Tomsk Polytechnic University

PHYSICS III
Laboratory Guide

PHYSICS II

Methodical Instructions in General Physics Laboratory Practice Work for Students of all Specialization.

The Methodical Instructions have been discussed and approved by the Methodical Council of the Theoretical and Experimental Physics Department.

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Experiment 1. Determination of Refraction Index of Liquids by Means of Refractometer

1. Devices and Instruments
A refractometer, set of liquids with the different refraction indexes, set of the sugar solutions with the different concentrations, pipettes, a wiper for a refractometer prism.

2. Purpose of Work
1. Determinate the refraction index of liquids by means of refractometer relatively of air.
2. Determine the analytic dependence of the refraction index from the concentration of the sugar solution.

3. Theoretical Contents
When the light rays cross a boundary of two clear homogeneous substances (see Fig.1) then a direction of the rays changes according to the law of refraction:
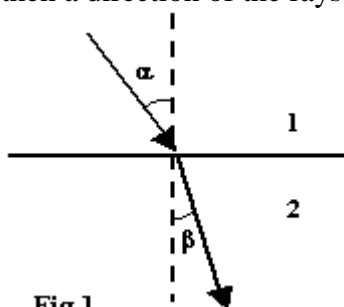

Fig.1.

$$\frac{\sin\alpha}{\sin\beta} = n_{21} \qquad (1)$$

where α - hade, β - refraction angle, n_{21} - relative refraction index, i.e. refractive index of the second substance 2 relatively of the first substance 1:

$$\frac{n_2}{n_1} = n_{21} \qquad (2)$$

where n_1, n_2 - the absolute refractive index of substance 1 and substance 2 correspondently.

In accordance with the wave theory of light the next relation is valid:

$$\frac{n_2}{n_1} = \frac{V_1}{V_2}$$

where V_1, V_2 — speeds of the light wave propagation in the substance 1 and substance 2 correspondently. Let a substance 1 is the vacuum. In this case $V_1 = c$, $n_1 = 1$ and $n_2 = \frac{c}{V_2}$. In the general form we get:

$$n = \frac{c}{V} \qquad (3)$$

The absolute refractive index of substance n_{abs} is a value that shows, as many times the velocity of light in vacuum is larger than the velocity of light in a substance.

In the refractometer's measurements *the relative refraction index* of a substance is usually determined relatively of the air in the laboratory:

$$n_{abs} = n_{air} n \qquad (4)$$

where n_{air} — absolute refraction index of air ($n_{air} = 1.00029$ at temperature t= 0^0C, the atmospheric pressure p= 760 millimeters of mercury and the wavelength λ= 589.3 nm), n — refractive index measured by means of the refractometer. The parameters t, p and λ

4

are the same. The refraction indexes are different for the different wavelengths. In this laboratory experiment the wavelength is invariable.

If the concentration of the solution is $(0 \div 30)\%$) then the next expression is valid for the refractometer's analysis of the dilute solutions:

$$n = n_0 + kx$$

$$(5)$$

where $n -$ refraction index of a solution, $n_0 -$ refraction index of a dissolvent, $k -$ concentration of a solution, $x -$ empiric coefficient which is called the increment of the refraction index. Determining n, n_0 and knowing x, we can find an analytic dependence of a refraction index of a solution from its concentration.

The method of the angle limit is used in this laboratory experiment. This method is based on the phenomenon of the total internal reflection.
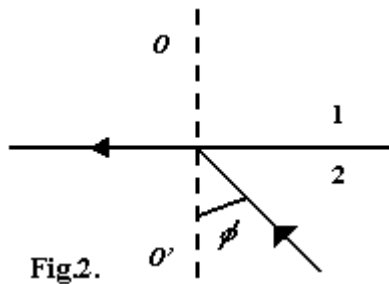
A medium is called "optically denser" when its absolute refraction index is larger. It's mean that the medium 2 is optically denser relatively of the medium 1 (see Fig.1) if $n_2 > n_1$. According to the law of refraction (see Formula 1):

Fig.2.

$$\sin\alpha > \sin\beta; \alpha > \beta \text{ (since } n_{21} = \frac{n_2}{n_1} > 1)$$

When the light ray crosses from the "optically denser" medium to the "optically less densely" medium, then it deflects from the normal *OO'*. Let the light ray moves from the medium2 to the medium 1 and $n_2 > n_1$ (see Fig.2). Some angle $\varphi_l < 90^0$ is called "the limit angle" when the refraction angle will be equal 90^0. In this case, the refracted ray will slide along the interface of two mediums. The angle φ_l can be found using Formula 1:

$$\sin\varphi_l = \frac{n_1}{n_2} \qquad (6)$$

If $\varphi > \varphi_l$, then the light ray will completely reflect from the boundary of mediums. This phenomenon is called the "total internal reflection". In the method of the limit an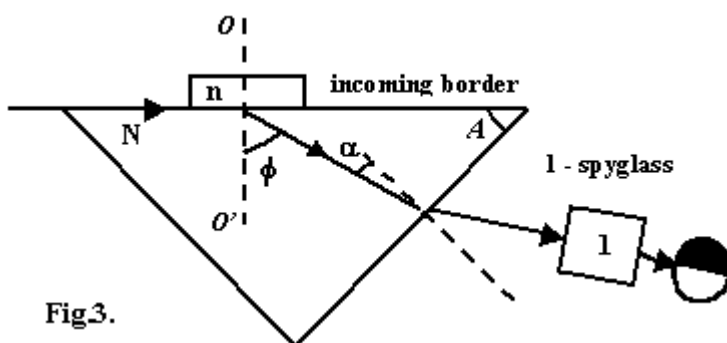gle a measuring prism with the known refractive index N (see Fig.3). The incoming border of the prism contacts with a substance. A refractive index of this substance n should be determined (n< N). The light ray slides along the interface of two mediums and refracts into the measuring prism

Fig.3.

under the angle φ. After that it falls on the output border under the angle α and leaves the prism under the angle β. An angle *A* is called a refracting angle of the prism. The output rays are observed in the spyglass (see Fig.3) whose field of vision is divided into two part: spotlit and dark. The border between spotlit and dark parts corresponds to the limit angle φ. It is directly measured by the method of the limit angle. An angle β is measured between the limit angle φ and the normal to the output border of the prism. In according to the law of the "total internal reflection" we have:

$$\sin\varphi = \frac{n}{N} \qquad\qquad (7)$$

$$\sin\beta = N \sin\alpha , \qquad\qquad (8)$$

where $\varphi = \alpha \pm A$.

The sign "+" corresponds to the case which is shown in Figure 3 and the sign "-" when the light ray moves in the opposite direction. Using Formulae (7) and (8) we get:

$$n = sinA \sqrt{N^2 - sin^2\beta} \pm cosA \, sin\beta \qquad\qquad (9)$$

4. Experimental Plant

The refractometer RPL-3 is used in this laboratory experiment. It's destined for the measurements of the refraction index of liquids. The measuring prism 1 (see Fig.4) is fixed and made from the heavy crown glass ($N = 1.5724$). Therefore, it's possible to measure a refraction index in the range $(1.300 \div 1.540)$ with the accuracy 0.001%. The prism 2 is called the mobile lighting prism. Two or three drops of an investigated liquid are put on the incoming border of the measuring prism 1 and pressed on the mobile lighting prism 2. The very thin layer 3 of the investigated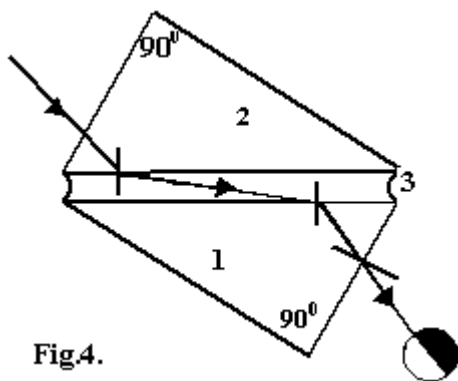 liquids is being formed between two prisms. The thickness of this layer is $(0.1 \div 0.2)$ mm. Since the layer is very thin it's possible to observe the phenomenon of the "total internal reflection". Graphically the refractometer is shown in Fig.5. Here: 1- an ocular, 2 – a prism block, 3 – a lighting lamp, 4 – a handle, 5 – a prism compensator.
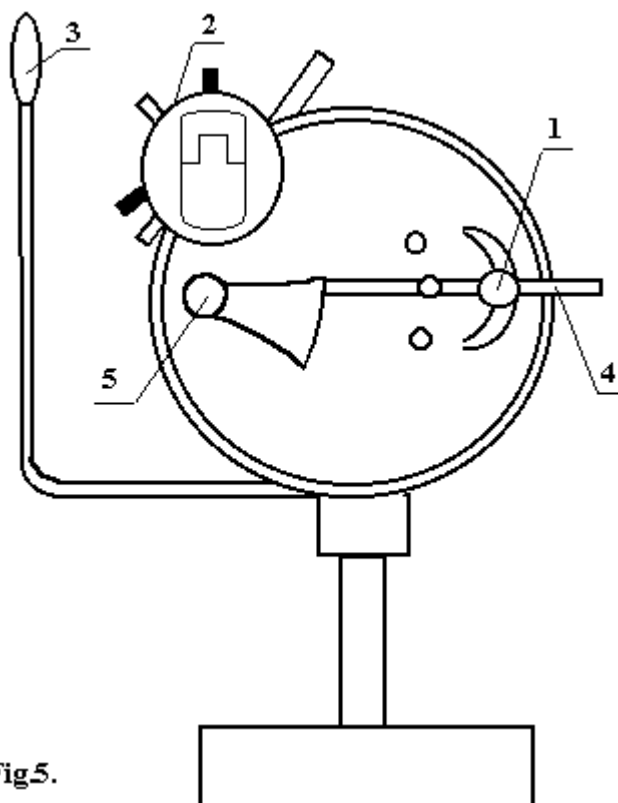

Fig.4.

