STUDY OF THE EMISSION AND ABSORPTION SPECTRA

Objectives*:* observation and identification of the Fraunhofer lines; study of the spectrum of hydrogen emission and calculation of the Rydberg constant; observation of emission spectra of inert gases and absorption spectra of solutions.

Equipment and accessories*:* monochromator, a prism, induction coil, reference sources, spectroscope, a set of spectral tubes; High-voltage generator "Spektr-1"; power supply BC-4-12; incandescent lamp; test tubes with solutions of absorbing substances.

INTRODUCTION

The study of atomic spectra was the key to understanding the internal structure of atoms. The experiment showed that independent lines of emission/absorption spectra of gaseous substances are not randomly distributed, but rather form so-called *series*, with wavelengths of the lines following a certain regularity. This pattern is most simple in the spectrum of hydrogen. Thanks to the work of Balmer (1885), and later Rydberg and Ritz, it was established that for all lines of the hydrogen spectrum the following expression is valid:

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

Here, n = 1, 2, 3... – an integer constant which sets the series, (for the Balmer series, $n = 2$); $m = n+1,\ n+2, ...$ – an integer constant corresponding to the individual lines in a series; λ – the wavelength; R – the Rydberg constant.

According to the Bohr theory, the energy of a hydrogen atom in the ground state is equal to:

$$E_n = -\frac{e^4 m_e}{8\varepsilon_0^2 h^2} \cdot \frac{1}{n^2}, \tag{2}$$

and transition of the atom from a state m to a state n is accompanied by absorption or emission of a photon with frequency determined by the following equation:

$$\nu_{nm} = \frac{e^4 m_e}{8\varepsilon_0{}^2 h^3} \cdot \left(\frac{1}{n^2} - \frac{1}{m^2}\right), \tag{3}$$

where e and m_e – charge and mass of the electron, respectively.

Using (2) - (3) the Rydberg constant can be expressed via other fundamental constants – the electron charge e and its mass m_e, speed of light c and the Planck constant h:

$$R = \frac{e^4 m_e}{8\varepsilon_0^2 c h^3}. \qquad (4)$$

The Fraunhofer lines are the absorption lines in the solar spectrum. The Fraunhofer lines were first observed in 1802 by the English physicist *William Wollaston*, and in 1814 they were rediscovered and described in detail by a German physicist *Joseph Ritter von Fraunhofer*, but only 45 years later German physicists *Gustav Robert Kirchhoff* and *Robert Wilhelm Eberhard Bunsen* had proven that these dark fixed lines were the atomic absorption lines. Nowdays, more than 20 thousand fraunhofer lines are known in the infrared, ultraviolet and visible regions of the solar spectrum. Some of the most intense Fraunhofer lines in the visible spectrum are listed in the Table of Spectral Lines.

This practical includes (1) calibration of the monochromator, (2) study of the noble gasses' emission spectra and determination of the Rydberg constatnt, (3) study of the Fraunhofer lines in the Sun spectrum, and (4) study of the absorption spectra of the coloured solutions.

