Diffraction Gratings and the Hydrogen Spectrum
Spring 2009

Introduction

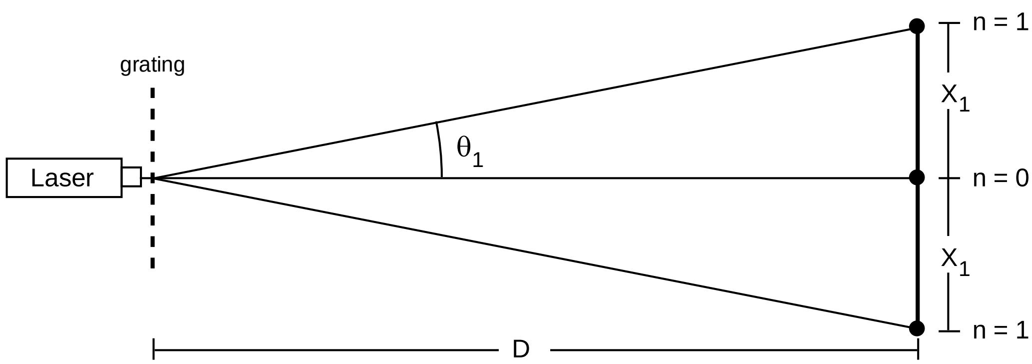
The object of this lab is to measure the wavelengths of light emitted from the hydrogen atom with high accuracy, and then construct an electron energy level diagram. You will be able to measure the hydrogen wavelengths within 1% of their expected values – within 0.5% if you are careful! *You will have **two weeks** to complete this experiment; collect all your data this week (up through part III), then finish your calculations next week. Before leaving today, show your instructor your calculated wavelengths; this can catch errors that will be harder to correct next week. You will be graded on the precision of your measurements!*

Experiment

Experiment notes: Some portions of this experiment can be performed with the lights in the lab turned on; others only with the lights off. Parts I and II can be completed with the lights on, and Part III only with the lights off. Be certain to practice reading the vernier scale (part II, step 5) with the lights on, then again with the lights off.

I. *Calibrating the diffraction grating:*

1. You will first calibrate your diffraction grating using the light from a He–Ne laser (λ = 632.8 *nm*). Set up the laser and grating as shown below (the grating side of the glass slide should face the laser). Align the laser perpendicular to the wall by holding a mirror against the wall and making sure that the light beam retraces its path back to the laser. Aim the laser near the center of the grating, and align the grating perpendicular to the laser beam by making sure that the diffracting maxima are located at equal distances from the central bright spot.



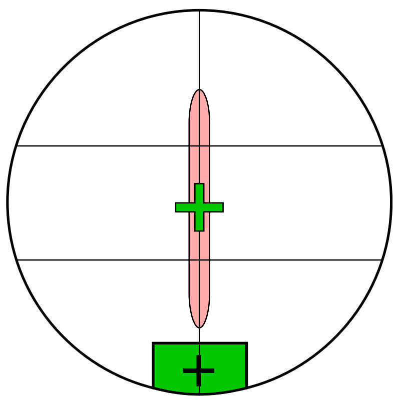
2. Use the grating equation $n\lambda = d \sin \theta$ to find *d*, the spacing between each slit of the grating. Use both first–(n = 1) and second–order (n = 2) maxima (*don't* use the small angle approximation here!). Calculate an average value for *d*. Be sure to complete your calculations for *d* before moving the grating!

II. *Setting up the spectrometer:*

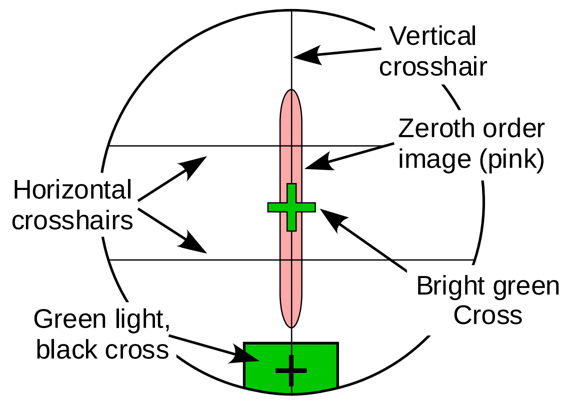
1. Turn on the hydrogen tube. Turn on the power to the *eyepiece* of the spectrometer. When the power is turned on, you should see a bright green square (with a black cross) at the bottom of the eyepiece. If you don't see the cross, or if it is not sharp, focus the eyepiece. When this cross is in focus, you should also see a set of cross hairs above the green square: one vertical, and two horizontal.
2. Place the glass slide containing the diffraction grating in the center (the *stage*) of your spectrometer. Aim the *collimator* (the tube with the slit at its end) at the hydrogen lamp and align the *telescope* (the tube

containing the eyepiece) parallel to the collimator. Turn the glass plate so that its grating side is facing the collimator, and is roughly perpendicular to the path of the beam coming through it.

3. Look through the telescope. Slide it left and right until you see a bright pink image of the tube through the slit (this is the zeroth order image). Line the vertical cross hair up on this image, rotating either the slit or the eyepiece as necessary to ensure that the two lines match up from top to bottom.
4. Gently rotate your grating clockwise or counterclockwise on the stage until a bright green cross appears in your field of view. Center the grating so that the bright green cross, the slit image, and the vertical crosshair are on top of each other, as shown below, left (an annotated view through the eyepiece appears below, right). This alignment ensures that the grating is perpendicular to the axis of the telescope.

