Measuring atomic spectra

Introduction

In this exercise you will calibrate a prism spectrometer and use the calibration curve to do the following:

- You will study the Balmer series of atomic hydrogen spectral lines and determine the Rydberg constant R_H.

- You will use the calibration curve to identify an unknown gas by measuring the wavelength of its spectral lines.

The apparatus is essentially a spectrometer plus a variety of spectral tubes which are the sources of the line spectra to be studied.

Calibration

Calibrating the spectrometer means determining the relationship between the wavelength of a spectral line and the scale reading on the instrument. Once this relationship is obtained, you can use it to convert the scale reading of an unknown line to the corresponding wavelength. Use the helium lamp and the helium spectral line tables from Appendix 2 to calibrate the spectrometer using one of the methods outlined below.

The smooth curve method

This is the simplest method of calibration. Not using Python, do a plot of wavelength against spectrometer scale reading. If you have correctly identified the wavelength of the lines you chose to measure, you should obtain a smooth curve. If it is not smooth, go back and check both your measurements and the wavelengths you assigned each line. The advantage of this method is simplicity. The disadvantage is the difficulty in drawing the correct smooth curve between the calibration points which limits the accuracy of your results.

The Hartmann relation

The relationship between the scale reading y and the wavelength λ is given by the Hartmann dispersion relation:

$$y = \frac{m}{\lambda - \lambda_0} + b \tag{1}$$

where λ_0 , m and b are constants. For your convenience, the constant λ_0 , which is a function of the optics of your spectrometer, has been measured for each spectrometer and is marked on the side of the instrument. Write a Python program for the spectrometer calibration using equation (1) y vs. $(\lambda - \lambda_0)^{-1}$. Determine m and b. In order to use the Python program in the next parts of this exercise, make it a user input program: it will prompt the user to give a measured value of scale reading y and it will output the corresponding λ value.

The Rydberg Constant

Use your calibration curve to measure the wavelengths of the bright lines in the visible spectrum of hydrogen known as the Balmer series. Since hydrogen is a molecule, you will see a number of molecular bands in the visible range as well but these will in general be much fainter than the bright atomic lines. In 1885 Balmer showed that the wavelengths of the atomic lines in the visible part of the Hydrogen spectrum satisfiy the relation:

$$\frac{1}{\lambda} = R_H\Big(\frac{1}{2^2} - \frac{1}{n^2}\Big) \tag{2}$$

for values of $n \geq 3$, where R_H is the Rydberg constant. There are four lines that you should see in the hydrogen spectrum that satisfy the Balmer relation. These include: a red line, a blue-green line and two violet lines. Measure their wavelengths and verify that Balmer's

equation is satisfied by writing a Python program to fit the data with equation (2). Determine the Rydberg constant R_H. What are the units of this number? *Hint*: Use $\Delta\lambda = 3$ nm as the uncertainty in λ.

Gas Identification

You can now test your skills and the calibration program by measuring the wavelengths of the spectral lines of unknown substances contained in the spectral tubes placed near the spectrometers. Identify a couple of unknowns by using Appendix 2 which lists the spectral lines of many common substances. Also, the colour of the light given off by the spectral light source often gives a hint to the gas contained.

Other calculations

Evaluate hcR_H where h is Planck's constant and c is velocity of light. This has units of energy. Convert to eV (electron volts) and compare it to the ionization energy of atomic hydrogen. What is the physical significance of hcR_H?

Hint: the lines of the Lyman series which are in the ultraviolet obey the relation:

$$\frac{1}{\lambda} = R_H\left(\frac{1}{1^1} - \frac{1}{n^2}\right) \tag{3}$$

for integers $n \geq 2$

APPENDIX 1

The tri-prism optical spectrometer, shown in Figure 1 is capable of resolving to about 0.1 nm (1 Angstrom). The instrument reads the wavelength of the light in arbitrary units. The visible spectrum is contained in 20 of the 50 divisions, with resolution by the vernier to 0.01 divisions. Repeatability is about 0.02 divisions. A calibration chart is required to convert scale readings to wavelength. Setting of the instrument is accomplished by aligning a cross-hair precisely on an image of the spectral line seen in the eyepiece.
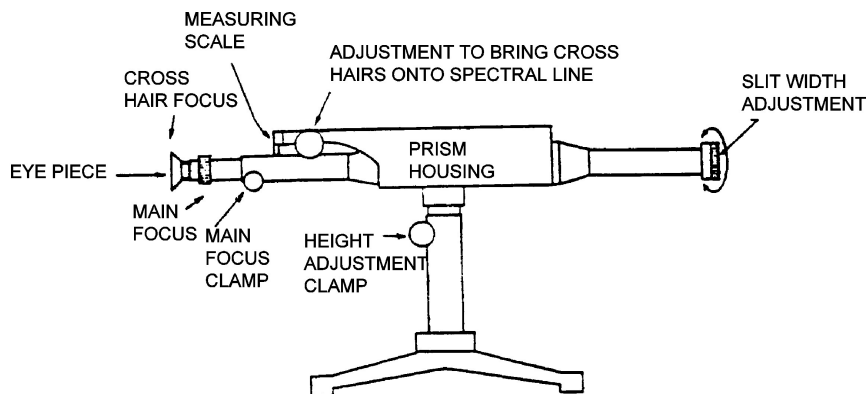

Figure 1: Main parts of the spectrometer

As seen in Figure 2, the light to be analyzed enters the slit, and due to diffraction, it diverges from the slit opening. The slit is situated at the focal point of the collimator lens, so after passing through it, the light is in a parallel beam. It then passes through the tri-prism. The central prism is the one which disperses the light. The first and third prisms are employed to straighten the beam and thus make the spectrometer easier to handle. After leaving the prism the dispersed beam passes into the measuring telescope. Real images of the slit are created in the plane of the cross-hairs, and these are examined using the eyepiece as a simple magnifier.
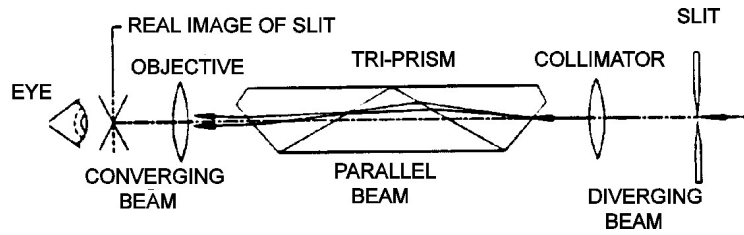
Figure 2: Optical arrangement of the spectrometer

OPERATING INSTRUCTIONS

Slit adjustment and line focus: Use a sodium lamp as source and find the bright yellow double line. Focus the spectrometer optics on the spectral line by moving the eyepiece assembly in or out of the black main frame with the knurled knob. Reduce the slit width until the sodium line resolves into two. Refocus if necessary. When the line is clearly focused, tighten the focusing clamp. The paint dot on the slit adjustment should be kept on the upper side of the spectrometer to maintain calibration. The spectrometer is now ready for use. When observing spectra the slit may be open or closed, as desired. Opening the slit will increase the brightness but decrease the resolution. Measure the wavelength of lines by precisely splitting the line with the centre of the cross hairs, and then reading the scale and vernier. *Precaution*: The vernier has only 50 divisions. Remember to add 50 to the vernier reading when the point is in the second half of a main division. When making observations in the violet it may be necessary to slightly push in the eyepiece in order to keep the cross-hairs in focus.

Note: Appendix 2 (Spectral Wavelength tables) is a separate document

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