

Experiment #6 Measuring the Balmer Series with a Grating Spectrometer

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Purpose

To measure the wavelengths of Balmer series of spectral lines from hydrogen and determine a value for the Rydberg constant.

References

1. For a description of how a diffraction grating works: Hecht, *Optics*, 4th ed., pp. 476-481; Knight, *Physics for Scientists and Engineers*, pp. 693-695. The relevant formula is

$$\lambda = d \sin \theta_D \quad (1)$$

2. For a description of the Rydberg-Ritz formula.

$$\frac{1}{\lambda} = RZ^2 \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right) \quad (2)$$

Knight, *Physics for Scientists and Engineers*, pp. 1212-1213; Beiser, *Concepts of Modern Physics*, pp. 127-130; Tipler, *Modern Physics*, 131-133.

Optional Prelab

1. You shine a laser with $\lambda = 628$ nm through a diffraction grating and find the first order maximum is 15° from the zeroth order or straight through beam. Calculate how far apart the lines are and how many lines there would be in 1 inch (2.54 cm).
2. If you take the value of R in equation 2 to be 110000 cm^{-1} calculate the wavelength in nm of the spectral line that corresponds to the $n = 4$ to $n = 2$ transition if $Z = 1$. What colour would the line be?

Theory of Operation

You will be using a spectrometer to measure the spectrum of hydrogen. In order to do this you will need to properly install the diffraction grating in the spectrometer. This should be done for you but here is the basic idea. Referring to the schematic in Fig. 1 you will place the gas discharge tube in front of the *slit*. You can control the width of the slit with the knob on the side. The illuminated slit is the “object” you are looking at and examining

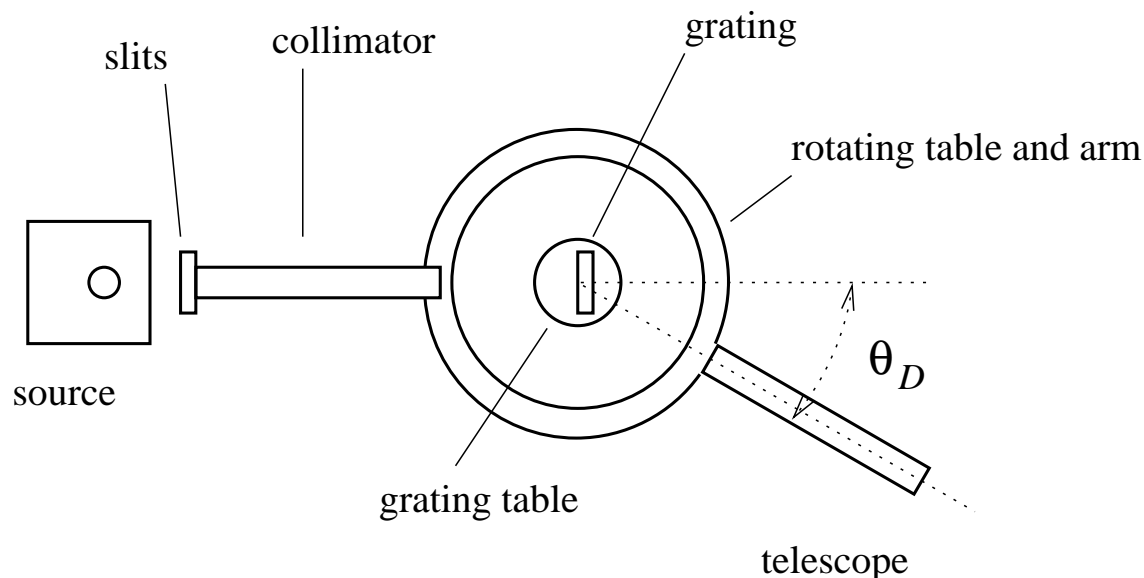


Figure 1: Spectrometer schematic. There are various locking mechanisms and fine adjustments I have not shown here.

with the optical parts of the spectrometer. The *collimator* holds the slit in one end and has a converging lens at the end closest to the grating. The object is put at the focus of the lens so that the image of the slit appears at infinity (just look through if you don't believe me). Because the image is "distant" light rays coming from it are essentially parallel and the wave fronts are flat. Look at the references to see how the *grating* works but essentially it leaves one beam undeflected (*the straight through beam*) and then it also diffracts the beam according to equation 1. It does not change the wave front from being planar so in order to best see the image at infinity you focus the telescope to infinity. The telescope is on an arm so that you can accurately record the deflection angle when the lines line up with the *crosshairs*. This combination of telescope and collimator with the image at infinity allows for extremely accurate measurements of θ_D .