In this experiment the wavelength of the light ray is fixed. An object glass of a sighting device is placed inside the refractometer, but the ocular – outside. Using the handle 4 the ocular (with the object glass) can shift along a scale of the refraction indexes n. A scale factor is 0.001. An extra scale (with the scale factor from 0 to 95%) is placed from the right of the first scale. It is used for the experiments with the sugar

Fig.5.

solutions. In a field of vision of the ocular one can simultaneously see a border of the dark and light fields, the graduation marks of two scales and three cross hairs, which are parallel to the boundary. You combine the graduation marks with the border of the dark and light fields and take the readings on the scale you need.

5. Experimental Procedures

Part 1. Determination of the refraction index of liquids:

1.   Switch on the lighting lamp. The light has to fall on the window of the measuring block perpendicularly.

2.   Set the sharp image of scales and the cross hairs rotating the ocular.

3.   Open the measuring block (the lighting prism), put on put on the incoming border of the measuring prism 2-3 drops of an investigated liquid and close the block quickly.

Note: Don't touch the surface of the prism with a pipette. It can scratch the surface.

4.   Combine the cross hairs with border of the light and dark fields. Record a scale graduation in Table 1. It corresponds to a value of the refraction index. Repeat the experiment three times.

5.   Open the measuring block, put on the measuring prism 2-3 drops of the distilled water and close the block. Open the block again and wipe dry the surfaces.

6.   Repeat the experiment for other liquids.

Table 1

Investigated liquid	n_1	n_2	n_3	Average n

Part 2. Determination of the dependence of the refraction index from the concentration of the sugar solution.

1.   Measure the refraction index of the distilled water n_0 (see items 3-5 of Part 1).

2.   Measure the refraction index of the sugar solution n_1, whose concentration is equal $x_1 = 10\%$.

3.   Make the measurements for the concentrations of the solution $x_2 = 15\%$ and $x_3 = 20\%$. Repeat every measurement three times.

4.   Record the data in Table 2.

Table 2

Concentration of the solution	n_1	n_2	n_3	Average n

5.   Plot the dependence of the refraction index n from the concentration of the sugar solution x.
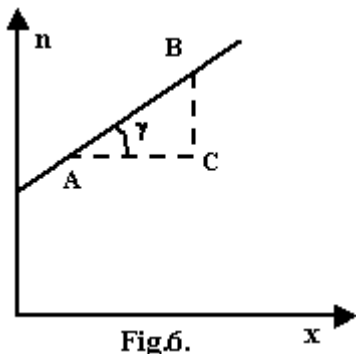

Fig.6.

6.   Determine a value of an increment of the refraction index k (see Fig.6). $k = \mathrm{tg}\gamma = \dfrac{BC}{AC}$. The side of the triangle BC is the difference of the refraction indexes at the points B and C. The side AB is the difference of the concentrations at the points A and C.

7.   Plot three triangles at the different points of the graph, calculate three different values of the increment and calculate the mean value of k.

8. Record an analytic dependence *n (x)* using Formula 5 and the findings of *k, n_0*.

6. Test Questions

1. What devices are called the refractometers?
2. What's called the relative refraction index? What's called the absolute refraction index? What's the physical sense of the absolute refraction index?
3. How does the refraction index depend on the concentration of the solution?
4. What is the phenomenon of the "total internal reflection"?
5. What is the method of the "limit angle"?
6. What design has the refractometer used in this laboratory experiment? What is the accuracy of the experiment?

Experiment 2. Determination of Dependence of Refraction Index of Prism from Wavelength of Light

1. Introduction
When a beam of a natural light passes through a prism placed in vacuum or air then a spectrum is observed on a screen located behind the prism. I. Newton discovered the phenomenon of the color dispersion. The color dispersion is called the dependence of he refraction index n from the wavelength of the incident light λ.

2. Purpose of Work
Determine the dependence of the refraction index of the glass prism from the wavelength of light.

3. Theoretical Contents
The classic theory of the dispersion was originated on the basis of the electronic theory of a substance. It explains the phenomenon of the dispersion by an interaction of the light waves with the electrons of atoms. The absolute refraction index of a glass is equal:

$$n = \frac{V}{c}$$

(3)

where V – velocity of light in a substance, c – velocity of light in vacuum.

The electrons are hold near its balance locations by the quasi-elastic forces performed the harmonic oscillations with the rest frequency ω_0. The falling light wave creates the forced oscillations of electrons with the frequency ω. Thus, every particle radiates the secondary waves. The secondary waves, laying on the first ones, form the resultant waves. An amplitude and phase of these waves differ from the ones of the first waves. Therefore, the light waves with the different frequency ω have the different velocities and refraction indexes in a substance (see Formula 1). It is convenient to observe a spectrum and make measurements using a prism when the prism is set in a parallel light beam near the angle of the smallest deflection δ_{min} (see Fig.1). An angle of a deflection δ is called an angle between directions of the falling light ray and the outgoing one. The value of δ depends on the wavelength of light λ, the hade α and the refracting angle of the prism A. The angle δ has a lower-range value δ_{min} if $\alpha = \alpha'$ (for the same prism). The refraction index n can be found from the next formula (for a given wavelength):

Fig.1.

$$n = \frac{\sin\dfrac{A+\delta_{min}}{2}}{\sin\dfrac{A}{2}}$$

(2)

The measurements of A and δ_{min} are made by means of a goniometer.

4. Experimental Plant

The experimental plant is shown in Fig.2. The basic parts of the goniometer are a collimator (1) and a spyglass (2). The collimator is fixed on a heavy base. The spyglass

Fig.2.

can be rotated relatively the fixed limb (3). The limb is a metallic disc located horizontally. The limb was divided in degrees. The spyglass rotates along with a circular nonius (4). A position of the spyglass relatively the limb is made by means this nonius. The accuracy of the scale reading is about 0.1^0. A little table (5) is centered with the limb and can be rotated too. On this table is put a prism (6) from a substance whose refraction index is investigated.
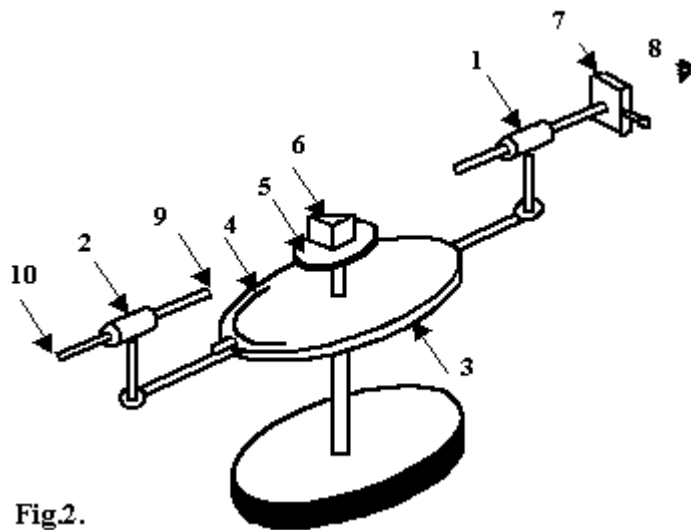
The collimator (1) is a metallic tube near the one side of which is set an objective. The other side is connected with a slit (7). This slit is located at a focal plane of the objective and directed to the light source (8). A slit width is adjusted by means of a microscrew. The collimator and spyglass are centered thus the rays of the light source (8) are on the point of the focal plane of the spyglass objective (9). In this plane is located a vertical thread (sometimes a cross of threads). Looked at the ocular of the spyglass (10) we can simultaneously observe the thread and the slit image.

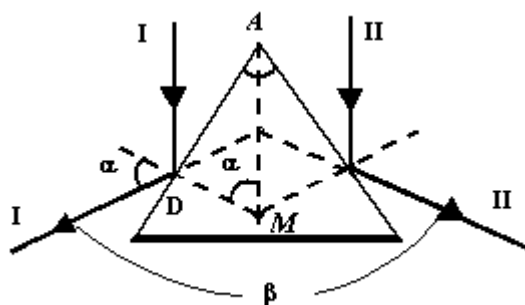## 5. Determination of Refraction Index of Prism

Fig.3.

Let the parallel beam of light falls on a dull side of the prism (see Fig.3.). The ray I reflects from the left side of the prism and the ray II – from the right side.

A sum of angles at the point D is equal 360^0, i.e.

$$4\alpha + \beta = 360^0 \qquad (3)$$

From the triangle ADM we can find:

$$\alpha = 90^0 - A/2 \qquad (4)$$

Using Formulas (3) and (4) we get:

$$4(90^0 - A/2) + \beta = 360^0$$

$$A = \beta/2 \qquad (5)$$

Thus, to determine the refraction angle of the prism A you need to measure the rotation angle β. This is the angle between the rays reflected from the left and right sides if the prism.

