Name: _____ _____Date: _____ Course number: ___ _____
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Lab section: _____ Partner's name(s): _____ Grade:_____

EXPERIMENT 14

The Atomic Spectrum of Hydrogen

0. Pre-Laboratory Work [2 pts]

1. You will be using a diffraction grating in this lab exercise as a dispersive element in a spectrometer. When you begin to examine the Balmer series of atomic hydrogen, you will observe an indigo line, a red line and a violet line as you move the spectrometer's telescope away from the zero angle (zeroeth order) position. What will be the sequence of the spectral lines, starting from the zero angle position? Explain why, showing some calculations or a diagram. (1pt)

2. What is the expected measured *grating separation*, *d*, if you use a 600 groove/mm grating? A 300 groove/mm grating? Show your work. (1pt)

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EXPERIMENT 14

The Atomic Spectrum of Hydrogen

1. Purpose

The purpose of this experiment is to verify the quantum nature of the Balmer series, specifically for atomic hydrogen, using sodium as a calibration source.

2. Introduction

One of the earliest successes of quantum mechanics was the explanation of the spectrum of atomic hydrogen. It has long been known that atomic hydrogen had some regular features in its spectrum. These regularities can be expressed as,

$$\frac{1}{\lambda_{i,j}} = R\left(\frac{1}{n_i^2} - \frac{1}{n_j^2}\right) \qquad \textbf{Equation 14.1}$$

where $n_i < n_j$ are both integers and R is a constant. The spectral lines are classified into series that are sets of lines with a common value of the integer, n_i. The expression for wavelength has been written as the wavenumber (inverse wavelength, usually quoted in units of cm^{-1}) of the j^{th} member of the i^{th} series. The various series of the spectrum of atomic hydrogen are listed in *Table 14.1*.

According to the Bohr theory, the Rydberg constant, *R*, is given to first approximation by,

$$R = \frac{k^2 me^4}{4\pi\hbar^3 c} = 1.097\,x10^{-2}\ nm^{-1} \qquad \textbf{Equation 14.2}$$

where *e* and *m* are the electron charge and mass, respectively, *c* is the velocity of light, $\hbar$ is Planck's constant divided by 2π, and $k = 1/4\pi\varepsilon_o$. Sometimes there is a small correction that takes into account the mass, *M,* of the nucleus. This involves replacing the mass of the electron, *m,* with its reduced mass, μ, given by,

$$\frac{1}{\mu} = \frac{1}{m} + \frac{1}{M} \qquad \textbf{Equation 14.3}$$

In this lab you will examine the spectrum of atomic hydrogen in the visible region. This will restrict your test of the theory to three spectral lines of the Balmer Series. The chart on the wall of the laboratory should be sufficient to verify the quantum nature of the expression for the Balmer series and allow you to obtain an estimate of the hydrogen spectrum. You can also verify the value of the Rydberg constant by explicit calculation using *Equation 14.2*.

The apparatus for this experiment consists of a telescope spectrometer with *a diffraction grating* as its dispersive element, as in *Figure 14.1*. A diffraction grating is a planar device with a certain number of parallel "grooves" per unit length. These grooves are separated by a constant distance, *d.* The grating is situated on one side or *face* of a slab of glass. The grating

holder should specify the face upon which the grating has been placed. The grating will also be labeled with the number of grooves per mm. This number is approximate only and the true grating separation must be measured.

