

Balmer Series

1 Objective

In this experiment we will observe the Balmer Series of Hydrogen and Deuterium.

- Review basic atomic physics.
- Calibrate an optical spectrometer using the known mercury spectrum.
- Study the Balmer Series in the hydrogen spectrum.
- Determine the Rydberg constant for hydrogen.
- Compare hydrogen with deuterium.

2 Apparatus

The instrument used in this laboratory is a so-called “constant-deviation” spectrometer. Fig. 1 shows the composite prism used in this device and the optical path for an incident ray. It may be seen that the angle of incidence and the angle of exit can remain fixed for all wavelengths by an appropriate rotation of the prism. This has obvious advantages for positioning and alignment of source and detector. All that is required for the spectral analysis of light is to rotate the prism relative to the incident light keeping the incident ray and the axis of the analyzing telescope fixed at a 90 deg angle. The rotation of the prism, i.e. the dial, is calibrated with a known source (Hg in our case), and an interpolation between the known lines is used for the final calibration. Review the principles of the constant-deviation spectrometer.

Our spectrometer is a quality instrument which must be handled carefully. To adjust the spectrometer, first bring the cross-hairs into sharp focus by sliding the ocular in or out to suit your vision. Next bring the slit into sharp focus by turning the large knurled ring near the center of the viewing telescope. When the instrument is properly adjusted, the cross-hairs and the slit will be in sharp focus and there will be no parallax between them.

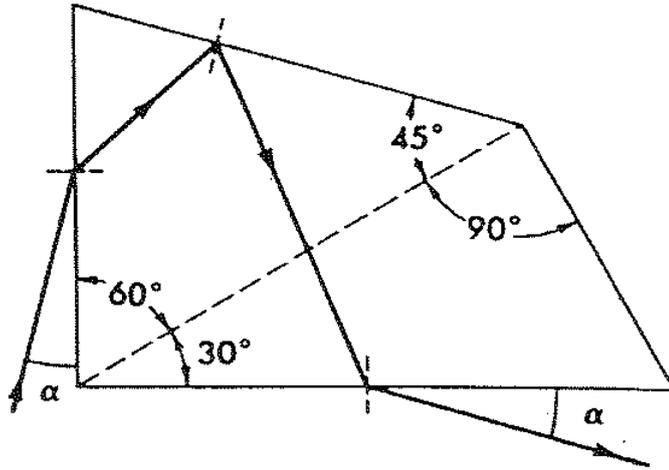


Figure 1: A Pellin-Broca constant-deviation prism. The prism acts as a spectrometer because it has a wave-length dependent index of refraction.

3 Calibration of the Spectrometer

Turn on the mercury tube and let it warm up for a few minutes. With the spectrometer slit wide ($\frac{1}{2}$ to 1 mm) find a line of the mercury spectrum. Now narrow the slit until the mercury line becomes sharp and narrow. In practice the narrower the slit, the better is the resolution of the instrument. However, narrowing the slit also causes loss of intensity. In almost all optical equipment there is a trade off between resolution and intensity. The optical scientist must decide, within the limitations of his/her instrument, how to compromise intensity and resolution requirements.

Locate all of the mercury lines that you can. You should see all of the lines listed below. In addition, you may see other faint lines from mercury, from impurities, or from more complicated molecular behavior.

404.7 nm	(deep violet very hard to see!!)
435.8 nm	violet
skip	(very weak blue-green)
546.1 nm	green
577.0 nm	yellow
579.0 nm	yellow
690.75 nm	red

When you are turning the screw drive which rotates the prism, note the positions on the dial which correspond to the mercury lines listed above (note that the numbers in the dial correspond to a given amount of rotation of the prism). Perform at least 4 runs for the spectrometer calibration. **Important:** turn the screw in one direction only to avoid error in gear back lash (the gears do not mesh exactly and there are dead spots when you reverse the direction). Use your data and the known values to calibrate your instrument performing a linear least squares fit. (You can review least square fit in “Fit straight line with unequal errors” under additional resources or in 6.3 and 6.4 in Ref. [3].)

4 The Hydrogen Spectrum

Observe the spectrum of hydrogen. You should see at least four and possibly five lines. Collect at least 4 runs of data. Show your raw and your corrected (using the above calibration) data. The wavelengths which you observe can be fitted with least square fit by an expression of the form of equation 1.

$$\frac{1}{\lambda} = R \left(\frac{1}{2^2} - \frac{1}{n^2} \right), \quad n = 3, 4, 5, \dots \quad (1)$$

R is the Rydberg constant, and n is the principle quantum number. Use the above equation to find the value for R . You must correctly identify each wavelength with the right quantum number in order to get R as a constant. You should get four or five evaluations of R and their uncertainties. In addition, determine R using a linear fit to equation 1.

Expression 1 above was discovered empirically in 1885 by a Swiss high school teacher named Balmer for whom this spectral series is named. Although the original equation in a slightly different form was good guess work by Balmer, it remained for both Rydberg and Ritz to suggest independently in the 1890’s that equation 1 might be modified to be

$$\frac{1}{\lambda} = R \left(\frac{1}{m^2} - \frac{1}{n^2} \right), \quad m = 1, 2, 3, \dots \quad n = 2, 3, 4, \dots \quad n > m \quad (2)$$

giving rise to the possibility of the existence of other spectral series which were subsequently observed. Equation 2 is also basic to the Ritz combination principle. If we convert the hydrogen emission wavelengths to frequencies, we find that certain pairs of frequencies added together give other frequencies which appear in the spectrum giving rise to other series, which ones are these?

The value of the Rydberg constant, $R (= \mu e^4 / 8\epsilon_0^2 ch^3, \mu = \text{reduced mass})$, was explained theoretically only after the Bohr model (1913) and the comprehensive development of Quan-

tum Mechanics in the 1920's. Quantum theory owes much to experiments of the type performed with the constant deviation spectrometer.

Measure, with at least 4 data runs, the Balmer spectrum for deuterium and determine R . Why would you expect it to be different from hydrogen? In addition, test the resolving power of your instrument by observing the doublet splitting of the yellow Na lines ($\lambda = 589.0$ nm and $\lambda = 589.6$ nm). Describe as quantitatively as possible whether you could resolve these two lines or not. What is the resolution of your experimental apparatus?

5 Analysis

What is your value of the Rydberg constant and its standard deviation? Compare your results with the accepted value for hydrogen: $R = 1.0967758 \times 10^7 \text{ m}^{-1}$. In your report/labnotebook discuss the atomic/quantum physics underlying the hydrogen spectrum.

Calculate the expected difference between hydrogen and deuterium, for the Rydberg constant and for the wavelength of the H_α line. Compare your hydrogen and deuterium results with the expected results in your calculation. Could you measure any difference, and, in particular, could you even expect to see any difference based on your Na result? Discuss.

6 References

[1] Melissinos and Napolitano, Chapters 1,5,6.

[3] Data Reduction and Error Analysis for Physical Sciences, 3rd ed. Philip R. Bevington, D. Keith Robinson.