

## The First Session: Prism Monochromator

### Junior Lab: BALMER LINES

It is the overall aim of this lab to use optical spectroscopy to unravel some of the physics associated with the hydrogen atom, *i.e.*, investigate the Balmer Lines. To do this it is first important to understand optical spectroscopy and useful to study the spectra of other common optical sources while we are at it.

In an optical spectroscopy experiment there are three important components: a sample which generates the light, a spectroscope (or sometimes a monochromator) which separates the light into its different wavelength components, and a detector which is arranged to separately detect these different wavelengths.

In the first session we will use various sources, a prism spectrometer and the naked as a detector.

As described starting on page 474 of "Fundamentals of Optics" by Jenkins and White a prism separates light into different wavelengths because the index of refraction varies with wavelength,  $n(\lambda)$ . Consider the situation of all the wavelengths of light entering the prism at the same angle and emerging from the prism with angle  $\theta$ , as shown in Fig 23A. The rate of change,  $d\theta/d\lambda$  or the **angular dispersion** of the prism is given by equation 23c. The angular dispersion describes how much the light is spread in direction. The more spread the better! Note that this spread is typically not very simple (at least not linear) because  $dn/d\lambda$  is not a constant over the wavelengths of interest. As described on page 479 for normal dispersion one can model the dispersion by the two-constant Cauchy equation 23d.  $n(\lambda)$  for typical glasses are shown in Fig. 23B and representations of the helium spectra for different glasses are shown in FIG 23C, where the spectra are scaled and aligned for  $\theta$  but labeled for  $\lambda$ . Not only are the  $\lambda$  scales very different they are non linear!

Now the angular dispersion is important for a spectrometer, however, it is not the most important criterion for judging a spectrometer. That is the chromatic resolving power. (This is in analogy to the magnification of a microscope versus its *spatial* resolving power. Magnification is to angular dispersion as *spatial* resolving power is to *chromatic* resolving power. Where the resolving power of a microscope measures the ability to resolve or distinguish between, two closely separated sharp sources (see FIGURE 15H) or relates to the spatial broadening of the image of the sharp source (see FIGURE 15I for typical spatial resolution criteria). Indeed, it is the resolving power of a microscope (or telescope) that is the most important property of that instrument. For example one can always increase the magnification of a microscope more, but a bigger fuzzy or poorly resolved image is not useful.)

Both spatial and chromatic resolving powers are a consequence of the diffraction of light in the instrument. As described starting on page 327 if the size of the prism face limits the refracted beam one finds the resolving power given by equation 15j. Where  $\lambda/\Delta\lambda$  is the resolving power. In words,  $\Delta\lambda$  is a measure of the broadening of a spectrally sharp source with wavelength  $\lambda$ . Or  $\Delta\lambda$  is the minimum wavelength separation of two lines in a source that the instrument is able to distinguish. The larger the chromatic resolving power the better, *i.e.*, the smaller the  $\Delta\lambda$  that one can distinguish.

In the first experimental session you will "play" with the prism spectroscope by investigating the spectra of low pressure Hg and Na lamps as well as a bunch of other interesting "household" sources.

Start with the Hg lamp. Make sure there are two glass plates in front of the two light exit holes. These are necessary to block the UV lines from the Hg source that can damage your eyes.

Our prism spectrometer consists of a entrance slit followed by a collimator which makes the diverging light from the entrance slit parallel, followed by the prism itself followed by a telescope which focuses the parallel rays of a given wavelength of light from the prism into the eye. Note entrance slits were not included in the Jenkins and White description. Actually that description, specifically the derivation of chromatic resolving power, is for a perfectly sharp line source *i.e.* a very narrow slit. One uses the slits to vary the amount of light into the prism open the slit and more light. This is at a loss of effective chromatic resolving power but an increase in signal. The chromatic resolving power determined above is that in the limit as the slit width goes to zero. As discussed below, having control over the entrance slit is very important for the alignment of spectroscopy system as a whole.

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### Coarse Alignment:

This only needs to be done if the prism has been moved! So do not move the prism if you are not specifically asked to!

Use intense Hg source with entrance slit open.

1. Align source with respect to entrance slit (position source as close to slit as possible and move it laterally relative to the slit) to optimize intensity and uniformity beam out of collimator. (Note output from the collimator should be a parallel beam.)
2. Orient prism so that all of the beam hits the entrance face of the prism at an angle of about ?? at the same time as. (Note the factor to be used to determine the chromatic resolving power is the B dimension of the prism only if the full face of the prism is illuminated.)
3. Position the telescope so that the colored spectra can be observed. (Note that with the slits open the colored light viewed through the telescope can be very intense!) If sufficient light is observed reduce the slit size until the lines are sharp. This will probably require the telescope to be focused as discussed below. Now rotate the prism, by rotating the prism table, so that spectral lines are moved to the right most possible position as viewed through the telescope. This puts the prism in the minimum deviation position.
4. Re-check that the prism's entrance and exit faces are properly oriented relative to the collimator at telescope, respectively. If not repeat steps 2 through 4.

### Fine Alignment:

This should be done when sources are changed.