6. Determination of the Least Deflection Angle

Turn the table of the goniometer (5) as it is shown in Fig.4. You have to observe a line spectrum in the field of vision of the spyglass. Turn slowly the table with the prism so as the spectrum remained in the field of vision, but the falling angle α decreased. At the
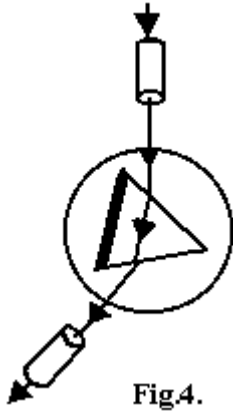
same time the angle δ decreases too. Catching the moment when the vision of spectrum comes to a stop and begins to move to the opposite direction. It corresponds to a situation when the angle δ has reached its lowest value and begins to increase. At this moment you stop turning the table. Combining the vertical thread of the spyglass with every lines of spectrum make the readings of angles φ_1', φ_2', φ_3' … for these lines. Repeat the same operations for the right side of the prism and spectrum make the readings of angles φ_1'', φ_2'', φ_3'' … . The least angle of the deflection, e.g. for the first line of spectrum, is equal:

$$\delta_1 = \frac{\varphi_1' - \varphi_2''}{2} \qquad (6)$$

Fig.4.

Experimental Procedures

1. Set a light source (a mercury lamp) in front of the collimator slit. Get a sharp vision of the slit moved in or out the spyglass ocular.
2. Put on the table of the goniometer the prism as it's shown in Fig.3. The dull side of the prism has to be parallel to the plane of the collimator outcome and direct to the objective of the spyglass.
3. Turn the spyglass so as the reflected rays from the right side of the prism got to the spyglass. Find the slit vision, combine the vertical thread of the spyglass with it and make the readings on the limb and nonius.
4. Record the data in Table 1.

Table 1

No.	Readings of the limb and nonius		Angle β	Average β	$A = \beta/2$
	Right side	Left side			
1					
2					
3					

5. Find the spectrum (see Fig.5), determine the least angles of the deflection for all lines (see Fig.5). Record the data in Table 2.

Table 2

No.	Color of line	Brightness of line	λ, nm	Readings of limb and nonius		$\varphi' - \varphi''$	δ	n
				Right side	Left side			
1	Red	Bright	670					
2	Orange	Faint	612					
3	Yellow	Bright	579					
4	Yellowy-green	Bright	538					
5	Bluish-green	Faint	489					
6	Blue	Bright	436					
7	Violet	Bright	405					

Note: Sometimes you cannot observe all lines of the spectrum.
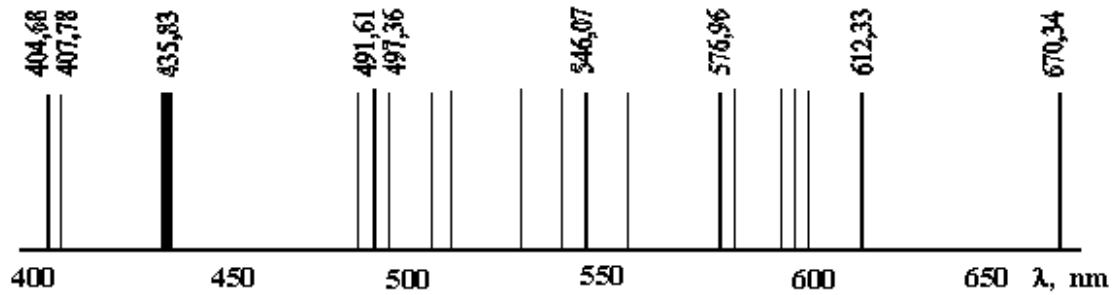6. Calculate the refraction indexes of a substance using Formula (2). Record the data in Table 2.

Fig.5.

7. Plot a graph of the dependence of the refraction index from the wavelength of light $n = f(\lambda)$.

8. Additional Task

1. Change a light source. Take a hydrogen tube as a new light source. The next lines of the hydrogen spectrum are the most intensive (see the table below).

No.	Color of lines	λ, nm
1	red	656,2
2	bluish-green	436,1
3	violet	434,0

2. Make a single determination of the least deflection angle for these lines of spectrum.
3. Calculate the refraction indexes using Formula (2) and plot the findings on the previous graph for the mercury tube.

4. Analyze the results of this experiment.

8. Test Questions

1. What is a dispersion of light?
2. What's a curve of dispersion?
3. What is the goniometer? Explain it. How is an accuracy of a circular nonius determined?
4. How is a refraction angle of a prism determined?
5. What is the least deflection angle? How is it determined?

Experiment 3. Hydrogen Spectrum Research and Determination of Rydberg Constant

1. Devices and Instruments
Universal monochromator UM-2, lens with the focal length f = 94 mm, fluorescent lamp, discharge tube with hydrogen, power unit for a mercury lamp, Ruhmkorff coil.

2. Purpose of Work
Research a visible region of the hydrogen spectrum and determination of Rydberg constant

3. Theoretical Contents
It is well known that the isolated atoms emit the line spectra. The lines of these spectra are well ordered and form the certain groups or serieses. The atom of hydrogen has the simplest spectrum. The line disposition of the hydrogen spectrum is described by the formula:

$$\frac{1}{\lambda} = R\left(\frac{1}{n^2} + \frac{1}{m^2}\right) \tag{1}$$

where λ - a wavelength, R – Rydberg constant, n – an integer which has a definite value for every series, m – an integer which has a value in the interval $[n+1, \infty)$. R is the constant for all serieses of the hydrogen spectrum. A wave number $\bar{\nu}$ is called a quantity that is inversely proportional to the wavelength λ: $\bar{\nu} = \frac{1}{\lambda}$

Thus, Formula (1) is changed:

$$\bar{\nu} = R\left(\frac{1}{n^2} + \frac{1}{m^2}\right) \tag{2}$$

Therefore, a distance between two adjacent spectral lines decreases if the number m increases. When $m = \infty$ we get a limiting value of the wave number:

$$\nu_\infty = \frac{R}{n^2}$$

The quantity ν_∞ is called a boundary of a series. The spectral lines take up the closer positions when $\bar{\nu} \to \nu_\infty$. Swedish physicist Rydberg proved that the wave numbers of the some other elements are the difference of two functions of the variables n and m:

$$\bar{\nu} = \text{T}(n) - \text{T}(m) \tag{3}$$

The function T (n) is a constant magnitude for every series and the function T (m) is a variable one. These functions are called the spectral therms. A position of any line is possible to calculate knowing a system of therms for a given element. It is a difference of two therms and called the combinative principle.

The nature of the spectral therms was explained in Bohr theory. It is discovered that the combinative principle of Rydberg is one of the basic laws of physics. A light radiation process by an atom obeys this law.

According to Bohr theory, an atom has a series of the algoristic energy values E_1, E_2, E_3 …that are called the energy levels. When the atom jumps from the one energy level to the other one then a quantum of energy $h\nu$ is emitted or absorbed. Here: h – Planck's

constant, ν - frequency of the light wave. If the energy of the atom before the radiation is equal E_m and after the radiation - E_n then

$$h\nu = E_m - E_n \qquad (4)$$

If $\nu = c/\lambda$ then $\nu = c\,\overline{\nu}$, where c is a velocity of light in vacuum.
Finally, we get:

$$\overline{\nu} = \frac{E_m}{ch} - \frac{E_n}{ch} \qquad (5)$$

Comparing Formula 3 with Formula 5 we see that the spectral therms are proportionate to the energy values E_i (accurate within an additive magnitude) :

$$\text{Ti} = -\frac{E_i}{ch}$$

The minus means that the energy of atom is negative at the corresponding choice of a zero value of the potential energy. A normal state of atom is the state with the least energy, i.e. the atom is on the lowest energy level.
The energy of the hydrogen atom for all stationary states can be calculated using Formulas 2 and 5:

$$E_n = -Rhc\frac{1}{n^2} \qquad (n = 1,2,3\ldots\infty)$$

where n is a number of the energy level.
According to these conceptions, the integers n and m are the numbers of the levels. The transitions of the atom from level to level cause a radiation process. The levels and the
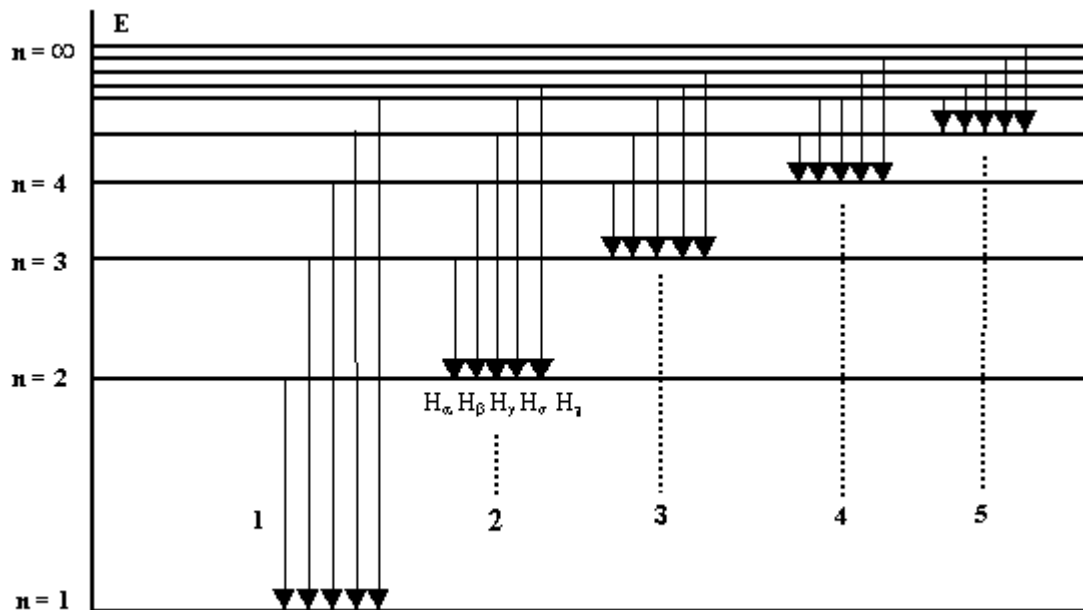

