light?
4. Discuss Young’s experiment.
5. Give the equation for the position of interference fringe maxima in Young’s experiment.
6. What is the diffraction grating constant?
7. In what wavelength range of electromagnetic radiation does the human eye detect a signal, that is, see?
8. What is a diffraction grating?
9. What is monochromatic light?
10. What does coherence of light mean?
11. Visible light with a wavelength of 550 nm falls on a single slit and produces the second diffraction maximum at an angle of 45°relative to the direction of incidence of the rays. What is the width of the slit?
12. In Young’s experiment, monochromatic light with wavelength $\lambda = 600$nm was used. Calculate the maximum number of fringes obtained on the screen after the light passes through the slits. The distance between the slits is $d = 2\ \mu m$.
13. A beam of light with wavelength $\lambda = 6 \cdot 10^{-7}$m falls perpendicularly on a diffraction grating. At what angle is the third-order fringe observed if the grating has 200 lines per 1 mm?
14. List the features of laser light that distinguish it from the light of an ordinary light bulb.
15. What is dispersion? What dispersive elements do you know?

Course of Activities:

1. Determine the diffraction grating constant d.
2. With the instructor’s permission, turn on the laser.
3. Place the diffraction grating at a distance of at least one metre from the screen.
4. Measure, using the ruler placed on the rail, the length $l$from the diffraction grating to the screen.
5. Measure, using a ruler, the length $a$between the zero-order fringe and the first, neighbouring fringe.
6. Reduce the distance between the diffraction grating and the screen.
7. Repeat steps 4 to 6 until ten values of length $l$and ten values of length $a$are obtained.
8. Estimate the measurement uncertainties:
   - distance between fringes Δa, taking into account the size of the fringes,
   - distance between the grating and the screen Δl, taking into account the precision of screen positioning.
9. Perform calculations according to the instruction and prepare a trial graph in a spreadsheet. In the calculations, remember to use the basic SI units for all lengths.
10. Prepare a measurement protocol and measurement uncertainties.

NOTE:

- The diffraction grating constant is the distance between two adjacent slits. It can be determined on the basis of the parameters placed on the housing, frame, of the diffraction grating, for example the number of lines per 1 millimetre of grating width.
- The nominal wavelength of the laser light can be read from the nameplate.

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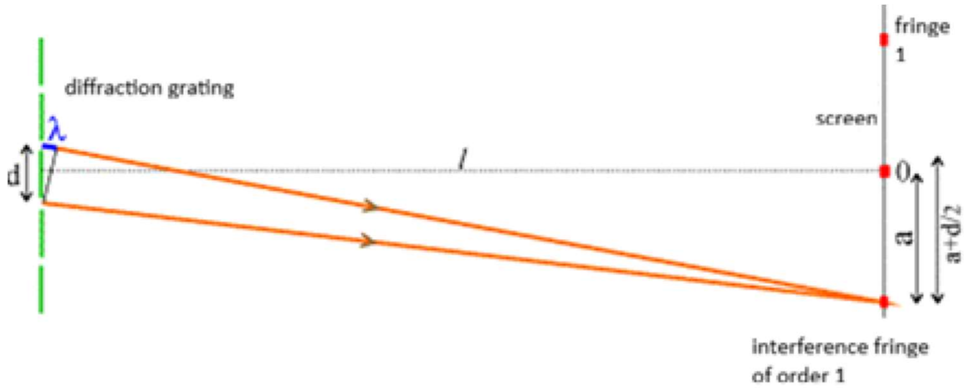
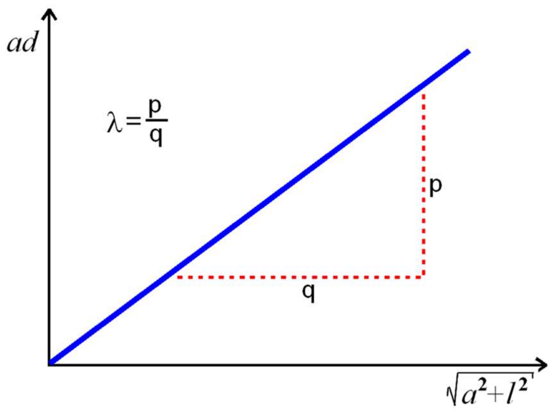
Methodological Template

Student 1: Determination of the wavelength of light using a diffraction grating.
Student 2: Verification of the diffraction grating equation.