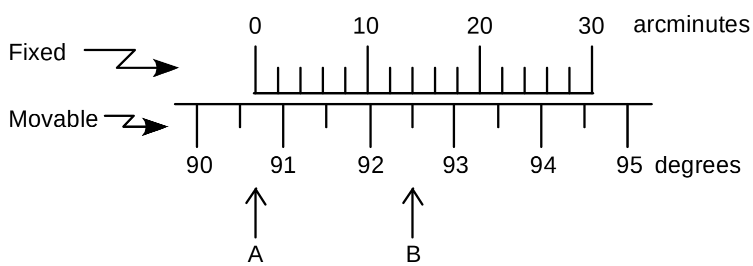


The view through the eyepiece



Annotated eyepiece view

5. Practice reading the vernier scale. The spectrometer has two verniers; be sure to use *the same one* for all your measurements. A simplified view of the scale appears as follows:



The inner (fixed) portion of the scale is marked from 0 to 30 *arcminutes*. The outer (movable) portion is marked in half-degree (30 arcminute) increments. The vernier is read as follows:

a. Note the position of the line under **0** on the fixed scale (position **A** in the sketch). This gives the first digits; in the example shown, it is between 90° 30' and 91°, so we'll start with 90° 30'.
b. Next, see which line on the *top* portion matches with a line on the *bottom* portion. Read the value from the top scale; in the example, the mark under 14' (position **B**) lines up.
c. Add this reading to your first measurement: 90° 30' + 14' = **90° 44'**

Note that you'll need to convert this measurement into *decimal degrees* before you can use it in subsequent calculations.

III. *Measuring the hydrogen wavelengths:*

1. Set up a data table in your report with the headers shown below. The first two columns will allow you to keep track of which lab partner's measurement are being recorded (*all* partners in the group should read *each* line!). You will record your measurement of the angle of each line in degrees and arc minutes in columns three and four. The angles are converted to decimal degrees and recorded in columns five and six, then θ is calculated and recorded in column seven. The wavelength is calculated, and then the average of each partner's wavelength calculated.

Color	Observer	θ_{left} (° ')	θ_{right} (° ')	θ_{left} (°)	θ_{right} (°)	θ (°)	λ (nm)	λ_{avg} (nm)

2. Look through the telescope when it is aligned with the slit, and you will see an image of the hydrogen tube. Moving the telescope to the left and right of this image will reveal three colored lines: violet, blue-green, and red (there is also a fourth, very faint violet line, but it is not visible in these spectrometers). These are the famous *Balmer lines*.
3. *Carefully* measure the angles for the first–order red line on both sides of the central image (θ_{left} and θ_{right}), then swap partners and re-measure. Since you are trying to measure wavelengths as precisely as possible, *a difference of more than about 3 or 4 arcminutes between you and your partners measured angles should be rechecked to discover the source of the discrepancy*. When you agree, calculate θ as follows:

$$\theta = \frac{|\theta_{left} - \theta_{right}|}{2}$$

This calculation makes it unnecessary to set the scale to zero when the telescope is aligned with the slit. *However, it is important to also record the angle for the* ***zeroth*** *order image, in case the other angles need to be checked later!*

4. Measure the angle for the blue-green and violet lines, and then calculate the wavelength for each hydrogen emission line using the value of *d* you measured in Part I.

IV. *Determining the wavelengths and colors from the hydrogen energy levels:*

The photons you have just measured have energy quanta assigned by Einstein to be:

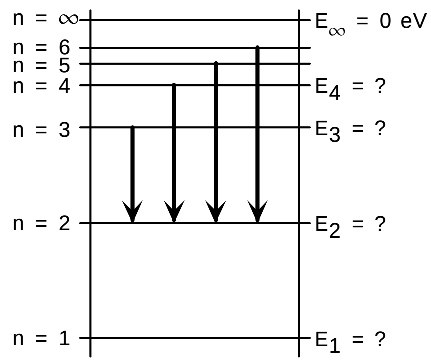
$$E_{photon} = \frac{hc}{\lambda} \qquad (1.1)$$

where hc = 1239.9 *eV•nm*. These represent the difference in the electron energy of two quantum states of the hydrogen electron.

Historically, the energies of these electron states were found to fit this empirical formula:

$$E_n = -\frac{13.61}{n^2} \qquad (1.2)$$

The energy is calculated in units of electron-volts (*eV*). Here, *n* (= 1, 2, 3, …) refers to the quantum level, *not* the order of the image, as in part I. Bohr (1915) showed these states correspond classically to simple quantization of angular momentum $(L_z = n\hbar)$ but Schrödinger's quantum mechanics (1925) showed a completely different connection.



1. Use equation (1.2) to calculate the energy levels for each state (n = 1…6) and write them on an energy-level diagram, as shown at right.
2. As an electron goes from a *higher* to a *lower* state, energy is conserved:

   $$E_{\text{electron, initial}} = E_{\text{electron, final}} + E_{\text{photon}}$$

   Use this expression to find the photon energies for transitions from n = 6, 5, 4, and 3 to n = 2.
3. Now use equation (1.1) to calculate the wavelength of the photons emitted from each transition calculated above. Compare your results with those measured using the spectrometer.

Discussion

- Summarize your measured and expected λ's, and their % differences.
- Discuss the agreement between the expected wavelengths (from your energy level diagram) and the measured wavelengths. Write the color of the observed line next to its transition on your energy level diagram.
- Discuss any systematic error that may have occurred and its possible source.