Balmer Series v2.0

Johann Balmer

Background. The Balmer Series describes distinct lines in the emission spectrum of excited hydrogen gas. Rather than emit light in a broad continuum of wavelengths, atomic hydrogen produces distinct wavelengths that are precisely resolved with a suitable spectrometer. In 1885, Johann Balmer quantified the arrangement of wavelengths of hydrogen with a simple mathematical formula now known as the Balmer Series. This work provided the experimental foundation that led to the development of the Bohr Model of the atom.

Equipment. This experiment uses a constant-deviation spectrometer. It is based on a Pellin-Broca prism as shown in Figure 1. A light ray composed of multiple wavelengths strikes the top surface at an angle θ. The prism is made of glass that has *dispersion*, i.e. the index of refraction changes as a function of wavelength. The light ray is refracted at the top surface and – depending on the refractive index – experiences total internal reflection at the right side surface. This is the same phenomenon that confines light in an optical fiber. The ray is refracted at the left surface and emerges at the same angle θ as shown. When the prism is rotated by an amount δ, a different wavelength is selected from the incident beam. In this way the rotating prism functions as a spectrometer.
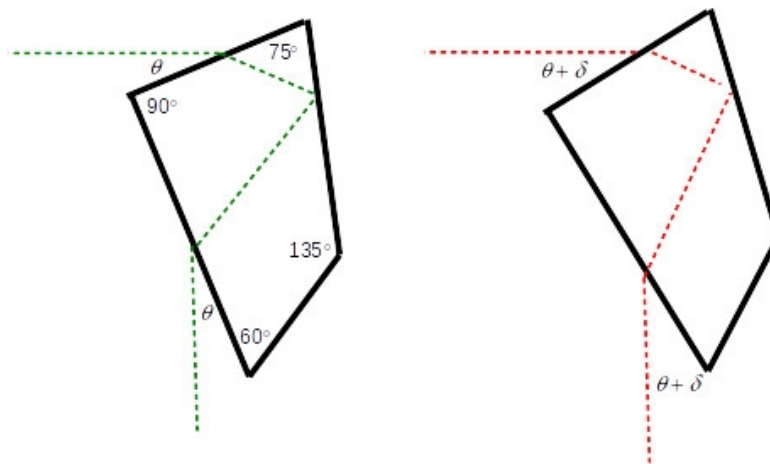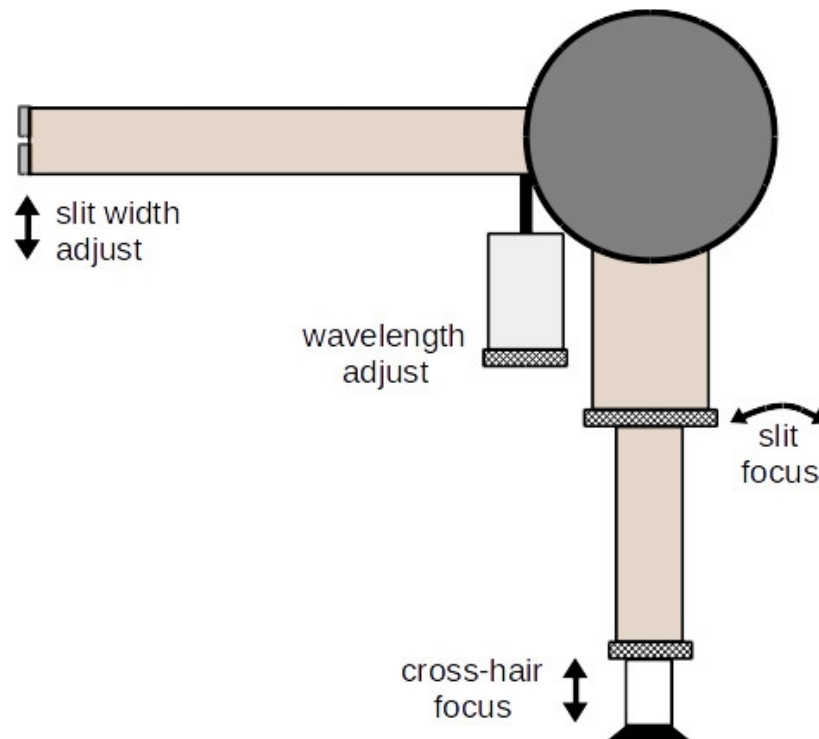

Figure 1: Principle of the constant deviation spectrometer.

A diagram of the spectrometer is shown in Figure 2. It has 4 adjustments that are controlled by the experimenter. Cross hairs that are brought into focus by sliding the eye piece as shown. The spectrometer must first be calibrated with a known reference; a mercury lamp will be used here.

Place the mercury lamp in the excitation fixture and switch it on. Allow ~60 seconds for the lamp to warm up. Locate the lamp near the input slit; distance is not critical. Using a combination of the slit focus knob, slit width, and wavelength adjust, locate calibration lines of Hg. Highest precision is obtained with the slit width as narrow as possible at the expense of a dimmer signal. There will be many lines visible, but the following six distinct wavelengths are sufficient to calibrate the tuning dial:

690.75 nm (red)
579.0 nm (yellow)
577.0 nm (yellow)
546.1 nm (green)
435.8 nm (purple)
404.7 nm (deep purple)

Center the lines as accurately as possible in the cross-hairs and record the dial reading. It is unlikely a spectral line will coincide with a dial tick mark, so make an estimate for numbers to the right of the decimal point. The dial has backlash, so it's important to make at least 4 data runs to get a reliable calibration. The data will define a calibration line that can be analyzed with least-squares-fit.

When calibration of the dial is complete, switch to a hydrogen lamp. You should be able to find at least 4 spectral lines and possibly a fifth. Use the calibration curve to convert the dial readings into wavelength (λ). The Balmer Series is:

$$\frac{1}{\lambda} = R \left[\frac{1}{2^2} - \frac{1}{n^2} \right] \quad n = 3, 4, 5, \ldots$$

where R is the Rydberg constant for hydrogen and n is the principle quantum number. The lines must be identified in the correct sequence to make the series work.

A value of R can be extracted for each wavelength and also by plotting the points in the form of the series equation and determining the slope. Compare with calculation.

Repeat for the deuterium lamp and explain any difference in the Rydberg constant that is extracted and calculated.

Test the resolving power of the spectrometer by observing the spectrum of a Na lamp. There is a doublet line at 589.0 and 589.6 nm. Can the doublet be resolved? Why or why not? Can this provide any insight on the ability to distinguish between hydrogen and deuterium?