Experiment Nr. 49

Determination of wavelength using prism spectrometer

Theory

The study of emitted spectra of electromagnetic waves by excited atoms makes for one of the most important methods to investigate on the structure of atoms and the forces, which act between nuclei and electrons. The observation of discrete lines in the spectra of excited atoms played a crucial role in the development of quantum mechanics.

In this lab course, one shall study the spectral lines of several discharge light sources and atomic hydrogen in the range of visible light with the help of a prism spectroscope. By measuring the wavelengths of the hydrogen lines, one shall determine one of the fundamental constants of nuclear physics, the so-called Rydberg constant R and Plack constant h.

The decomposition of light into its spectral colours inside of a prism is caused by dispersion. Dispersion occurs, when light is being diffracted at the boundary layers between air and glass. It is designated to the fact, that the refraction index is dependent on the wavelength for most materials. In imaging systems (microscope, telescope, camera), dispersion leads to aberrations (imaging errors), which have to be minimized by using complex lens constructions and special lens coatings. In nature, dispersion, occurring when light gets reflected and diffracted on water drops, leads to the appearance of rainbows.

The emergence of discrete lines in the spectrum of absorbed or emitted electromagnetic radiation by single atomic gases is only to explain sufficiently by quantum mechanics. Nevertheless, some fundamental properties can be derived from the semi-classical Bohr (atom) model. The Bohr model rests upon basic assumptions:

- An atom consists of a heavy nucleus and a shell of much lighter electrons
- Electromagnetic radiation is only absorbed or emitted when an electron changes from one state (1) of energy E_1 to a state (2) of energy E_2 by performing a so-called quantum jump. The energy of the absorbed or emitted electromagnetic radiation during the transition is given by the energy difference $|E_2 - E_1|$.

The atom can absorb or emit electromagnetic radiation only for very distinct energies, namely $E = E_2 - E_1$. The wavelength λ of the radiation arise from the energies with

$$\lambda = \frac{hc}{E},$$

where h is the Planck constant and c is the speed of light. Therefore, the spectrum of electromagnetic radiation is determined by the energy spectrum of the allowed orbital states of the electrons. The correct calculation of the energy spectrum has to be done quantum mechanically. A simple classical calculation though, yields the same result for a rough description of the structure of the spectrum as the correct quantum mechanical description would give. In case of the hydrogen, for the wavelength of the emitted radiation from a transition of a state n_1 to a state n_2 of lower energy, one has

$$\frac{1}{\lambda} = R\left(\frac{1}{n_2^2} - \frac{1}{n_1^2}\right),$$

where R is the Rydberg constant. Only a few of the transitions generate spectral lines in the wavelength range of visible light. In particular, those are the first three lines of the so-called Balmer series, which correspond to the transitions from $n_1 = 3$, 4 and 5 to $n_2 = 2$.

Practical part

The prism spectrometer scheme is illustrated in Fig. 1. The light source (selected discharge lamp) illuminates a narrow slit. A beam of parallel light generated by the collimator is then being refracted in the prism and, due to dispersion, decomposed into its spectral colours. The multi-coloured reproductions of the slit emerge in the focal plane of the eyepiece lens which then can be observed in the telescope ocular. The ocular is equipped with a hair cross which, by turning the prism table around the rotation axis of the spectrometer, is being aligned with the line one wants to measure. The wavelength can be directly read off from the micrometre scale with a precision up to one nanometre.

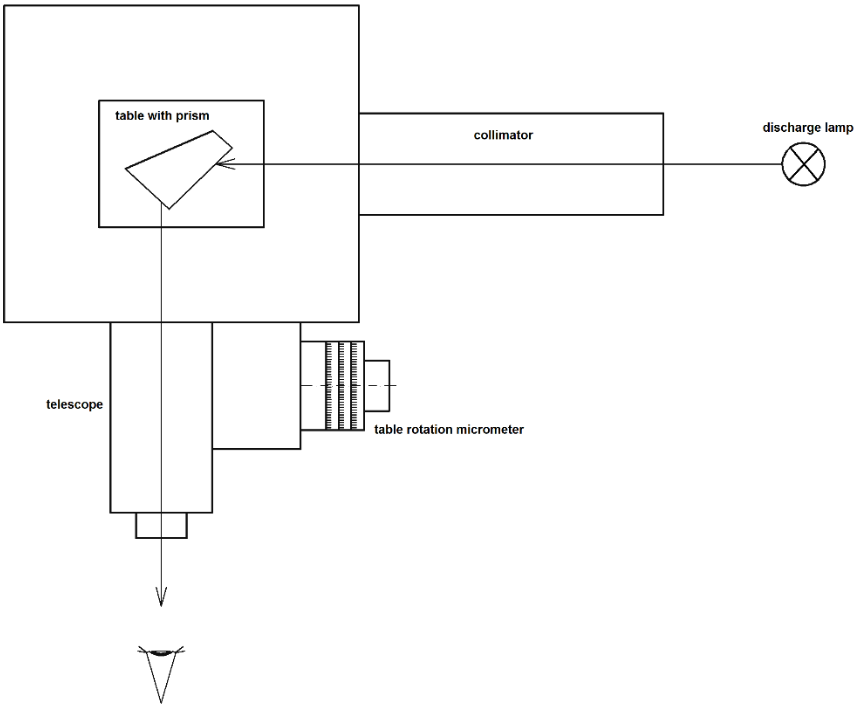

Fig. 1 Prism spectroscope scheme

Measurement objectives

1. Determine the calibration curve of the prism spectroscope using several spectral lines of selected discharge lamps (helium, cadmium, mercury). Use the linear regression as the best curve fit.

2. Determine the wavelength of two lines of the hydrogen discharge lamp. Using the calibration curve from the Objective Nr. 1 calculate the tabular values of these spectral lines. Compare the results to the tabular data.

3. Use the calculated wavelengths for the determination of the Rydberg constant *R* (use the Balmer series formula).

4. Use the definition of the Rydberg constant from the Bohr model and determine the Planck constant *h*. Use the formula

$$R = \frac{m_e e^4}{8\varepsilon_0^2 h^3 c},$$

where m_e is mass of the electron, e is the electron charge, ε_0 is the electric constant (vacuum permittivity) and c is the speed of the light.