Experiment 112-8

Grating and Prism Spectrometer

Introduction

Diffraction Gratings[1]**:** A master diffraction grating is made by ruling a large number of finely, closely spaced lines on a sheet of glass or metal with a diamond point cutter. The gratings used in this experiment are replicas that have been cast in resin from a master grating.

Diffraction gratings with a high line density resolve interference maxima into very sharp and widely spaced fringes. Moreover, the fringes are so narrow and so widely spaced that the different wavelengths of light passing through the grating produce fringes at angles sufficiently different that they can be distinguished from one another. That is, the deviation angle at which a bright fringe is produced depends upon the wavelength of the light.

The angles at which these bright fringes occur can be measured with a device called a spectrometer. These angles, along with the diffraction grating line spacing can then be used to calculate the wavelength of the light passing through the grating via the grating equation

$$m\lambda = d\sin\theta \qquad m = 1, 2, 3, \ldots , \tag{8.1}$$

where the order of the spectrum is given by the integer values of m. Light emitted from an elemental gas typically consists of a number of discrete wavelengths (colors). A grating spectrometer can be used to determine the wavelengths of these colors.

Prisms[2]**:** When light is refracted through a prism it is dispersed into its constituent colours, and the angle at which the light emerges from the prism depends upon its wavelength. A prism spectrometer can be used to measure the deviation angles. Since the deviation angles also depend upon the index of refraction of the glass from which the prism is made, they can be used to calculate the index of refraction at the different wavelengths via

$$\mu = \frac{\sin\left[\left(A+D\right)/2\right]}{\sin\left(A/2\right)} \tag{8.2}$$

where A is the apex angle of the prism and D is the angle of minimum deviation for the spectral line.

Propagation of Errors: The normal rules for addition/subtraction and multiplication/division apply to Equations (8.1) and (8.2). However, since they both contain trigonometric functions, it’s necessary to work out a technique for propagating the measurement errors through them. Consult §3.2.5 on page 12 of the Laboratory Companion to see how it can be done.

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[1] Physics, Volume 2 by Halliday, Resnick, & Krane, pp. 981–986
[2] ibid., pp. 890–893

Purpose

The objectives of the experiment are (1) to use a grating spectrometer to determine the wavelengths of the visible lines in the sodium spectrum and (2) to use a prism spectrometer to determine the index of refraction of the glass from which the prism is made at the wavelengths of the visible lines in the sodium spectrum.

Procedure

1. Preliminary Setup

A diagram showing the basic parts of a spectrometer is shown in Figure 8.1. Light enters the collimator through a slit at the front of the spectrometer. The collimating lens focuses the light into a parallel beam, which then passes through either a diffraction grating or a prism placed on the prism table. After being bent through some angle, the beam of light is then viewed through the telescope, which can be rotated until the image of the slit is centered on the cross hairs. The angle that the light has been bent through can then be read on the protractor using the vernier scale attached to the telescope.