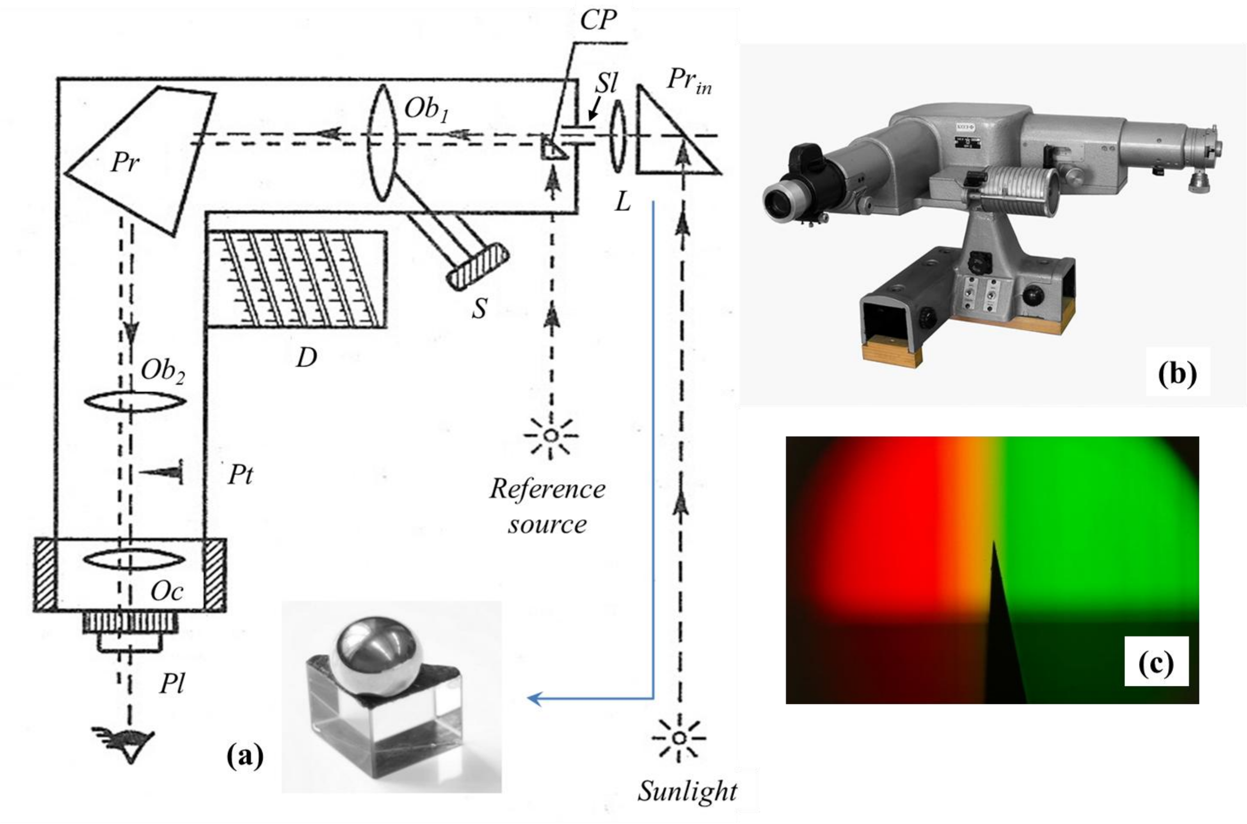

Fig. 1. Experimental setup: schematic (**a**), general view (**b**), and view of the pointer *Pt* as it is appeared in front of a continuous spectrum (**c**). Inset in (**a**) shows a photograph of the input prism Pr_{in}.

EXPERIMENTAL SETUP

Emission and absorption lines are observed with a special spectroscopic tool - *monochromator* (depicted in Fig. 1) which helps to determine the wavelength of the spectral lines with a reasonable precision. The Sunlight is directed into the monochromator with use of the input prism Pr_{in}, which can be rotated in any direction. The light from a reference source (for which gas discharge tubes are used) is coupled from the side.

Attention! A high voltage produced by an induction (or "spark") coil (also known as Ruhmkorff coil named after *Heinrich Ruhmkorff)* **is used to power the gas tubes. Special care and cautiousness are required during this practical.**

The light from the source, focused by the lens (*L*) at the input slit (*Sl*) of the monochromator, passes through the objective (Ob_1) lens and is transformed into a parallel beam. Inside the monochromator, the light is dispersed by a prism (*Pr*) and the spectrum is focused by the objective (Ob_2) onto the plane of the pointer (*Pt*). The picture is observed with the aid of an ocular eyepiece (*Oc*) which is protected by a polaroid (*Pl*). During the work with a monochromator, you first have to focus the eyepiece, achieving a clear image of the pointer. Then rotate screw (*S*), which moves Ob_1 in order to achieve a clear image of the spectral lines in the plane of the pointer (which is wavelength dependent). The width of the spectral lines is set by adjusting width of the input slit. The wavelengths of the spectral lines are determined as follows. With the help of the drum (*D*), the pointer is adjusted with a certain spectral line. Then the readings from the drum are read and the required wavelength is determined from the specific calibration curve (which is instrument dependent). A coupling prism (*CP*) allows simultaneous observation of spectra produced by different sources.

A simple spectroscope which is used to study absorption of the coloured solutions is depicted in Fig. 2. The spectroscope consists of three main parts: the collimator *C*, the prism *Pr*, and the telescope *T*. The light source under investigation is placed in front of the slit of the collimator. The beam formed by the lens L_1 is dispersed by the prism. The spectrum is observed with aim of a telescopic system consisting of the lenses L_2 and L_3. In the third auxiliary pipe there is a scale *Sc*, illuminated by a light bulb. The scale is located in the focal plane of the lens L_4. The image is obtained in the focal plane of the lens L_2.

