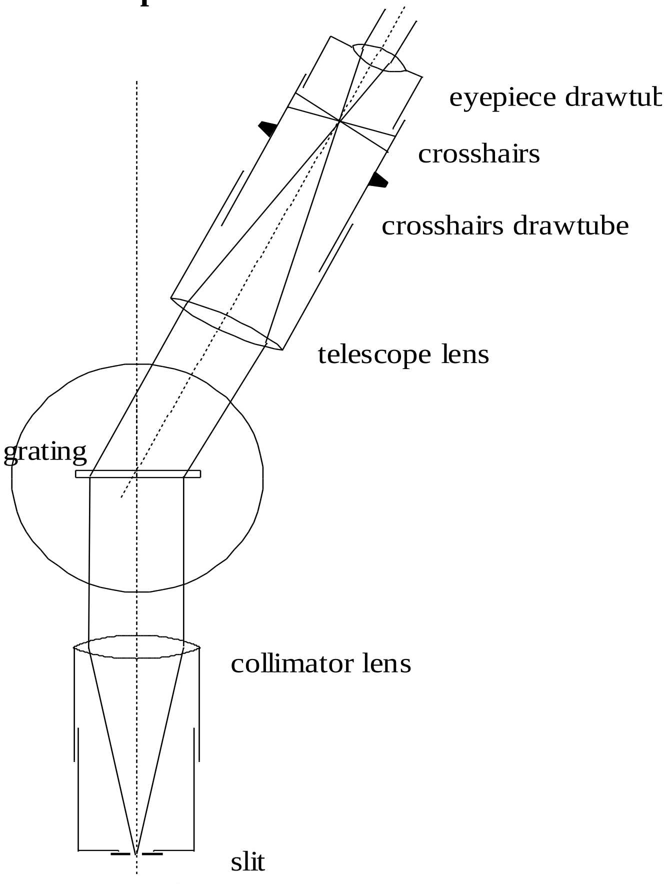
Physics 122
Winter 2012

Hydrogen Spectrum

The emission lines of hydrogen was one of the important, well-established, and unexplained sets of experimental results that Bohr was able to fit with his quantum model of the atom. In this lab, you will accurately measure their wavelengths. This is a lab in which you can obtain very accurate results, and that should be your main “lab-skills” goal this week. However, in order to obtain accurate results, you need to take extra care in the setting up of your apparatus, i.e. the focusing and alignment of your spectrometer. If you do an absolutely amazing job, you might be able to determine the difference in the frequencies emitted by deuterium and hydrogen.

The Set-Up

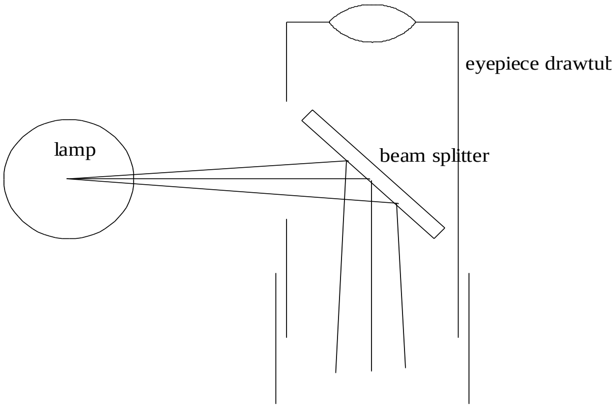


Alignment of the spectrometer

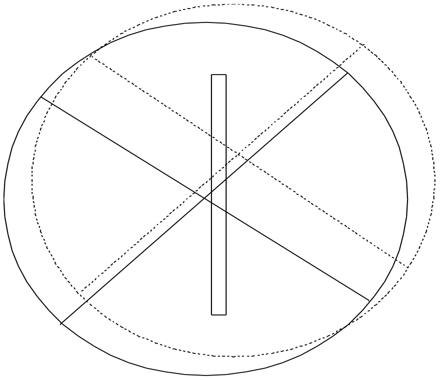
1. Move the eyepiece in and out until you can focus comfortably on the cross hairs. This adjustment is not critical, and may be different for each observer. Feel free to readjust the eyepiece drawtube anytime to bring the crosshairs into good focus.
2. Unscrew the diffraction grating from the central platform and look through the telescope at a distant object. Adjust the large chrome ring near the eyepiece lens until the distant object is brought into good focus. (This step sets the distance between the telescope lens and the crosshairs to be equal to the focal length of the lens.) You should see both the crosshairs and the

distant object in good focus, and *there should be no parallax* between them. Move your eye back and forth to check for parallax.