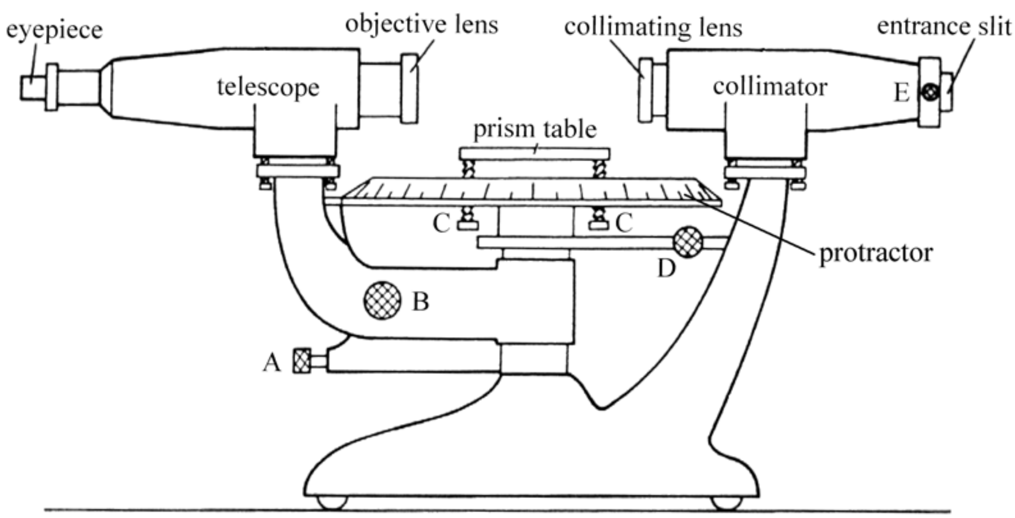

Figure 8.1 Parts of a Spectrometer

A. The knob at **A** is used to clamp the telescope in place so that it cannot be moved. It should always be loosened when large adjustments to the telescope's position are made.
B. The knob at **B** is used to finely adjust the position of the telescope. Knob **A** must be clamped before the fine adjustments can be made.
C. The knobs at **C** can be used to level the prism table with respect to the optical axis. Consult with your lab instructor before attempting this.
D. The knob at **D** is used to clamp the protractor as well as the prism (and grating) table. It must be clamped when angular readings are taken with the combination of the protractor and vernier scales.
E. The knob at **E** is used to adjust the width of the slit at the front of the collimator. One edge of the slit remains fixed on the optical axis, the other edge is adjustable.

All the adjustable parts of the spectrometer should move with little effort. Damage to the spectrometer can occur if you force parts to move. If some part is tight, it is probably because it is clamped in place. Find the appropriate knob and loosen it.

The initial adjustment of the spectrometer consists of adjustments to the telescope and the collimator. First, adjust the eyepiece of the telescope so that the cross hairs are sharply focused. Next, swing the telescope to one side and point it at some distant object. (Take it out into the hall.) Adjust the telescope lens until the object is as sharply focused as possible and eliminate parallax between the image and the cross hairs. Once these adjustments have been made they should not be touched for the rest of the experiment.

Next, place a light in front of the entrance slit of the collimator. View the slit through the telescope. Adjust the collimator lens until the image of the slit is in the plane of the cross hairs. You should use parallax focusing to accomplish this.

After these adjustments have been made, the light entering the slit on the front of the collimator will be focused into a parallel beam by the collimator lens. It will then be focused on the cross hairs of the telescope by the objective lens of the telescope. This image of the slit can then be viewed through the eyepiece.

2. Grating Spectrometer

Mount the diffraction grating holder on the prism/grating table and put the diffraction grating in place. Loosen the knob D and rotate the table so that the grating is perpendicular (judged by eye) to the optical axis of the collimator. Tighten knob D to clamp the table in place.

Place the sodium lamp in front of the entrance slit of the collimator. Rotate the telescope so that it is in line with the collimator axis and view the slit through the telescope.

Vary the slit width while observing it through the telescope. Notice that only one side of the slit moves. When determining line positions, you should align the cross hairs with the *fixed side of the slit*. Start with the slit fairly wide open; you can make the slit wider for faint spectral lines to make them easier to see.

If you have a problem seeing the cross hairs in the telescope, illuminate them with a light near the telescope. You will have to experiment with the positioning of the desk lamp so that it is bright enough to illuminate the cross hairs, but not so bright as to obliterate the spectral lines.

Align the telescope cross hairs with the fixed side of the slit and note the protractor and vernier scale[3] readings.

Rotate the telescope to the left of the collimator axis and observe the lines in the sodium spectrum. Choose one easily visible line and align the cross hairs with the fixed side of the slit. Read the protractor and vernier scales. Move the telescope to the other side of the collimator axis and align the cross hairs on the same spectral line (check to make sure you are using the fixed side of the slit). Note the scale readings. The left and right deviation angles (relative to the centre reading) should agree with within 0.1º. If they do not, the grating is not perpendicular to

[3] The vernier scale on the spectrometer is calibrated to tenths of a degree. There will be times, however, when no line on the vernier matches exactly with one on the protractor. If this happens record the decimal part of the reading as half way between the two vernier lines which most closely align with the protractor scale marks. In other words, you should be able to estimate the scale readings to the nearest 0.05 degrees.

the axis of the collimator. Correct the orientation of the grating by half of the difference and repeat until agreement at the 0.1° level is obtained.

