

Emission spectra analysis on a spectrometer

Aim of the experiment: determination of the dispersion curve of a spectrometer and the Rydberg constant for hydrogen atoms.

Instruments: a prismatic spectroscope, Geissler tubes, Ruhmkorff inductor, high voltage supply unit for direct and alternate current, microscope lamp, transformer TVO-8/50, 2 stands with insulators, 6 conductors.

Problems: dispersion of light, emission spectra, Bohr's theory of the atom, spectral series.

1. Introduction.

Light emitted by any source of radiation is composed of electromagnetic waves of different lengths. White light passed through a narrow slit and then through a prism (a solid body limited by two planes making an angle φ , other planes arbitrary) undergoes twofold refraction on the inclined walls and is split into colours because of different angle of refraction of light beams of different colours which means of different wavelengths (see the figure below). The full range of wavelengths of visible light covers the length from $0.78 \mu\text{m}$ corresponding to red light to $0.40 \mu\text{m}$ corresponding to violet light. The split of white light into colours is a direct consequence of the fact that the value of refraction index depends on the light wavelength.

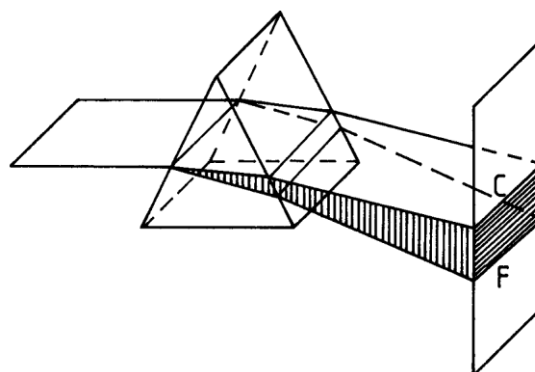


Figure 1. Refraction of white light in a prism.

The image obtained as a result of white light refraction is called the *spectrum*. If particular colours pass continuously into one another, the spectrum is called continuous. The continuous spectrum is obtained as a result of refraction of white light emitted by solid bodies and liquids heated to high temperatures. Gases made of diatomic or multiatomic

molecules give band spectra made of alternate bright and dark bands, instead of single lines of individual wavelengths.

When light is emitted by monoatomic gases or vapours of solids, the spectrum is composed of individual colour lines whose number and positions is characteristic of each gas or vapour of a solid. Therefore, the spectrum permits identification of atoms that emit it. The method of identification of atoms based on their spectra is called spectral analysis. In order to perform spectral analysis it is necessary to know the wavelength of particular lines. This wavelength can be found on the basis of the line position knowing the dispersion curve of a given spectrometer, so the dependence of line wavelength on its position measured in on an arbitrary scale. In order to determine the dispersion line, the position of the line of an element whose spectrum is known e.g. helium, is assigned.

According to the Bohr theory, an electron can occupy only strictly defined states (energy levels) in an atom. On passing from one level to another, the electron has to absorb or emit the energy equal to the energy difference between the levels in the form of a quantum of light $h\nu = E_n - E_m$. Using the Bohr model it is possible to derive the formula for the energy E_n , so the frequency ν of the emitted electromagnetic wave:

$$\nu = cR \left(\frac{1}{n^2} - \frac{1}{m^2} \right), \quad (1)$$

where c – is the speed of light, $n = 1, 2, 3, \dots$; $m = n+1, n+2, n+3, \dots$ and R is the universal constant depending on the type of nuclei, known as the Rydberg constant.

For each value of n a set of spectral lines is obtained, each of which corresponds to a different value m , making one spectral series. Particular spectral series have their special names:

- $n = 1$ — P. Lyman series,
- $n = 2$ — J. J. Balmer series,
- $n = 3$ — F. Paschen series,
- $n = 4$ — F. S. Brackett series,
- $n = 5$ — A. H. Pfund series,
- $n = 6$ — C. Humphreys series.

Only some lines belonging to different spectral series are in the visible range, many of them are in the ultraviolet range or in far infrared range. Particularly suitable for studies is

the Balmer series of hydrogen atom as its three most intensive lines H_α ($m = 3$), H_β ($m = 4$) and H_γ ($m = 5$) are in the visible range. Knowing the wavelengths of the lines it is possible to calculate the Rydberg constant R_H for each of them separately.