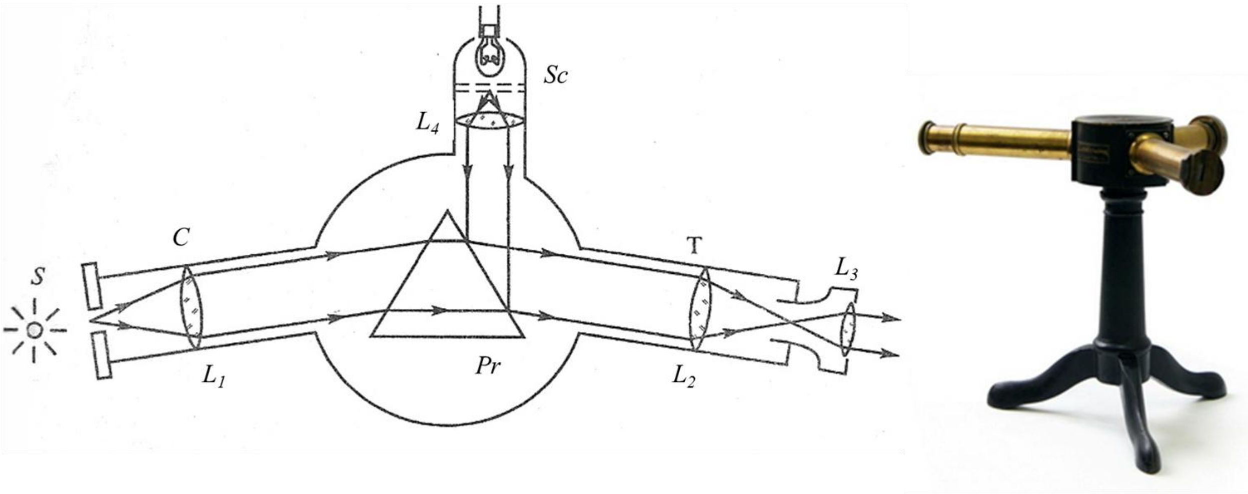

Fig. 2. Schematic of a spectroscope (left) and a photograph (right).

MEASUREMENT AND DATA PROCESSING

Part 1. Study of the absorption and emission spectra using a monochromator

Task 1. Calibration of the monochromator is carried out using a reference spectrum of a well-known species

Place a mercury lamp in front of the monochromator's slit. Observe the spectrum noting the brightest lines (double yellow, green, blue, and violet). Identify the lines using Table A-1. Make a table dependence of $\boldsymbol{\lambda(\varphi)}$. Plot a calibration chart $\boldsymbol{\lambda(\varphi)}$, where $\boldsymbol{\lambda}$ is the table value of the wavelength, and $\boldsymbol{\varphi}$ is the monochromator drum readings. Fit the measured points by a smooth line. This chart will be used to determine the wavelengths of the investigated spectra.

Task 2. Observation and identification of the Fraunhofer lines using reference gas tubes and calibration chart

1. To observe the Fraunhofer lines, direct the sunlight with the input prism into the slit of the monochromator. In the upper half of the field of view of the monochromator's *Oc*, it is possible to observe fuzzy weak black bands on the background of a continuous spectrum. To obtain a clear picture of the Fraunhofer lines, it is necessary to reduce the width of the entrance slit and at the same time, by rotating the Pr_{in} , achieve maximum illumination of observed picture.

2. Position a reference gas tube (H, He, Ne, Kr tubes are used) in front of the side input of the monochromator. In this case, the radiation spectrum of the reference source will be observed in the lower half of the monochromator's *Oc*.

3. Ensure that there are Fraunhofer lines in the solar spectrum, corresponding to the emission lines of hydrogen.

4. Fill in Table 1, noting the correspondence (yes/no) of the observed emission and absorption lines, and the drum angle from which the wavelength should be determined.

5. Repeat this procedure for other gas tubes available. Find out whether Fraunhofer lines are present in the solar spectrum, corresponding to the emission frequencies of iron, neon, krypton, and helium.

6. Determine wavelengths of all the measured lines using the calibration chart.

7. Compare measured wavelengths with that known from the literature (as provided in the Supplementary Materials). Perform the error analysis and estimate relative and absolute errors.