For all the first and second order spectral lines that can be seen on both sides of the collimator axis, record the angular positions in a table similar to the one shown. You may have to adjust the slit width for brighter and/or fainter spectral lines.

m	Color	Left scale reading θ_L (°)	Right scale Reading θ_R (°)	Deviation angle θ (°)	Wave-length λ (nm)	Error $\Delta\lambda$ (nm)
0	Slit	54.00	54.00	–	–	–
1	Blue-Grn	36.90	71.10	17.10	498	3
1	Green 1	32.30	71.65	19.675	514	3

The deviation angle θ is calculated by dividing the difference between the left and right scale readings by two. Use Equation (8.1) to calculate the wavelength of each of the lines. The spacing *d* between the slits on the diffraction grating can be calculated from the manufacturer's specification that the gratings have been ruled with 15,000 lines per *inch*. Compute the error in each wavelength value via the methods described in §3.2.5 of the Laboratory Companion.

Look up the reference values for the spectral lines of the sodium spectrum in suitable reference source like the Handbook of Chemistry and Physics. The relative intensity of the lines should also be given: you probably saw only the brightest of the spectral lines. Can you match up the reference values with the values you found?

When calculating the error in your wavelength values a relative error of 0.001 in the grating line spacing *d* was assumed. This error is a systematic rather than a random error. Are your calculated wavelengths systematically high or low when compared with the reference values?

3. Prism Spectrometer

Remove the diffraction grating and the grating holder from the spectrometer table. Place a prism on the table and orient it as shown in Figure 8.7. Carefully slide the white circular lid over the prism to serve as a positioning jig. Set the telescope to read the angle of the light that is reflected off each face of the prism. The difference between the scale readings at points *a* and *b*, shown in the figure, equals <u>twice</u> the apex angle. Calculate the value of A. (It should be close to sixty degrees.)

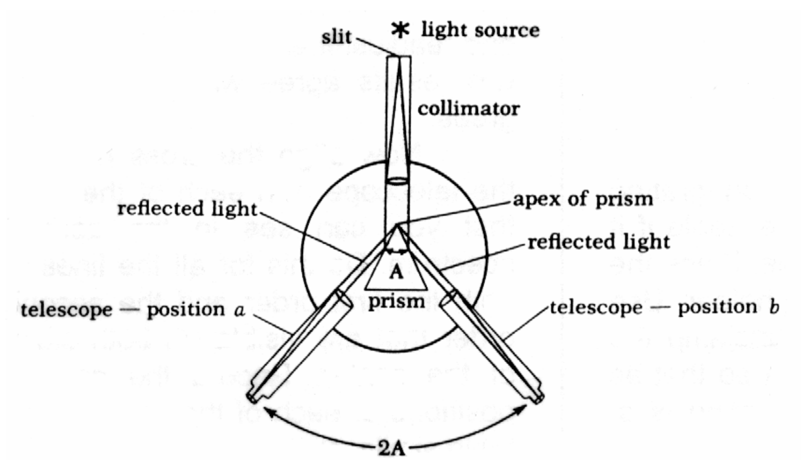

Figure 8.7 Determination of Apex Angle of Prism

Now, using the positioning jig, rotate the prism on the spectrometer table so that it is oriented as shown in figure 8.8A. You should observe the lines in the sodium spectrum.