The Rydberg constant of hydrogen atom is

$$R_h = \frac{m_e e^4}{8\epsilon_0 h^3 c \left(1 + \frac{m_e}{m_p}\right)}, \quad (2)$$

where m_e is the electron mass and m_p is the proton mass (nucleus of the atom), the other terms in the equation are the universal constants.

2. Instruments.

The main elements of a spectroscope are shown in Fig. 2. Light from the source studied Z_1 falls on a slit (S_z) in the focus of the lens S_1 . The slit together with the lens make a collimator generating a parallel light beam. After passing through the prism, the rays of the same wavelength are parallel. The rays of different wavelengths correspond to different angles measured with respect to the optical axis of lens S_2 , so that all of them have focal points in one focal plane, but the lens for each wavelength (each colour) is at a different distance from the optical axis. Finally, in the focal lengths narrow and separated images of the slit appear, which are the spectral lines of the colours that contribute to the light emitted by the source. The image of the spectrum can be observed against a scale. The spectroscope is equipped in an additional collimator with the scale (S_k) in the place of the slit. The scale is lit by the second source of light Z_2 (microscope lamp). The scale divisions are transparent but the background is opaque. The prism is fixed and protected against the negative effect of dispersed light.

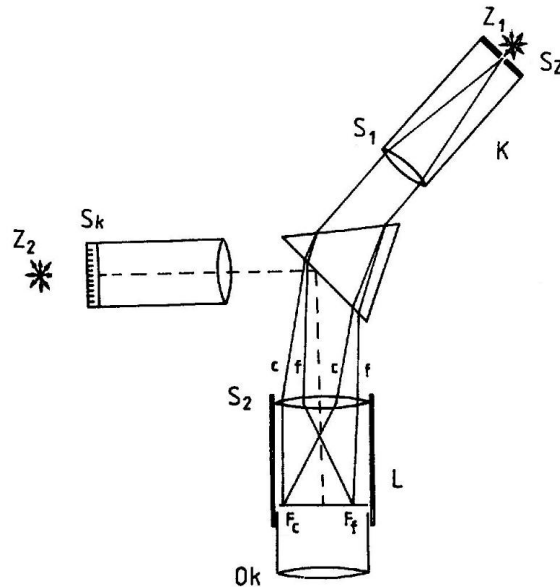


Figure 2. Scheme of a prismatic spectroscope.

A small telescope and a collimator are often movable and prior to each measurement their arrangement should be checked. The first regulation of their arrangement is performed as follows. For the spectroscope without the prism, the sharpness of the image is regulated by directing the telescope towards a distant object, e.g. a fragment of architecture seen through the window. It is also necessary to regulate the sharpness of the cross hair. At the correct arrangement no parallax is observed, so the cross does not move against the far image when the eye moves with respect to the telescope. The telescope is placed on the common axis with a collimator (still without the prism). The slit should be lit by a strong source of light, preferably monochromatic, and then the distance between the slit and lens S_1 is adjusted to get a sharp image of the slit in the telescope. As the small telescope was set to infinity, the collimator gives a parallel beam. At the correct regulation of the instrument, also the image of the slit does not show parallax. At the next step, the axis of the collimator and the telescope are arranged in such a way that the image of the slit is exactly at the cross hair, vertical and placed exactly in the middle of the field of vision. At this point the regulation is complete, from now on only the width of the slit can be regulated in the collimator. The image of the slit must be sharp and narrow but at the same time with no diffraction broadening of the edge.

Light the collimator with the scale (S_k) using the light from the microscope lamp (a bulb of 6V/5A - 30 W) connected to a transformer TVO-8/50 and regulate the sharpness of the scale and its position against the spectrum by rotating the collimator by a small angle. Brightness of the scale can be regulated by a control knob on the front panel of the

transformer TVO-8/50, which is also used for turning on the lamp. The arrangement of the collimator and the small telescope should be blocked by the two screws under the table of the spectrometer. The spectrum can be recorded on a photographic film or another detector in the focal plane and/or observed through the eyepiece (Ok.).

3. Measurements.

The experiment must begin with checking the spectroscopy arrangement. To do this at a distance of 2-3 cm in front of the collimator slit you should place a stand with a tube with helium connected to the high-voltage power supply unit of direct current. The tube should be positioned in such a way that the spectra viewed through the telescope were the brightest possible (Fig. 3.).