Table 1. Observation and identification of the Fraunhofer lines

Reference source	**Line #** **Line colour**	**Drum readings, φ**	**Fraun-hofer line (+/-)**	**λ, nm**	**λ_{table}, nm**	**Schematic drawing of the spectrum**
H	**1.**					
	2.					
	…					
He						
Ne						
Kr						
Fe						

Task 3. **Computation of the Rydberg constant**

1. From Table 1, identify H_α, H_β, H_γ lines.
2. Using formula 1, calculate an experimental value of the Rydberg constant. Determine R_{avg} and ΔR_{avg}.
3. Compute theoretical value of the Rydberg constant using (3).
4. Compare results. Fill in Table 2.

Table 2. Calculation of the Rydberg constant

#	**colour**	**λ_{exp}, Å**	**λ_{theor}, Å**	***n***	***m***	**R_{exp}, m^{-1}**	**$\overline{R_{exp}}$, m-1**	**ΔR_{exp}, m^{-1}**	**$\overline{\Delta R_{exp}}$, m^{-1}**	**R_{theor}, m^{-1}**
1										
2										
3										

Part II. Study of the absorption spectra using a spectroscope

Task 4. **Absorption spectra of coloured solutions**

1. Using a spectroscope observe continuum spectrum produced by a heated body, for which a spiral of a bulb serves. Make a schematic drawing of the spectrum observed. Fill in the corresponding line in the Table 3.
2. Place a test-tube containing a coloured solution between the light source and the slit of the spectroscope. The light irradiating the slit should be well-focused. Observe the absorption spectrum of the coloured solution. Make a schematic drawing of the spectrum observed. Fill in the corresponding line in the Table 3. If necessary, adjust the brightness of the bulb and width of the spectroscope's slit.
3. Repeat this procedure for all the coloured solutions.
4. Compare all the spectra observed. Make a conclusion.
5. Make a statement about correlation between the dye colour and its absorption spectrum.

Table 3. Absorption spectra of coloured solutions

Solution's colour	**Observed spectrum (+/-)**							
	Red	***Orange***	***Yellow***	***Green***	***Light-blue***	***Blue***	***Violet***	***Schematic drawing of the spectrum***
No solution								
Red								
Orange								
Light-blue								
Violet								

QUESTIONS

1. Which radiation spectrum corresponds to dilute gases consisting of specific atoms? molecules?
2. What are the ways to excite the atoms (molecules) of a gas?
3. Formulate the basic propositions of Bohr's theory.
4. What is the origin of the absorption spectra?
5. What is the nature of the Fraunhofer lines?
6. Find the radii of the first three Bohr electron orbits in the hydrogen atom.
7. Find the numerical value of the kinetic, potential and total energy of the electron in the first and third orbits in the Bohr model of the hydrogen atom. What wavelength will correspond to the spectral line corresponding to the transition of an electron from the third orbit to the first one?
8. What is the minimum energy that electrons should have, so that when the hydrogen atoms are excited by the impacts of these electrons, all the lines of all hydrogen series appear?
9. Draw, obeying the scale, the system of energy levels of the hydrogen atom; Show on it the quantum transitions corresponding to the head and boundary lines of the Lyman, Balmer, and Paschen series. Determine the wavelengths corresponding to 1) the boundary of the Lyman series 2) the Balmer series boundary 3) the Paschen boundary series.
10. Find the smallest and largest wavelength of the spectral lines in the visible region of the hydrogen spectrum.
11. Prove the formula (3), based on the Bohr quantization rule.

Supplement materials

Table A-1. Spectral lines of mercury

#	Colour	λ, nm	Brightness, a.u.	#	Colour	λ, nm	Brightness, a.u.
1	Red	709.2	20	18	Green	529.1	2
2		708.2	25	19		521.9	2
3		690.7	25	20		513.8	2
4		671.6	16	21		512.1	4
5	Orange	623.4	3	22		510.3	2
6		612.3	2	23		502.6	4
7		607.3	2	24		499.2	3
8	Yellow	587.2	2	25		491.6	10
9		585.9	6	26	Blue-green	489.0	3
10		580.4	14	27		482.7	3
11		579.0	100	28	Blue	435.8	400
12		577.0	24	29		434.7	40
13		567.6	16	30		434.4	4
14	Green	555.0	3	31		433.9	30
15		546.1	320	32	Violet	410.8	4
16		538.5	3	33		407.8	12
17		535.4	6	34		404.7	180