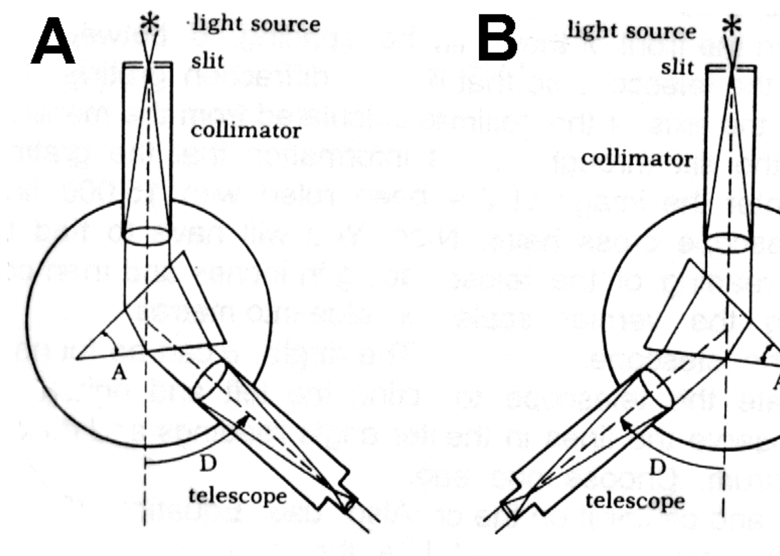

Figure 8.8 Determination of Angles of Minimum Deviation

Next, set the prism to obtain the angles of minimum deviation. To do this, rotate the prism using the positioning jig while you observe the spectrum through the telescope. Rotate the prism in the direction that reduces the angle at which the light is deviated. You will eventually come to a point where further rotation of the prism will cause the angle at which the light is deviated to increase. Find the position of the prism at which the angle through which the light is deviated is as small as you can make it.

Position the cross hairs of the telescope on the fixed edge of the slit image for each of the lines in the spectrum. (If necessary, you can change the slit width to make fainter lines easier to see.) Record the angular scale readings from the spectrometer.

Reposition the prism on the spectrometer table to orient it as shown in Figure 8 .8B and repeat the above procedure for this prism orientation. The angle of minimum deviation is half the difference between the corresponding scale readings on each of the two sides. Find the angle of minimum deviation for each spectral line.

Use Equation (8.2) to calculate the index of refraction of the glass of which the prism is made for each of the spectral lines. Use Equation (8.4) to calculate the uncertainty in each of these indices of refraction. Record all of your data in a table similar to the one shown below.

Color	Angle Left (deg)	Angle Right (deg)	D (deg)	μ	$\Delta\mu$
Red	103.85	3.35	50.25	1.644	0.005
Yellow 1	104.10	3.10	50.50	1.646	0.005

The graph in Figure 8.9 (over page) shows the index of refraction of various types of glass as a function of wavelength. What type(s) of glass have μ values that come closest to those you obtained for the glass in the prism in your experiment?

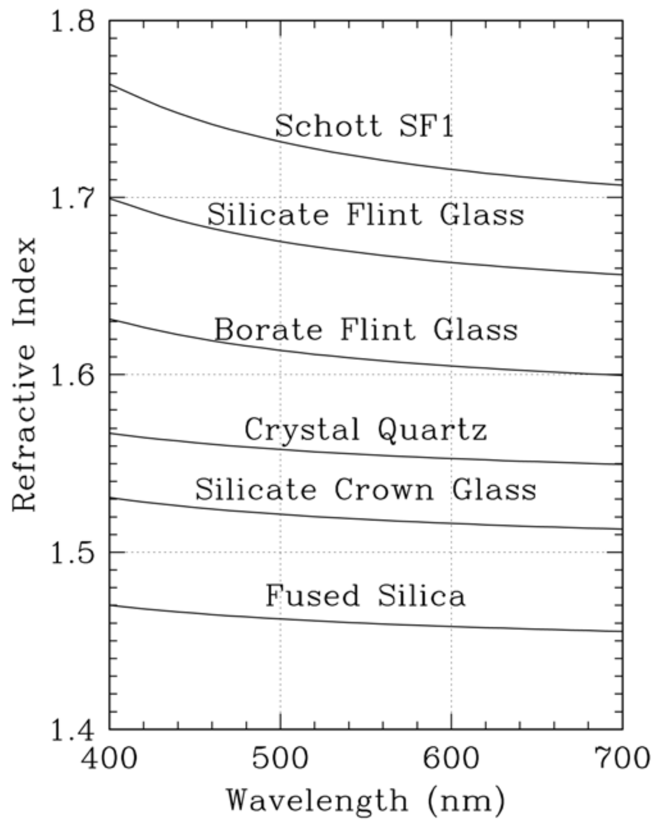

Figure 8.9 Index of Refraction