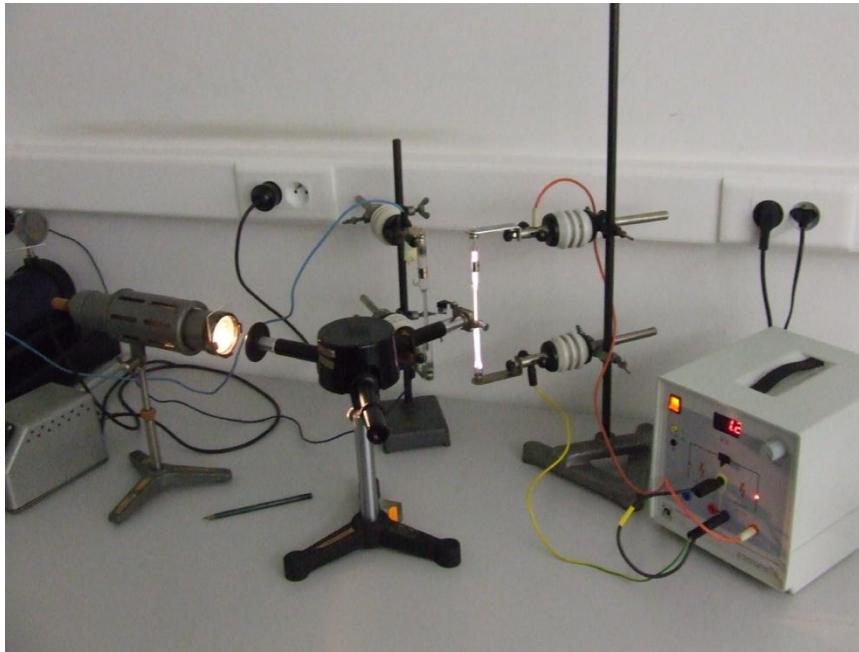


Figure 3. Experimental setup with the helium filled tube positioned in front of the collimator slit.

In order to obtain a sharp image you should start with setting the slit width to about 2 mm. Having obtained the image the slit is narrowed to obtain the narrowest possible lines. If the sharpness of the image is not the optimum, the spectroscopy should be regulated again. When the sharp spectrum is obtained, you should read off the positions of individual lines on the scale. Measurements of the hydrogen spectrum should be performed using a tube with hydrogen that should be placed in front of the collimator slit after delicately moving

away the tube with helium. The tube with hydrogen is excited by an inductor supplied through a low-current power supply unit. Do not change the voltage of inductor supply which is set to 8-9 V.

4. Calculations.

The scale of the spectroscope used is relative so you cannot read off the wavelength directly. In order to establish the lengths of the waves in a given spectrum, the spectroscope should be first calibrated, which means that the specific wavelengths should be assigned to the scale used. The calibration is performed with the use of helium emission. Particular lines in the helium spectrum are at first identified on the basis of the data from physical tables and then the lines are assigned with the corresponding wavelengths (rounded up to three significant digits). Read off the positions of the lines on the scale and write the results in the table of measurements. It is recommended to note also the relative intensities of the lines:

(*b* – very strong , *s* – strong , *m* - weak, with no symbol – very weak).

Draw the dispersion curve on the plotting paper sheet, estimate the error of the curve. On the basis of the dispersion curve estimate the lengths of particular lines in the spectrum of hydrogen. For identification of the spectrum the procedure is the reverse to that for the spectrometer calibration, the lines on the scale are assigned to the wavelengths.

Calculate the Rydberg constant for the lines H_α , H_β and H_γ from eq. (33.5). Calculate the mean value R , standard deviation S_{RH} by the method of Student-Fisher and the maximum error for one of the results.

5. Wavelengths of selected most important spectral lines.

Element	λ (nm)	colour	Element	λ (nm)	colour
Hydrogen	s 656	red	Mercury	623	orange
	m 486	green-blue		b 579	yellow
	434	violet		b 577	yellow
	410	violet		s 546	green
Helium m	706	red		496	green-blue
	s 668	red		m 491	green-blue
	588	yellow		b 436	violet
	505	green		m 408	violet
	s 502	green		b 405	violet
	m 492	green-blue		Sodium	589
	471	blue	Potassium	s 770	dark red
	m 447	blue		s 766	dark red
439	violet	m 405		violet	

(b – very strong, s – strong, m – weak, with no symbol – very weak)