Fig.1.

corresponding transitions for the hydrogen atom are shown in Fig.1.
The spectrum of the hydrogen atom consists of the several bands:
1.   The Lyman band is the ultraviolet part of the spectrum appearing by the transitions of atom from the higher levels ($m = 2,3,4\ldots$) on the basic level ($n = 1$):

$$\overline{\nu} = R\left(\frac{1}{1^2} + \frac{1}{m^2}\right) \qquad (6)$$

2. The Balmer band is the visible part of the spectrum appearing by the transitions of the atom from one of the higher levels ($m = 3,4,5\ldots$) on the second level ($n = 2$)

$$\bar{v} = R\left(\frac{1}{2^2} + \frac{1}{m^2}\right) \qquad (7)$$

3. The Pashen band is the infrared part of the spectrum appearing by the transitions from one of the higher levels ($m = 4,5,6\ldots$) on the third level ($n = 3$):

$$\bar{v} = R\left(\frac{1}{3^2} + \frac{1}{m^2}\right) \qquad (8)$$

The Brakket and Pfund bands are the utmost infrared parts of the spectrum.
In this laboratory experiment the next lines of Balmer bands is determined:

H_α - red		(m = 3)
H_β - bluish-green		(m = 4)
H_γ - blue		(m = 5)
H_δ - violet		(m = 6)

4. Experimental Plant

The appearance and optical scheme are shown in Fig.2 and Fig.3. The basic parts of the monochromator (see Fig.2): collimator 3, prism table 4, prisms 5, output tube 6, input slit 1, microscrew 2, output slit 8, spyglass 7, readout drum of the wavelengths 9, bearing rail 10.
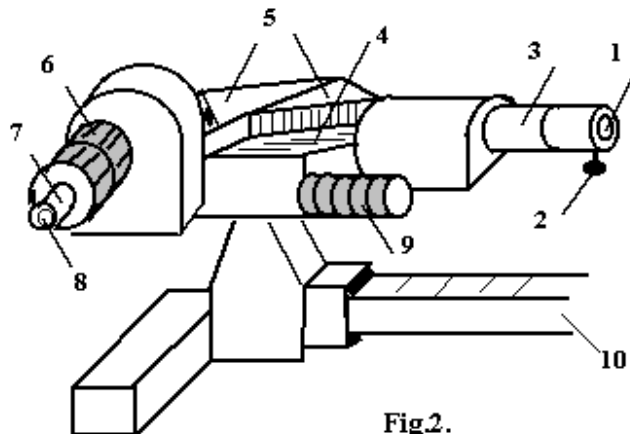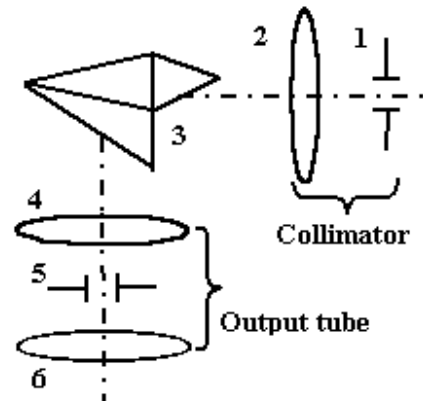

Fig.2.   Fig.3.

The collimator destines for a getting of a parallel light beam, which is directed to the prism. A divergent beam from a light source passes through the input slit 1 (see Fig.3) and falls on the objective 2 located within a focal length from the slit. As a result the parallel light beam is directed to a prism 3, which separates the light into the monochromatic components. At the same time the light beam changes its direction to 90^0.

The output tube destines for a chroma sort of the light rays. In other words we get a clear spectrum by means of the output tube. The parallel rays with the wavelength λ_1 passes through the objective 4 and gather in a certain point of the focal plane. The parallel rays with the wavelength λ_2 have other hade. Therefore, they gather in the other point of the focal plane. Thus, we get the spectrum in the focal plane of the spyglass, which is the color vision of the input slit. This spectrum is observed by means of the ocular 7 (see Fig.2). There is an index in the focal plane. This index is used for a determination of a position of a spectrum line. Some spectrum line is combined with the

index by means of the readout drum of the wavelengths 9 (see Fig.2). It's possible to get a sharp image of the index and spectrum line turning the ocular.

The readout drum of the wavelengths has the graduation marks in degrees. Turning the drum on one graduation mark (2^0) the prism system turns on 20''. To redefine the graduation marks of the drum in wavelength units a graduation of the drum scale is made. For this purpose a fluorescent lamp is used as a light source with the well-known line spectrum. Combining the spectrum lines with the graduation marks of the drum you get some data. Using these data you plot the graduation graph: on the y-coordinate – the graduation marks of the readout drum and on the x-coordinate – the corresponding wavelengths.

5. Experimental Procedures

Part 1. Calibration of monochromator.

8. Set a fluorescent lamp on the bearing rail in front of the collimator slit at the distance 453 mm. Switch on the lamp.

9. Light up the input slit of the monochromator. The light source should be at the distance 130 mm.

10. Make a width of the input slit about 0.01-0.02 mm using the microscrew 2 (see Fig.2). Find some spectral line using the readout drum of wavelengths. Get a sharp vision of the spectral line and index of the ocular.

11. Combine all the lines of spectrum with the index. Do it in series (from the red line to the violet line) counting out the data of the readout drum 9.

12. Record the data in Table 1.

Note: take the wavelengths of the mercury lamp spectrum in a lookup table.

Table 1

λ, nm						
n_0						

13. Plot the graph. A scale factor of the λ-axis has to be about 1nm.

Part 2. Measurement of wavelengths in the Balmer band and calculation the Rydberg constant

1. Set a hydrogen discharge lamp.

2. Repeat items 2-3 of the Part1.

3. Find the spectrum lines H_α, H_β, H_γ, H_δ, observing the hydrogen spectrum in the ocular and comparing these lines with the visions of ones in a figure, which is given by a laboratory assistant.

4. Determine a position of the mentioned lines repeating the item 4 of the Part 1.

5. Determine λ of all the fourth lines of this spectrum. Calculate the wave numbers of these lines accurate within one inverse centimeter.

6. Record the data in Table 2.

Table 2

m	3	4	5	6
n_0				
λ, nm				
$\bar{\nu}$, cm^{-1}				
R, cm^{-1}				

7.   Calculate the Rydberg constant for every line using the data of Table 2 and Formula (7). Calculate an average of R.
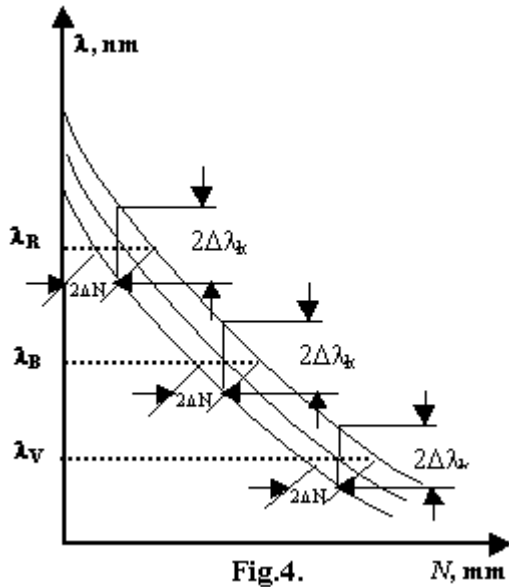

Fig.4.

8.   Calculate an error of a determination of the Rydberg constant. For this purpose you have to plot two curves, which are symmetric to the graduation curve of the monochromator. A distance between these symmetric curves (across) ΔN is equal a doubled scale error of the readout drum. The distance between the curves (upright) will be equal a doubled error of $\Delta\lambda$ for a given part of the spectrum (see Fig.4). Here: λ_R, λ_B, λ_V – wavelengths of the red, blue and violet lines of the spectrum correspondently.

6. Test Questions

1. Which regularities do you observe in the spectrum of hydrogen? Record a formula for the hydrogen spectral bands. What senses have the values in this formula?
2. What's a wave number? In which units is it measured?
3. What is the combinative principle? What are the spectral therms?
4. How many spectral bands has the hydrogen spectrum? How does the Bohr theory explain an origin of these bands?
5. How does the monochromator designed? What purposes does it use for?
6. What path of rays is in this device?
7. What is a graduation of the monochromator? How can you determine the wavelengths of the hydrogen spectrum using the graduation curve?

Experiment 4. Graduation of Saccharimeter and Determination of a Sugar Solution Concentration

1. Devices and Instruments
The saccharimeter SOK-1, set of tubes with a sugar solution, a light source.

2. Purpose of Work
1. Study of the saccharimeter.
2. Graduation of a device: determination of dependence between the graduation marks and an angle of a turning of a polarization plane.
3. Determine dependence between the graduation marks and a concentration of a sugar solution.
4. Determine unknown concentration of a sugar solution.

