The Second Session: Grating Monochromator

Junior Lab: BALMER LINES

As described starting on page 355 of "Fundamentals of Optics" by Jenkins and White a grating separates light into different wavelengths because of diffraction. That is different wavelengths diffract differently so that constructive interference of these different wavelengths occur at different angles. The general set up for far-field diffraction is shown in FIG 17E. The grating equation derived in class is equation 17f. Equation 17g shows this in the angular dispersion form that was used for the prism.

As with the prism spectrometer 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. As described starting on page 355 (Sections 17.1-17.3) the chromatic resolving power is affected by number of slits illuminated, or the number of individual light sources that combine together to give your diffracted output. FIGURE 17 nicely illustrates that more slits give sharper diffraction patterns and these in turn will allow for higher resolving power. Equation 17j gives the resolving power of a $\lambda/\Delta\lambda=mN$, where m is the order of the diffraction lines and N is the number of slits *illuminated*.

In this experimental session you will "play" with the grating spectroscope to: fine tune the spectrometer with the low-pressure Na lamp; "check" its calibration with the low pressure Hg lamp; determine the wavelength of the Balmer lines for the D_2 and H_2 source; and attempt to determine the identity of the "mystery" gas.

Start with the Na lamp. As for the prism spectrometer in the grating, one uses the slits to vary the amount of light onto the grating - 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 described 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.

Coarse Alignment:

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

Use intense yellow doublet of the Na 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.) Position the grating so that it is centered on the rotating stage and perpendicular to the in coming entrance beam. Note this sets the incidence angle, i, of equation 17f to 0.
2. Position the telescope so that the colored spectra can be observed (in particular the yellow doublet.). (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 in the Fine Alignment Section of the notes of Session I. You will notice that some "ghosting" of the doublet is observed. This definitely reduces the "effective" resolution of the instrument. It is caused by some multiple reflections inside the film on which the holographic gratings are etched. To eliminate this "ghosting" rotate the table holding the grating clockwise (looking down), while looking at the sharpness of the doublet. I find that an angle of incidence of less than 30^o fully eliminate the ghosting problem.

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.

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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 spectroscope 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:

In the case of the grating as long as you know the d-spacing of the grating lines and can measure angle θ and i accurately you can easily calibrate the spectrometer. This can be done either by using the grating equation (equation 17f), or its differential or Angular Dispersion form (equation 17g). If you choose the differential form of course you must measure one known line to calibrate the spectrometer. If you want you can calibrate using say five "known" lines of the Hg source, as you needed to do with the prism spectrometer. Whichever ways you do it check your calibration by looking at some independent line. Either way, this time, fit some reasonable function to your λ versus θ curve. This you can use to determine λ for any measure θ.

Excercises:

1. **Calibration:** Calibrate the grating spectrometer following the calibration procedure above.
2. **Chromatic Resolving Power:** Again examine the Na source. Now you should be able to resolve the doublet. Based on your $\Delta\theta$ for one of your lines determine $\Delta\lambda$ from your calibration. Does this agree with the known $\Delta\theta$? Estimate your resolving power by measuring the width of one of the double lines? Compare this experimental resolving power to one calculated from equation 17j. Be careful in your selection of Next try reducing the amount of light coming out or into the grating by using a stop. Does this affect the line widths that you see? It should but maybe only when most of the light is blocked.
3. **Examine the H_2 D_2 Source:** Note it takes a while for the source to turn on. Do not turn it off and on often. Measure the first four Balmer line (Balmer α, β, γ, and δ) they are red, cyan, blue and violet, respectively. (The yellow line is not a Balmer line.) The violet line may not be very intense due to the source and sensitivity of your eye to violet. Can you resolve any of these lines as "isotopic" doublets? (Actually it turns out that each of the lines of the resolved isotopic doublet we resolve for Balmer a is actually itself multiple lines! See the Scientific American article entitled "The Spectrum of Hydrogen" in the RED book.) Now determine your experimental wavelengths for your Balmer lines. Fit these to the Bohr model to determine your experimental Rydberg constant.
4. **Examine the Mystery Gas: Now** try to determine the identity of the gas in the discharge tube set up near the spectrometer. Do this by determining the wavelengths of several of the bright lines in the discharge emission. Compare the wavelengths and brightness of the lines to those for gases on the Bright Line Spectra chart on the wall. **C**an you determine the identity of the gas?
5. **Answer Questions: Make** sure you answer the questions in the original handout.