1. Start with the entrance slit open. Align source as described in 1 of Coarse Alignment, above, to maximize intensity of light.
2. Focus the telescope by: first moving the eye piece relative to the shiny telescope tube to bring the cross-hairs into sharp focus, and second moving the shiny telescope tube as a whole back and forth in the gray spectroscopy housing to bring spectral lines into sharp focus. (Note to properly align the instrument you must first use a source, which has sharp lines.) Now align the cross hairs with the line that you are interested in. For coarse travel move the arm by loosening the thumbscrew at the arm's central rotation axis, while for fine travel use the other thumbscrew to rotate the arm. Read the angle on the scale using the Vernier scale for improved precision. (Note the Vernier scale reads in minutes of arc.) To obtain the best resolving power (narrowest lines) the slit should be as small as possible. I find it best to shut the slit down such that spectral lines do not reach the bottom of your field of view. It is at the bottom of the field of view that your best measurements of line width can be obtained.

### Calibration:

It is best to calibrate the spectrometer using a source with a known spectrum, such as from the Hg source. (Note this requires us to know the spectrum!) Accurately measure the angular position of several lines. I suggest the dim red, the yellow doublet, the green, the blue and the two violet lines. Now look up the wavelengths in the table in the RED book. This table has Intensity and Wavelength of neutral (I) and singly ionized (II) atoms, *etc.*. The actual intensities of the lines depend on details of the source. The values listed should be taken as indicative of the intensities of our Hg source. (Note the "bright" line chart on the wall is somewhat different from this table.) In the RED book the brightest lines have a red mark next to them and the overall colors of the different wavelength regions are indicated. Now plot  $\lambda$  versus  $\theta$  for your lines. This is a graphical calibration of the spectrometer, *i.e.* by measuring a set of  $\theta$ s from another source you can determine the  $\lambda$  of a line by graphically interpolating using your Hg calibration. This will be sufficient for this first session.

1. **Tuning the Spectrometer & Chromatic Resolving Power:** Examine the Na source. The Na source has a bright yellow line, which is actually a doublet – two equally intense lines separated in wavelength (One at 589 nm the other at 589.6 nm, separated by 0.597 nm and each has a line width

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about  $1/10^{\text{th}}$  this separation). It turns out it is difficult to resolve it. But we will try. First try measuring the angular width of any bright line. I find it is best to do this by aligning the line not to the center of the cross hair but to one edge of the cross hair. While you are at it, also measure the effective angular width of the near vertical cross hair itself. Now examine the yellow doublet. Is it a doublet? Based on your  $\Delta\theta$  for one of your lines determine  $\Delta\lambda$  from your calibration. Continue on to determine your experimentally measured chromatic resolving power. Compare this to the theoretical value predicted from Equation 15j using  $dn/d\lambda$  for Telescope crown glass in Table 23B. How well do your experimental and calculated resolving powers agree? Next try reducing the amount of light coming out of the prism by using an exit stop. Does this affect the line widths that you see? It should but maybe only when most of the light is blocked.

**Even if you did not see the doublet, still estimate the resolving power for this prism spectrometer.**

### PRISM

The UV-filters should be in place - actually they are just soda-lime glass microscope slides but they will cut down the UV lines sufficiently.

The table of the wavelengths and intensities of a Hg spectra are in the book beside the spectrometer, but the table below should suffice.

Note the Spectrometer can read to the nearest minute of arc. It does this by using a vernier scale. Vernier scales are explained in "The Usborne Illustrated Dictionary of Science" Page 100. Note this explains a Vernier for a decimal scale. We have a vernier for 30 minutes =  $\frac{1}{2}^\circ$ .

To estimate the line widths of very sharp lines, I suggest you measure the "line width" between the prominent edges of the vertical cross hair. This can be done by bring the left edge of the cross hair to the edge of a sharp spectral line and reading the angle, and then moving the right edge of the cross hair to the SAME edge of the sharp spectral line. The difference is the angle subtended by the cross hairs.

Now it is quite easy to estimate line widths in terms of their fraction of the known line width associated with the cross hairs.

**What sources to look at:** -Try to stick to the same order.

<b>Na Source:</b>	Tune (and play) with the spectrometer – mostly use the Na doublet.
<b>Hg Source:</b>	Calibrate the spectrometer to get $\lambda$ vs. $\theta$ . I suggest you use 6 to 8 well spaced lines. The yellow, green, aqua, blue, violet#1 and violet#2 lines are bright ones.
<b>Compact Fluorescent</b>	This should be very similar to the Hg source. <b>Why?</b> Semi-quantitatively compare this spectra to that for the Hg source. <b>Are there new lines? are they broad?</b>
<i>For the rest of the sources you only need to be qualitative -just recording the colors and intensity (very bright, medium bright, dim) observed is sufficient.</i>	
<b>Incandescent</b>	<b>Is this source broad? Should it be?</b>
<b>Quartz Halogen</b>	<b>Is the spectrum noticeably different from the incandescent?</b>
<b>LED Lamp</b>	<b>Is the spectrum noticeably different from the incandescent?</b> <b>Take some care here.</b>
<b>LEDs on Batteries</b>	<b>How do the spectra compare to the incandescent.</b>
<b>Red</b> small      clear	<b>Are they only one color?</b>
<b>Orange</b> small      clear	<b>Are these blackbody sources?</b>
<b>Yellow</b> big            yellow	
<b>Yellow</b> small      clear	
<b>Green</b> big            clear	
<b>Blue</b> small      clear	

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**Calibration:** Measure the angular positions of the same lines you used in the Photo-Electric Effect experiment. Calibration consists of a plot of  $\lambda$  vs.  $\theta$ .

<b>Color</b>	<b>nm</b>
Yellow	578
Green	546
aqua	491
"Blue"	436
Violet#1	405
Violet #2	365