3. Theoretical Contents
A light has a dual nature. In the one case, the light is an electromagnetic wave and, in the other case, it is a photon flux. A phenome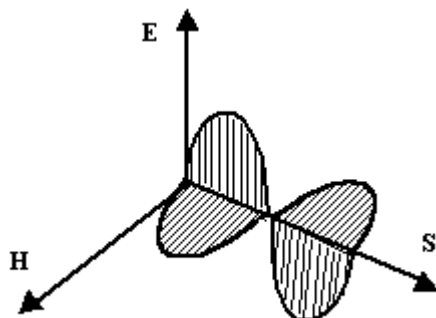non of a light polarization relates to the phenomena, which base on the laws of the wave optics. The electromagnetic waves are transverse. It's mean that the vectors of an electric field **E** and magnetic field **H** oscillate in the mutually perpendicular planes and perpendicularly to a direction of a light ray **S** (see Fig.1).

Fig.1

The usual light sources (a sunlight, an incandescent lamp, a mercury lamp an so on) are a collection of an enormous quantity of the elementary sources (atoms, molecules). These sources emit the light independently each other, with the different phases and orientations of the vectors **E** and **H**. The orientations change chaotically in time. Therefore, the resultant wave has the equitable orientations of **E** and **H** in a plane, which is perpendicular to the wave direction **S** (see Fig.1). Such light is called *natural* or *nonpolarized*.

Using the special devices called the polarizers can change the natural light into the plane-polarized or line-polarized one. The vectors **E** and **H** don't change its orientation in time. In this case, a plane **E, S** is called the plane of oscillations and a plane **H, S** – the polarization plane. Every polarizer has a special plane called the *polarizer plane*. The oscillations, which are parallel to this plane, pass through the polarizer freely. An opposite situation exists for the perpendicular oscillations.

Fig.2

Let the vector **E** oscillates in a plane that forms some angle φ relatively a polarizer plane. In this case, it's possible to resolve the oscillation with amplitude E into two oscillations with amplitudes $E_{\parallel} = E\cos\varphi$ and $E_{\perp} = E\sin\varphi$ (see Fig.2). A light direction is perpendicular to the plane of Figure. The oscillations with $E_{\parallel}$ will pass through the polarizer, but the oscillations with $E_{\perp}$ will be stopped. A light intensity is proportional to squared amplitude of oscillations. Let I_0 is an intensity of a plane-polarized light falling on a polarizer. Than an intensity of light passed through the polarizer is:
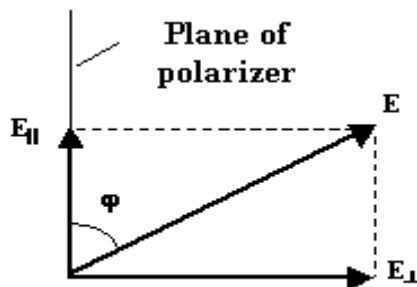
$$I = I_0 \cos^2\varphi \qquad\qquad (1)$$

where φ - an angle between the plane of oscillations and the polarizer plane. This expression is called the *Malus's law*. In the natural light all the values of φ are equiprobable. Therefore, a portion of the passed light is equal the average value of $\cos^2\varphi$, i.e. ½. Let set two polarizers on a path of a natural light (see Fig.3 and Fig.3a).
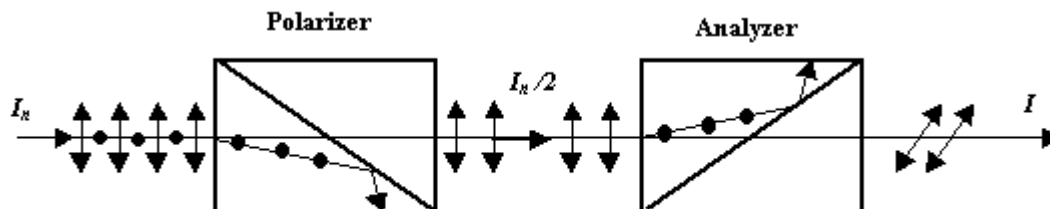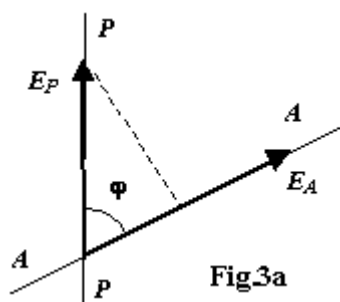

Fig.3

Fig.3a

Here: φ - an angle between the polarizer planes. An intensity of light passed through the second polarizer is:
$$I = \tfrac{1}{2}\, I_n\cos^2\varphi \qquad (2)$$
where I_n – an intensity of natural light falling on the first polarizer. When the polarizer planes are parallel ($\varphi=0$) then the maximum intensity is equal $0.5I_n$. When $\varphi = \pi/2$ then $I_n = 0$. The second polarizer is used for the determination of a polarization degree of light falling on it. Such polarizer is called an analyzer.

Optical active substances

Some substances have a property to turn a polarization plane of the plane-polarized light passing through its and are called the optical active substances. There are such substances as petroleum, turpentine, nicotine, tartaric acid, quartz, a water solution of sugar and etc.

An rotating angle of a polarization plane φ is proportionate to a thickness of layer of a optical active substance l and concentration of an active substance in a water solution C:
$$\varphi = \alpha l C \qquad\qquad (3)$$
The coefficient α depends on the nature of substance. It's called the *rotation constant*. The rotation constant weakly depends on the temperature and inversely proportional to a squared wavelength ($\alpha \sim 1/\lambda^2$). Usually, the angle φ is measured in degrees, the thickness l – in decimeters and concentration C – in g/cm^3. In this case, the constant α is called the specific rotation and marked as $[\alpha]$:
$$\varphi = [\alpha]\, l C \qquad\qquad (3')$$
A direction of rotation of a polarization plane is chosen for an observer looking towards a light beam. If the polarization plane rotates clockwise then a substance is called right rotational or positive, otherwise – left rotational or negative.

Philosophy of measurement

If an optical active substance is placed between polarizers with the parallel planes then a field of vision is light. To get darkness one needs to rotate one of the polarizer on the angle φ, which is determined from Formula 3. Therefore, it's possible to determine a concentration of a solution C. It needs to know a specific rotation of a given substance $[\alpha]$, a thickness of an optical active layer l and measure a rotational angle φ.

The penumbra polarimeters are used in practice. In such polarimeters a lighting of a half-fields of vision is set equal. A diameter CC' divides a field of vision into half parts (see Fig.4). In the one half the light oscillations lie in the plane P_1 and in the other half – in the plane P_2. An angle between the planes is equal φ. If these light beams will pass through the analyzer whose plane A is perpendicular to the plane P_2 then this beam will be absorbed and the half of the field of vision 2 will be dark. The other half will be light. If the polarizer plane A has a symmetric orientation relatively the oscillation planes P_1 and P_2: $A \perp OC$ or $A \| OC$ (see Fig.5) then both fields of vision will have an equal lighting. The line OC halves an angle between directions P_1 and P_2. We observe a weak lighting (a penumbra) if a position of analyzer is: $A \perp OC$ (see Fig.5a).
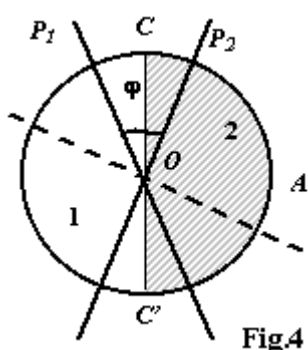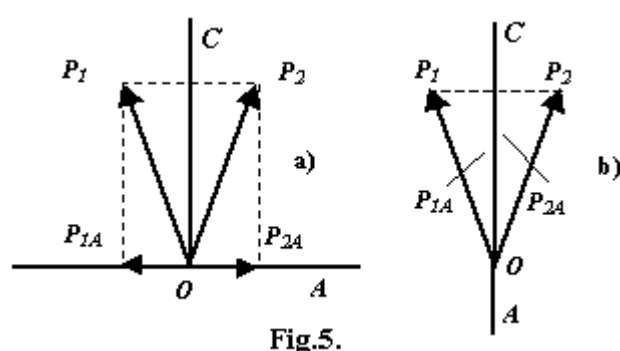
From the beginning it's tried to obtain an equal darkening of half-fields of vision without an optical active substance. After that the analyzer is used with the optical active substance. At that an angle of a polarizer turning is equal an angle of a turning of the polarization planes by means of the optical active substance.

4. Experimental Plant

The saccharimeter used in this laboratory experiment consists of two parts: a polarizer and an analyzer (see Fig.6). The polarizer P and the analyzer A are fixed in given saccharimeter. A quartz jack K is used for a setting of an equal lighting in the field of vision. This jack consists of a plane-parallel plate L and two quartz wedges K_1, K_2. The plate L is made from the left-rotated quartz and the wedges – from the right-rotated
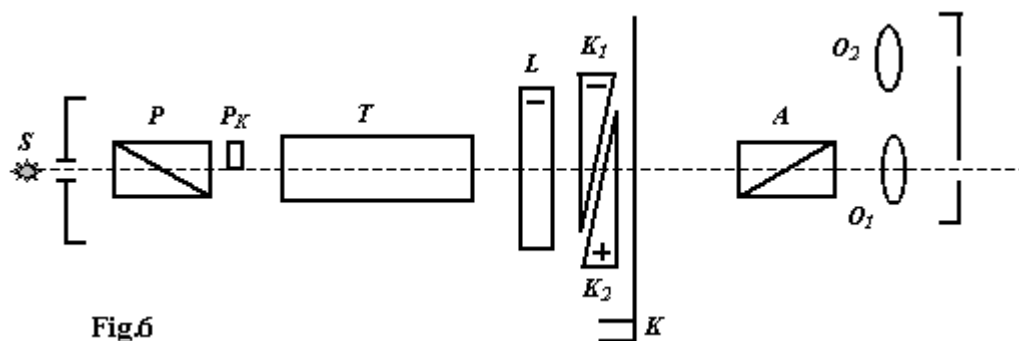
quartz. One of the wedges (K_2) is moveable, at that a thickness of the quartz jack changes. The moveable wedge is connected with a scale N sliding on a fixed nonius. To halve the field of vision, a thin quartz plate P_K is placed behind the polarizer P. The thickness of this plate is about $(0.2 \div 0.3)$ mm. A polarized light divided on two parts passes through a chamber T containing the saccharimetric tubes. An intensity of light, passed through the analyzer, is observed in the ocular O_1. The scale readings are made by the ocular O_2. An incandescent lamp with an ground glass and filter is used as a light source S.