From the diffraction grating equation: $d \cdot \sin\alpha = n \cdot \lambda$, for the first fringe: (n=1) we obtain:

$$ad = \lambda\sqrt{l^2 + a^2}$$



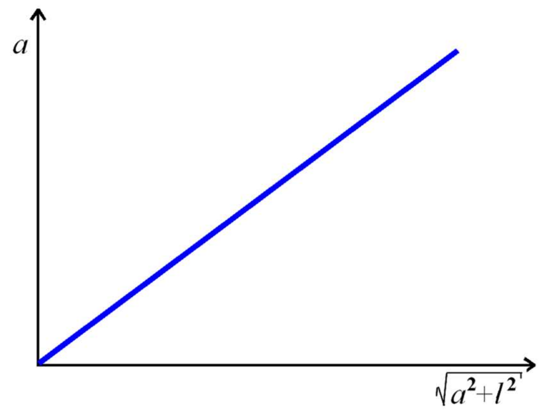


Therefore, in order to determine the wavelength of laser light, one should:

- perform measurements of the dependence of the position of the first fringe a on the distance between the diffraction grating and the screen l,
- determine the distance d between the slits of the grating,
- prepare a graph of the dependence:

  $a \cdot d$ as a function of $\sqrt{a^2 + l^2}$

- read the wavelength from the graph.



Therefore, in order to verify the diffraction grating equation, one should:

- perform measurements of the dependence of the position of the first fringe a on the distance between the diffraction grating and the screen l,
- prepare a graph of the dependence:

  a as a function of $\sqrt{a^2 + l^2}$

- analyse its linearity.

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Report Guidelines – Determination

Student 1: Determination of the wavelength of light using a diffraction grating.

I. Methodology (conceptual plan of the exercise)
II. Course of the exercise
II.1. Course of activities
II.2. Sketch of the measurement setup
III. Results

1. Measurement results

		1	2	3	4	5	6	7	8	9	10
a	[mm]										
l	[m]										

Δa =

Δl = ... d = ... [m] $\lambda_{nominal}$ = ... [nm]

2. Calculations (example calculations - referring, for example, to measurement no. 7)

$$a \cdot d =$$

$$\Delta(ad) = \Delta a \cdot d = \ldots$$

$$\sqrt{a^2 + l^2} = \ldots$$

$$\Delta\sqrt{a^2 + l^2} = \frac{a}{\sqrt{a^2 + l^2}}\Delta a + \frac{l}{\sqrt{a^2 + l^2}}\Delta l = \ldots$$

3. Calculation results

		1	2	3	4	5	6	7	8	9	10
ad	[ ]										
$\sqrt{a^2 + l^2}$	[ ]										
Δad	[ ]										
$\Delta\sqrt{a^2 + l^2}$	[ ]										

4. Graph

- calculation of λ (the slope of the “best-fit” straight line)
- calculation of λ' (the slope of the deviated straight line)
- calculation of $\Delta\lambda = |\lambda - \lambda'|$

5. Summary

The determined value of the wavelength λ is ...
The accuracy of the method $\Delta\lambda$ is ...

Within the limits of the result $\lambda \pm \Delta\lambda$, the nominal value of the laser light wavelength is / is not included*.
*Choose the correct option.
Additional conclusions, observations, causes of measurement uncertainties..

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Report Guidelines – Verification

Student 2: Verification of the diffraction grating equation.

I. Methodology (conceptual plan of the exercise)
II. Course of the exercise
II.1. Course of activities
II.2. Sketch of the measurement setup
III. Results

1. Measurement results

		1	2	3	4	5	6	7	8	9	10
a	[mm]										
l	[m]										

Δa =

Δl = ...

2. Calculations (example calculations - referring, for example, to measurement no. 3)

$$\sqrt{a^2 + l^2} = \ldots$$

$$\Delta\sqrt{a^2 + l^2} = \frac{a}{\sqrt{a^2 + l^2}}\Delta a + \frac{l}{\sqrt{a^2 + l^2}}\Delta l = \ldots$$

3. Calculation results

		1	2	3	4	5	6	7	8	9	10
a	[...]										
$\sqrt{a^2 + l^2}$	[...]										
$\Delta\sqrt{a^2 + l^2}$	[...]										

Δa =

4. Graph

5. Summary

Since on the graph … it is possible to draw a straight line passing through all measurement uncertainty rectangles, there are no grounds to conclude a deviation from …
Alternatively:
The deviation from linearity in the range … may result from …
Additional conclusions, observations, causes of measurement uncertainties.