You can also move the grating table but that is not necessary here so it is locked in place. It has been setup so that the incoming beam is perpendicular to the grating.

As a first step you will "calibrate" the spectrometer by measuring the deflection angles for the known strong visible lines of the mercury spectrum. (This can also be compared to the stated "lines per inch" on the grating.) Now measure the deflection angles for the bright visible lines of the Balmer series of hydrogen. Use your mercury calibration to convert these angles to wavelengths. Graphically verify that these lines satisfy the Rydberg-Ritz formula for $n_f = 2$ and determine the Rydberg constant.

Rules of Thumb/Pitfalls to Avoid

1. The spectrometer makes very accurate measurements (roughly 0.02 degrees). The most common reason for points that do not properly lie on curves is the simple *mistake* of reading the whole number of degrees incorrectly. You should retake these points.

2. Make sure you are getting the maximum amount of intensity from the gas discharge tubes (your sources) into the spectrometer for the given slit size. Keep the source close to the slit at the front of the collimator tube. Move your telescope to the straight through beam. Slide the discharge tube holder from side to side until you reach maximum intensity. This should allow you to see all of the lines. Also you can eliminate “ghosts” around the lines by slightly shifting the spectrometer.
3. The Vernier scale on the spectrometer is marked out in “minutes” of arc. There are 60 minutes in a degree and the main scale is marked off in half degree increments so 30 minutes is all you need on the Vernier scale.

Procedure/Analysis

1. Spectrometer setup. This will be done by a demonstrator. Don’t adjust the focus controls on the telescope or the collimator.
2. You should observe several groups of Hg lines: a very close pair of yellows, an intense green, a pair of dark greens (don’t measure these), a bluish-violet, and a pair of violets that are fairly faint. The wavelengths of these lines in nanometres are:

Colour	λ (nm)
yellow pair	577, 579
intense green	546
bluish violet	436
first violet of pair	408
second violet of pair	405

The lines should appear sharp, not as broad swaths of colour. Consult the *Handbook of Chemistry and Physics* if you want more accurate values. Measure the deflection angles of these lines. The best procedure is to move the arm to get close, then “lock” it in position and use the fine adjustment until the vertical crosshair is right on top of the line. (This may even make the line “wink out”.) Also make one measurement of angle for the “straight through” or undeflected beam (as a zero θ_0 ; we have tried to set it close to numeric zero but you should check.)

3. Repeat a measurement on one of the lines that is hard to see and see how well you can reproduce your earlier measurement.
4. Calibrate your spectrometer by making a graph of the sine of the deflection angle versus the tabulated wavelength. The result should be a straight line and the slope should be the spacing of the grating d . Check and make sure that this is the case. Problems with units can sometimes creep in.
5. Consult the notes about the high accuracy trick if you want a good estimate of uncertainty (plot $y - m_{est}x$ vs. x so that you can see your error bars). The error in the sine of the wavelength comes from your ability to measure the angle and the ability to

measure the “zero” angle. If you make an error of $\Delta\theta$ minutes of arc when making a measurements of θ and θ_0 then the error in $\sin(\theta - \theta_0)$ is

$$\Delta(\sin(\theta - \theta_0)) = \frac{\sqrt{2}}{(60)(57.3)} \cos(\theta - \theta_0) \Delta\theta. \quad (3)$$

6. Now make measurement of the Balmer series with the hydrogen discharge tube. Determine wavelength by inverting your calibration curve, and graphically verify the Rydberg-Ritz formula by plotting $1/\lambda$ versus $\frac{1}{n_f^2} - \frac{1}{n_i^2}$. The more common unit for $1/\lambda$ is cm^{-1} . Convert wavelength to cm and then take the reciprocal. Please show values for the wavelength and wavenumbers (the cm^{-1}) in the same table with your angle measurements. The visible Balmer series has $n_f = 2$ and n_i running from 3 to 5 or 6. You may or may not see the $n_i = 6$ line. Of course $Z = 1$ for hydrogen.
7. Determine your Rydberg constant and uncertainty.