6. **Experimental Procedures**

1.　　Switch on the light source. Get a sharp image of a field of vision, divided on two semicircles with a different light, turning the ocular O_1. Get a sharp image of a scale turning the ocular O_2.

2.　　Turn a cap screw of the quartz jack K, to get an indiscernible boundary of penumbras and the uniformly blackout field of vision. As that, a zero mark of nonius has to be against a zero mark of scale. You can observe that in the ocular O_2.

3.　　Put into the chamber T a tube with a sugar solution of the known concentration C_1.

4.　　Restore the uniformly blackout field of vision by means of the quartz jack K. The penumbras should be indiscernible again. Make a scale reading N.

5.　　Repeat the measurements (items 2-4) several times.

6.　　Record the data in Table 1.

Table 1

Concentration C [g/cm^3]	No. of exp.	Scale readings of nonius N [points]	Angle of turning of a polarization plane φ [degrees]	An average scale reading $N_{average}$ [points]	Length of a cuvette tube l [dm]	A specific rotation of sugar $[\alpha]$ $\left[\dfrac{degree}{dm g/cm^3}\right]$
$C_1=$	1					
	2					
	3					
	4					
	5					
$C_2=$	1					
	2					
	3					
	4					
	5					
$C_3=$	1					
	2					
	3					
	4					
	5					
$C_X=$	1					
	2					
	3					
	4					
	5					

7.   Repeat the items 2-6 for other known concentrations of the sugar solutions and for an unknown concentration.

8.   Plot a graduation curve $N_{average} = f\{C\}$ using the data of Table 1, marked on the x-coordinate the known concentrations and on the y-coordinate – the average scale readings $N_{average}$.

9.   Determine an unknown concentration C_X using the value of $N_{average,X}$ and the graduation curve.

10.   Calculate the angles of turning of the polarization plane φ using Formula 3'.

Note: use in calculations the next data – T= 200C, λ= 589 nm, [α]= 0.71 $\left[\dfrac{degee}{dmg/cm^3} \right]$.

11.   Plot the second graduation curve $N_{average} = f\{φ\}$.

12.   Determine the angle $φ_X$ using $N_{average,X}$ and the graduation curve $N_{average} = f\{φ\}$.

13.   Compare the determined angle $φ_X$ with the calculated (items 10 and 12).

6. Test Questions

1.   What is a phenomenon of a light polarization?
2.   What are a plane of oscillations and a polarization plane?
3.   What does the Malus's law mean?
4.   Record an expression for a light intensity passed through two polarizers.
5.   What substances are called optical active?
6.   Which parameters have an influence on a turning angle of a polarization plane of an optical active crystal, a solution of an optical active substance?
7.   How can the turning angle of the polarization plane be changed by means of the polarizer and analyzer?
8.   Explain a philosophy of measurement by means of a penumbra polarimeter.
9.   Explain an optical scheme of saccharimeter.

Experiment 5. Determination of the Planck Constant and Stefan-Boltzmann Constant by Means of an Optical Pyrometer with a Disappearing Filament

1. ## Introduction

A thermal radiation is universal among the different ones. All the bodies, having a temperature higher than the absolute zero temperature, are the sources of the thermal radiation. This is a reason that the thermal radiation studied well. A problem of an energy distribution of spectrum of a perfectly black body was one of the basic in a development of the modern physics ideas. Its solution led to the discovery of the universal constant h and creation of the quantum mechanics.

The laws of radiation of the perfectly black body are applied for the high temperature measurements. A device used for these measurements is called an optical pyrometer. A field of the experimental physics, developing the principles of the temperature measurements by the optical methods, is called the optical pyrometry.

2. Devices and Instruments

A pyrometer with a disappearing filament, voltmeter, ammeter, autotransformer and plate of a nichrome oxide.

3. Purpose of Work

Experimentally check one of the basic laws of the thermal radiation – the Stefan-Boltzmann's law and determine the Stefan-Boltzmann and Planck constants by means of the pyrometer with the disappearing filament.

4. Theoretical Contents

The basic characteristics of the thermal radiation are the integral and spectral emittances. A value, which is equal an energy radiated every second by unit of a body surface, is called an integral emittance R_T. This characteristic is valid for all wavelengths radiated by the body. The integral emittance is often called the radiosity.

Let dR_T is the energy radiated in the limit of the wavelengths from λ to $\lambda+d\lambda$. A value, which is equal an energy radiated every second by unit of a body surface and in this wavelength limit, is called the spectral emittance $r_{\lambda T}$:

$$r_{\lambda T} = \frac{dR_T}{d\lambda}$$

The characteristics $r_{\lambda T}$ and R_T depend on the wavelength, temperature and nature of a substance. Therefore, the integral emittance is:

$$R_T = \int_0^\infty r_{\lambda T} \cdot d\lambda$$

$$(1)$$

Besides, the bodies, which radiate the electromagnetic energy, can absorb the energy radiated by the other heated bodies. Every body is characterized by a value, which is called the spectral absorption ability or absorption coefficient. It depends on the body temperature, wavelength of the radiation and nature of the body. The spectral absorption ability $\alpha_{\lambda T}$ of body is the energy portion absorbed every second by the unit surface of

body in the limit of wavelengths from λ to λ+dλ. The body, absorbed all energy falling on it, is called absolute black. The spectral absorption ability of this body $\alpha_{\lambda T} = 1$ for every wavelengths and temperatures. In reality, $\alpha_{\lambda T} < 1$.

According to the Kirchhoff's law, the ratio of the emittance to the absorption ability depends not on the nature of body. It is the universal function of wavelength and temperature:

$$\frac{r_{\lambda T}}{\alpha_{\lambda T}} = f(\lambda, T)$$

Since $\alpha_{\lambda T} \equiv 1$ for the absolute black body then $f(\lambda, T) = r_{\lambda T}$. Thus, the Kirchhoff's function $f(\lambda, T)$ is the spectral emittance of the absolute black body. Basing on the hypothesis of the quantum nature of the radiation, Planck derived a formula:

$$r_{\lambda T} = \frac{2\pi\pi^2 h}{\lambda^5} \cdot \frac{1}{\exp\left(hc / \lambda kT\right) - 1} \qquad (2)$$

Using Formulas 1 and 2 we get the next expression:

$$R_T = \int_0^\infty \frac{2\pi h}{\lambda^5} \cdot \frac{d\lambda}{e^{hc/\lambda kT} - 1}$$

The result of integrating is the Stefan-Boltzmann's law:

$$R_T = \frac{2\pi^5 k^4}{15 c^2 h^3} T^4 = \sigma T^4 \qquad (3)$$

where σ - the Stefan-Boltzmann constant.

The constant σ was determined experimentally. Knowing it, Planck calculated the constant h using the formula:

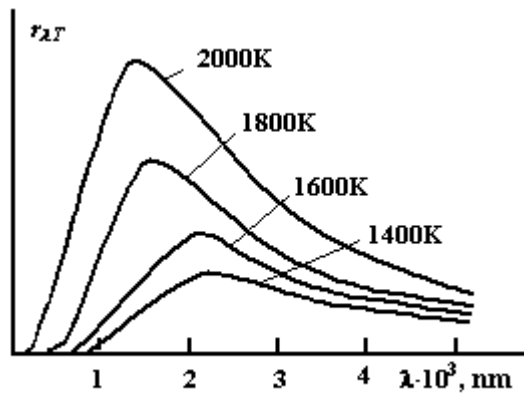$$h = \sqrt[3]{\frac{2\pi^5 k^4}{15 c^2 \sigma}} \qquad (4)$$

The dependencies of the spectral emittance from the wavelength are shown in Fig.1. An area under the curves is equal R_T.

Let T_1 is the temperature of the absolute black body, T_0 – the temperature of the environment, which is considered as the absolute black body. According to the Stefan-Boltzmann's law, the next expression is valid for the absolute black body:

Fig.1

$$R_T = \sigma(T_1^4 - T_0^4)$$

The radiation of the real bodies obeys such regularity, but it is less in $\alpha_{\lambda T}$ times for every wavelength in comparison with the absolute black body. In Figure 2 are shown the emittances of the several bodies at some temperature: 1 – the absolute black body, 2
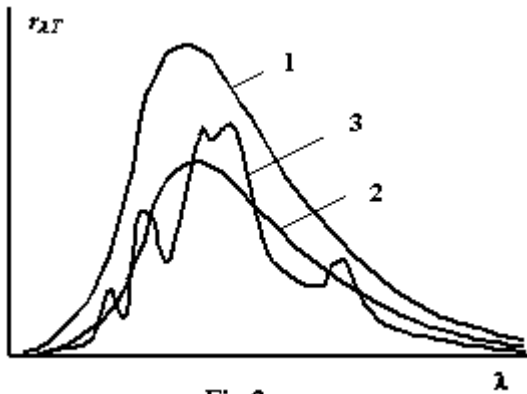
Fig.2.