3. Place a light source behind the slit. If you line up the telescope with the collimator you should see the image of the slit. Move the slit drawtube in and out until its image is in focus and there is no parallax relative to the crosshairs. (The distance from the collimator lens to the slit should now be more or less equal to the focal length of the collimator lens.)



4. Final adjustment: This is the definitive check on the focusing arrangements, but more importantly it determines the correct orientation of the plane of the grating. Place the diffraction grating back onto the central platform and set it as close to perpendicular to the collimator tube as you can. Make sure that the eyepiece tube is parallel to the collimator (the image of the slit should pass through the center of the crosshairs). Near the eyepiece lens, in the chrome tube, is a hole. Just inside that hole is a 45° beam splitter. Shine a diffuse light beam into the hole and look for a reflection image of the crosshairs with the circle (see figure below). If you don't see it, try using cards to block out different sources of light.



Crosshairs, reflected crosshairs, and slit all seen at

Note that the system is not quite aligned in this fig

You can block the light from behind the grating and then with a second card block and unblock the path between the eyepiece tube and the grating…this will help you discover which images are the reflected images. If everything is aligned and in focus, you will see the slit (illuminated with the light from a Hydrogen tube), the crosshairs, and the reflected image of the crosshairs and they will all be in focus. (This cannot be done unless the distance from crosshairs to the telescope lens is indeed equal to the focal length of that lens. In addition, this assures that the grating is perpendicular to the axis of the collimator tube.) If not, you can move the reflected image by adjusting the orientation of the grating—you can change the vertical tilt by turning the thumbscrews underneath the grating platform, and you can turn the grating horizontally by turning the grating platform's adjustment knob (at the very bottom).

5. Note that there are two "locks", one for the telescope, and another for the grating platform. After the spectrometer is adjusted, the grating table should be locked, and a piece of masking tape placed over those knobs, so you don't accidentally touch them.

Calibration of the Instrument.

1. With the slit clearly in focus and passing through the center of the crosshairs, note and record the reading on the vernier scale on the platform. This is the “zero order” position. Note that the vernier can be read to the nearest minute of arc: *it divides each half degree into thirty parts*.
2. Read the grating density (no. of lines per inch) from the label on the grating slide and convert this number to a spacing distance (the inverse). Note that the label only says that this value is approximate. In the next step, you obtain a more accurate measure of the grating spacings.
3. Put a mercury gas tube behind the slit and move the telescope to one side until you see the first order green emission line. Note the angle of the telescope relative to the zero position (read the vernier scale again). Find the angle of the (first order) green line on the other side of the zero order position. Take the average of the two measurements, and use the known wavelength of this emission line, λ= 546.1 nm, along with the equation for diffraction patterns, which is

$$n\lambda \quad = \quad d\sin\theta,$$

(n=1 in this case), to calculate d, the spacing between grating lines.

Measurements of the Hydrogen Emission Line Frequencies

1. Replace the mercury tube with a hydrogen tube. Use a handheld grating slide to see the emission lines of hydrogen. These are the lines for which you will use the spectroscope to measure the wavelengths.
2. Note the zero position again, and find the first order peaks for the emission lines. Determine the angles of all the emission lines. Take data on both the left and right sides. Repeat the measurement of the “zero” setting now and then. Estimate the uncertainties in these measurements.

Measurements of the Deuterium Emission Line Frequencies

Replace the hydrogen gas tube with a deuterium gas tube and make the same measurements as with hydrogen. Note that the deuterium spectrum appears to the eye almost identical to that of hydrogen. The difference is very subtle. See if you can succeed in finding slightly different positions for these lines from those of hydrogen.

Analysis

1. Determine the wavelengths of all the lines you observed (include uncertainties) using the equation for diffraction patterns, which is

$$n\lambda \quad = \quad d\sin\theta,$$

where d is the spacing between gratings and n is the order of the diffraction peaks (which is probably 1 for your measurements).

2. For the hydrogen lines, compare your measured frequencies to the values expected in the Bohr model. You observed the visible-wavlength emission lines, i.e. the Balmer Series, and so

$$\frac{1}{\lambda} \quad = \quad R\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$

where R is the Rydberg constant and n = 3, 4, 5,…. Remember to use the reduced mass of the electron in your theoretical calculation of R.

3. If you succeeded in finding different frequencies for the deuterium lines, use them to determine the Rydberg constant for deuterium. Plot $1/\lambda$ vs. $1/n^2$ and fit a straight line through the points. The negative of the slope gives the Rydberg constant. (You can also use the y-

intercept (=R/4) as a check. Which do you think is more accurate?) From this result, determine the reduced mass of the electron in deuterium, and from that determine the mass of the nucleus. Finally, by comparing your estimate of its mass with the sum of the masses of the proton and neutron, estimate the binding energy of the deuterium nucleus.