– the graybody and 3 – the selective emitter. The emittance of the real body is described as:

$$R_T = \alpha_T \sigma T^4$$

where α_T – coefficient of the blackness of the real body. This coefficient is equal the ratio of the emittance of the real body to the emittance of the absolute black body at the same temperature T. The coefficient α_T depends on the temperature and nature of the body.

The Stefan-Boltzmann's law can be used for the determination of the Stefan-Boltzmann constant σ. For this purpose, it is necessary to determine the emittance R_T and corresponding temperature of body T only. The optical methods of the determination of temperature are based on the change of the integral and spectral emittances with the temperature. In the optical pyrometers, one of the radiation characteristics of the investigated body compares with the corresponding characteristic of the absolute black body. At that, these characteristics can be compared on the principle of the equality of the spectral and integral emittances, as well as on the identity of the spectral distribution. The temperature of the body subdivides into three types: energetic, chromatic and brightness. The brightness temperature of the investigated body is called the temperature of the absolute black body when the emittances of these bodies are equal for the same wavelength. Usually, this temperature is measured for the wavelength of radiation $\lambda = 660$ nm.

5. Experimental Plant

In this laboratory experiment the temperature of the red-hot body is measured by means of the optical pyrometer with the disappearing filament. At that, the spectral emittance of the red-hot filament of the pyrometer lamp compares with the emittance of the investigated body for the same wavelength.

The scheme of the experimental plant is shown in Fig.3. The objective of the pyrometer 3 gives the real vision of the surface of the heated body at the point of location of the
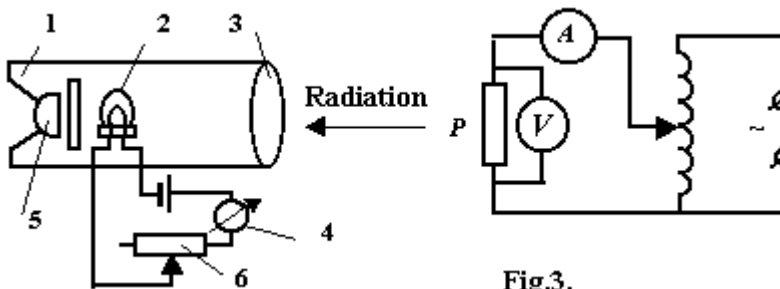

Fig.3.

lamp filament 2; 5 – the ocular of the pyrometer. The colour filter 1 is used for the observation of the narrow spectral band near the wavelength $\lambda = 660$ nm. The rheostat 6 changes the lamp brightness. A current of lamp is adjusted so as a vision of filament disappears against a background of a radiative surface. At this moment, a reading is made on a scale of milliammeter 4. Previously, the pyrometer is graduated relatively of the absolute black body, i.e. it is determined at which current strength the lamp radiates as the absolute black body. Usually, the milliammeter scale is graduated in centigrade degrees. This scale reading is the value of the brightness temperature of the real body. Always the brightness temperature is smaller then the thermodynamic temperature. It is mean that anyone real body radiates less than the absolute black body.

Using the Planck's formula (2) it can get the expression for the calculation of the true temperature:

$$T = \frac{T_{BR}}{1 + \frac{\lambda}{c_2} \cdot T_{BR} \ln \alpha_T}$$

where T_{BR} - the brightness temperature, λ - wavelength of radiation, the constant $c_2 = \frac{hc}{k} = 0.01\ m \cdot degree$. The brightness and true temperatures of the nichrome oxide are shown in Table 1 (for the wavelength $\lambda = 660$ nm).

Table 1

T_{BR} [^0K]	875	904	948	1017	1075	1130	1184	1243	1295	1352	1404	1467
T [^0K]	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	1550

The plate of the nichrome oxide is used for the determination of the Stefan-Boltzmann constant σ in this laboratory experiment. The temperature of this plate is measured at the different values of the power input. Knowing the readings of the voltmeter and ammeter the power of the heated body can be calculated: $W = IU$. On the other hand, in according to the Stefan-Boltzmann's law:

$$W = IU = \sigma \cdot S \left[\alpha(T) \cdot T^4 - \alpha(T_0) \cdot T_0^4 \right]$$

where S – a surface of an emitter, T_0 – a temperature of a surrounding medium and T - . the temperature of the emitter. Since $T_0^4 \ll T^4$ then

$$W = \sigma \cdot S \cdot \alpha(T) \cdot T^4$$

Finally, we get the expression for the determination of σ:

$$\sigma = \frac{IU}{\alpha(T) \cdot S \cdot T^4} \qquad (5)$$

6. **Experimental Procedures**

14. Assemble the electrical scheme (see Fig.3).
Note: don't switch on it yet.
15. Connect the clamps of the pyrometer with the accumulator.
16. Set the ocular of pyrometer so as you can distinctly see the filament of the pyrometer lamp. Get the sharp vision of it using the pyrometer objective.
17. Switch on the electric scheme. Set the electric current I_1 in the circle by means of the autotransformer T (all values of current are given by a teacher). Record the readings of the voltmeter and ammeter in Table 2.

Table 2

No. of test	U [Volt]	I [Ampere]	W [Watt]	T_{BR} [^0C]	T_{BR} [^0K]	T [^0K]	d [m]	l [m]	S [m^2]
1									
2									
3									

18. Change the brightness of the filament turning the pyrometer ring. Do it until the brightness of the filament will be equal the brightness of the red-hot plate (the filament should disappear against the plate background).

19. Make the reading on the pyrometer scale at this moment and record the value of T_{BR} in Table 2.

Note: the temperature is measured on pyrometer scale from 800^0C to 1400^0C.

20. Repeat item 5 for the electric currents I_2 and I_3. Record the data in Table.

21. Switch of the electric circle. Measure the line dimensions of the plate d, l by means of the caliper.

22. Plot the graph of the T-T_{BR} dependence for the nichrome oxide using the data of Table 1.

23. Determine the values of true temperature using this graph and readings of the pyrometer scale for every experiment.

24. Calculate the Stefan-Boltzmann constant σ using Formula 5. Determine the average value of σ.

Note: $\alpha(T) = 0.95$ for the nichrome oxide in the temperature limit 800-1400^0C.

25. Calculate the absolute and relative errors of measurements. Record the final result taking into account these errors.

26. Calculate the Planck constant h using Formula 4 and average value of σ.

7. Test Questions

1. What is the physical sense of the integral and spectral emittances? What are the units of these values?
2. What is the physical sense of the Stefan-Boltzmann constant?
3. What does the Malus's law mean?
4. What principle of work is used in the pyrometer with the disappearing filament work?
5. What temperature is called the brightness one?

Experiment 6. Research of Light Diffraction from Single and Many Slits

1. Introduction

The diffraction is the feature of light to skirt round the obstacles whose dimensions are comparable with the wavelength. In detail, Italian scientist F.Grimaldi described this phenomenon in 1665 and introduced the term – "diffraction of light". Ch. Huygens and O.J.Fresnel originated the elementary theory of the diffraction. The diffraction and interference are the basic proofs of the wave nature of light.

The diffraction in the parallel rays is called the Fraunhofer's diffraction. To study this diffraction a laser having such properties as the coherence, monochromatism and direction is used.

2. Devices and Instruments

A gas laser, an opaque screen with one slit, an opaque screen with two slits, diffraction lattice, screen and ruler.

3. Purpose of Work

1. Calculate a wavelength of radiation of the gas laser.
2. Get a diffraction pattern from a single slit and determine a slit width.
3. Get a diffraction pattern from two slits and determines a width of an opaque area between the slits.

4. Theoretical Contents

Diffraction from the single slit. If a parallel beam of a monochromatic light normally fall on a narrow slit (see Fig.1.), then the angles φ_n between directions corresponding to the diffraction maxima is defined as:
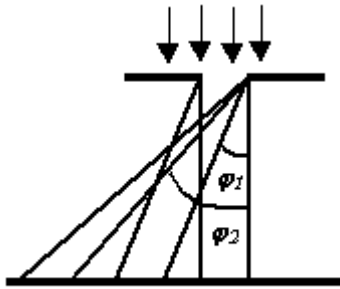
$$b\sin\varphi_n = (2n+1)\frac{\lambda}{2} \qquad (1)$$

where λ - a wavelength of light, b – a slit width, φ_n – an angle of a diffraction maximum of n-order ($n= 0, 1, 2, \ldots$).

Diffraction from two slits. Let b is the slit width, a – the opaque area between the slits and $a+b = c$ (see Fig.2.). Two identical parallel slits must give two identical diffraction patterns that are superposable on each other. However, the real diffraction pattern is more complicated. It's explained by the interference of the waves come from the first and second slits. Obviously, the diffraction m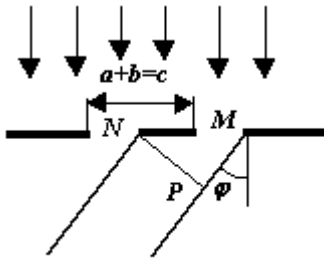axima will be at the same places, as the directions of the light propagation will remain the same both from the single slit and from two slits. And what is more, it's possible to exist the directions when the light sent by two slits will be mutually put out. Obviously, it will be the directions for the rays with the path differences $\frac{1}{2}\lambda, \frac{3}{2}\lambda, \frac{5}{2}\lambda \ldots$. These directions are called the directions of the diffraction minima and found from the condition:

$$MP =$$
$$MN \sin\varphi = (2n+1)\frac{\lambda}{2}$$
(2)

i.e. $c\cdot\sin\varphi_n = (2n+1)\dfrac{\lambda}{2}$ ($n= 0, 1, 2, 3, \ldots$)

Accordingly, for the directions of the diffraction maxima is valid the condition:

$$c\cdot\sin\varphi_n = n\lambda \qquad (n= 0, 1, 2, 3, \ldots) \qquad (3)$$

The examination of the diffraction from two slits shows that the diffraction maxima are more narrow and bright with compare the diffraction from the single slit. The diffraction pattern becomes more precise with the increasing of the number of slits.
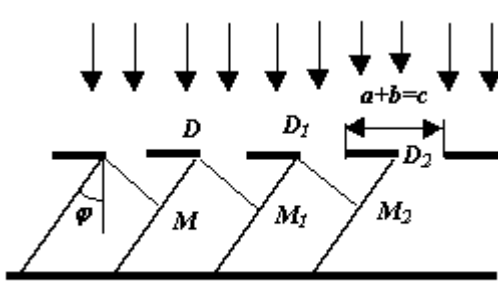
Diffraction from many slits. The system of the parallel slits placed at the equal distances is called the diffraction lattice. If b is the slit width and a – the opaque area between the slits then $a+b = c$ is called the period or constant of the diffraction lattice (see Fig.3.). Every secondary

wave propagates in different directions. Let choose some direction value-based of the angle φ. All slits are placed at the equal distances from each other. Therefore, the path differences of two neighboring slits DM, D_1M_1, D_2M_2 …will be equal too for the whole diffraction lattice. The value of this path difference is (see Fig.3.):

$\Delta l = DM = (a+b)\cdot\sin\varphi = c\cdot\sin\varphi$

The result of the superposition of the secondary waves depends on the path difference, which changes with the angle φ. The positions of the diffraction maxima can be found from the condition:

$$c\cdot\sin\varphi_n = n\lambda \qquad (n= 1, 2, 3, …) \qquad (4)$$

where λ - the wavelength of light, c- the constant of the diffraction lattice.

5. Experimental Plant

The experimental plant is shown in Fig.4. The helium-neon laser 1 is used in this laboratory work. The beam of the parallel monochromatic rays falls on an opaque screen 2 with the single slit. The diffraction pattern is observed on the screen 3.
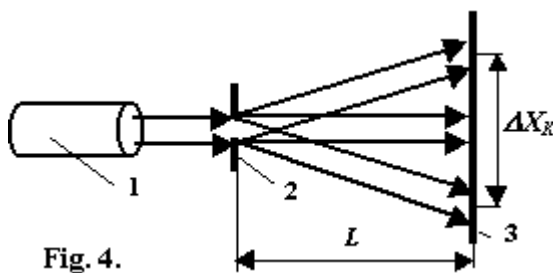
The operating principle of the gas laser.
The atom energy can possess the algoristic values. These values of energy $E_1, E_2, …, E_n$ are called the energetic levels (see. Fig.5).

The system of the energetic levels forms the energetic spectrum of atom. The lower level has the minimum energy. It's called the basic level. The other lev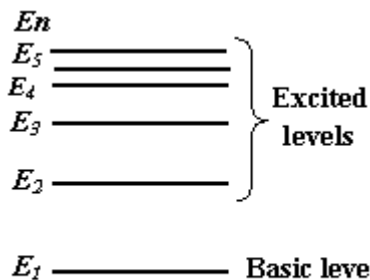els are called exited. The number of atoms with given energy are called the population of levels. If an atom located on the basic level E_1 gets some energy then it changes the energy state and passes on one of the excited levels. The excited atom can spontaneously pass on one of the lower levels. At that, the energy portion radiates in the form of the light quantum or photon. If the atom radiates by a passage from the energy level E_m to the level E_n then the frequency of the radiated (or absorbed) light quantum is:

$$\nu_{mn} = \frac{1}{h}(E_m - E_n)$$

where h − the Planck constant.

Such spontaneous processes of the radiation take place in the heated bodies and the luminous gases. Along with that processes, the stimulated radiation (or induced) exists. The atoms radiate under the influence of the external rapid-variable electromagnetic field, for example, the light. At that, an atom radiates a secondary wave whose frequency, polarization, direction of propagation and phase coincide with the characteristics of the external wave influencing on the atom. This effect of the stimulated radiation enables to control the radiation of atoms by means of the electromagnetic waves, generate and amplify the coherent light. The stimulated radiation of the excited atoms generates a whole avalanche of photons similar to the initial photon. As a result, the atoms emit the intensive coherent light wave. Along with the stimulated radiation by the atoms located on the upper level E_m, it exists the resonance absorption of atoms located on the energy level E_n. An atom with energy E_n absorbs the light quantum and transits on the upper level E_m. The resonance absorption

foregoes the beginnings of the light generation. To get the light generation the number of atoms on the upper level N_m has to be more than the number of atoms on the lower level N_n. The state of the substance, when the number of atoms on the level with the higher energy is more than the number of atoms on the level with the smaller energy is called the population inversion. The population inversion in the gas lasers is created by the collisions of the gas atoms or molecules with fast electrons generated by an electric discharge.

The helium-neon laser is used in this laboratory experiment. Some part of the *Ne* atoms transit from the basic level E_1 on the long-lived excited levels E_4, E_5 (see Fig.6) by an electric discharge. The population inversion is created for the energy levels E_4, E_5 in comparison with the short-lived energy level E_3. However, the metastable level E_2 prevents to create the population inversion. The metastable level is the excited level, the radiative quantum transitions from which on the lower levels are forbidden. The lifetime of such level is longer in comparison with the usual lifetime of the excited levels. The
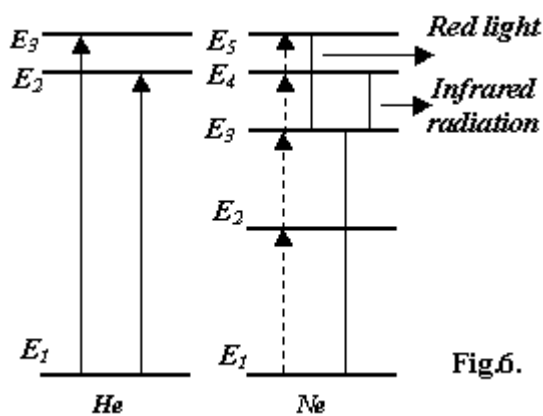

Fig.6.

helium-neon mixture is created to get over this problem. The energy of the excited levels E_2, E_3 of the helium atoms exactly coincide with the energies E_4, E_5 of the neon atoms.

When the excited atoms of *He* collide with the unenergized atoms of *Ne*, it is possible the resonance excitation. As a result, the *Ne* atoms will be in the states E_4, E_5, but the *He* atoms – in basic level. Thus, it occurs the additional occupation of the energy levels E_4, E_5 of the neon atoms. If the pressures of gases in the *He-Ne* mixture are chosen correctly then it is possible to get the population of the energy levels E_4, E_5 that exceed the population of these levels in pure *Ne*. Hence, this is a condition to get the population inversion between the levels E_4, E_5 and E_3. The transitions from the short-lived level E_3 occur when the *Ne* atoms collide with the walls of the discharge tube. These collisions differently influence on the population of the different levels. The population of the energy levels E_4, E_5 and E_3 practically do not change, as the lifetime of atom on these levels are appreciably shorter than the transit time of atom to the wall of the discharge tube. The lifetime of the level E_2 is comparable with the transit time. The wall-atom collisions make for the change of the E_2-level population. As a result, the *Ne* atoms transit from the E_3-level to the E_2-level and, consequently, the laser radiation is generated.

6. Experimental Procedures
1. Set the "current regulator" of the gas laser in the extreme left position.
2. Switch on the laser and wait about 2-3 minutes.
3. Push and take off the button "discharge initiation".
4. Set the value of the discharge current about 5-10 Ampere.
Note: a direct hit of the laser radiation in the eyes is very dangerous for your eyesight.
5. Put a holder with single slit into a rider.
6. Set the rider plane perpendicularly to an axis of a laser ray turning the rider carefully.

7. Measure the distances ΔX_1, ΔX_2, ΔX_3, … between the diffraction maxima of the first, second, third, … orders correspondingly (see Fig.4).
8. Measure the distance L from the slit plane to the screen 3.
9. Record the data in Table 1.

Table 1

Order of the diffraction maximum	ΔX_n			$\overline{\Delta X_n}$	φ_n	L
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

10. Put the holder with two slits into the rider.
11. Repeat the items 6, 7.
12. Measure the distance L from the slit plane to the screen 3.
13. Record the data in Table 2.
14. Determine the angles φ_n using the next expression and the data from Table 1:

$$\mathrm{tg}\varphi_n = \frac{\overline{\Delta X_n}}{2L} \qquad (5)$$

15. Calculate the wavelength of the laser λ for every measurement using Formula 4. Calculate the averaged wavelength, the measurement error $\Delta\lambda$ and the slit width using Formula 1.

16. Determine the angles φ_n using Formula 5 and the data from Table 2. Determine the value of c using Formula 3.

Table 2

Order of the diffraction maximum	ΔX_n			$\overline{\Delta X_n}$	φ_n	L
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

17. Determine the width of the opaque area between the slits for every value of **n**. Calculate the averaged value and the measurements error for the determination of the opaque area between the slits.

7. Test Questions

1. What phenomenon is called a light diffraction?
2. Record a condition of the formation of the diffraction maxima for single slit.
3. Record a condition of the formation of the diffraction maxima for two slits.
4. Explain the operating principle of the gas laser.