In *Section 3.1* you will align your spectrometer so that the telescope and collimator are focused properly on the slit image, and the grating is perfectly perpendicular to the optical path. In *Section 3.2* you will measure the groove separation of your particular grating by using a known wavelength of the sodium spectrum. In *Section 3.3* you will measure the angles of some of the spectral lines of the Balmer series. These angles will be converted to wavelength using the calibration value obtained in *Section 3.2.*

Series Name	*Wavelength Range*	*Series Expression*
Lyman	Ultraviolet	$\frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right)$, $n \geq 2$
Balmer	Near UV & Visible	$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$, $n \geq 3$
Paschen	Infrared	$\frac{1}{\lambda} = R\left(\frac{1}{3^2} - \frac{1}{n^2}\right)$, $n \geq 4$
Brackett	Infrared	$\frac{1}{\lambda} = R\left(\frac{1}{4^2} - \frac{1}{n^2}\right)$, $n \geq 5$
Pfund	Infrared	$\frac{1}{\lambda} = R\left(\frac{1}{5^2} - \frac{1}{n^2}\right)$, $n \geq 6$

Table 14. 1

3. Laboratory Work

3.1 Spectrometer Alignment

The spectrometer needs to be aligned to ensure accurate measurements of the sodium spectral lines (also on the chart on the wall) and hydrogen spectral lines. A side view of the spectrometer is shown in *Figure 14.1*. Below the telescope there is a pair of knobs. If you loosen the top knob, then the telescope will be free to move. Loosening the bottom knob allows the grating platform to rotate. If you rotate the platform, then the angles visible in the window on the platform will change. Learn how to keep careful track of these changes.

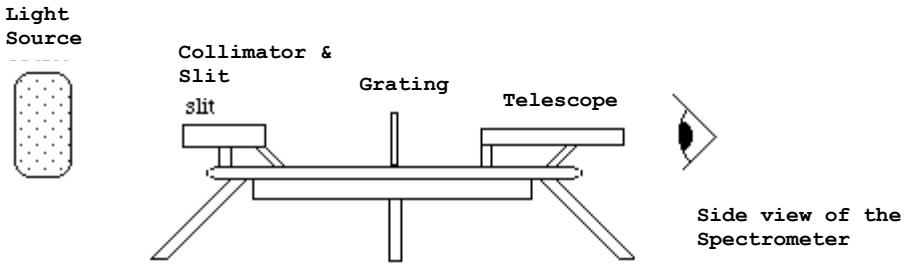

Figure 14. 1

Procedure
Setting up the Spectrometer

1. Turn on the sodium lamp and set it aside. (The sodium lamp is has a label that says "Na Light Source" on the back near the switch.) It needs a few minutes to warm up. You will know it is ready when the emitted light has a warm, yellow glow instead of a harsh purple, glow.

2. In the meantime, familiarize yourself with all of the controls on the spectrometer (listed in Appendix 1 of this laboratory). Learn the effect of loosening and tightening each knob as described in the paragraph above. By mastering the operation of the spectrometer *now*, you will save yourself time and frustration were you to loosen or tighten something incorrectly *later*.

3. Using the level, make sure that the diffraction grating holder is level in all directions. To do this, you will have to check the horizontal direction by placing the level on the top of the two posts of the grating holder, and in the vertical direction by placing the level vertically with the long end braced against the wide side of one post. (This is difficult because of the other hardware in the way; do the best you can.)

4. Rotate the *telescope* so that it points at a far wall with no obstruction (i.e. does not look at the slit.) While looking at this distant object, focus the telescope.

5. With the grating removed from the holder, align the telescope with the collimator/slit component as shown in *Figure 14.*2. Adjust the slit so that you only see a narrow slit of light through the telescope. **DO NOT REFOCUS THE TELESCOPE!** The image of

the slit will probably look fuzzy, so to bring the image into focus adjust the *collimator focus knob only*.

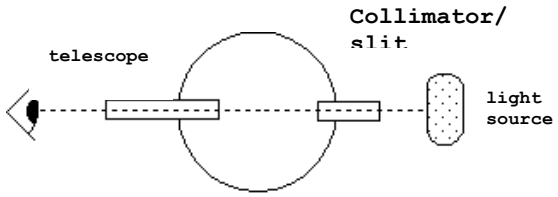

Figure 14. 2

6. After the lamp has had sufficient time to warp up, place it at the end of the collimator and adjust the slit size so as to provide a sharp line in the eyepiece. As you look through the telescope, you will notice there is a set of cross-hairs in the eyepiece. Align the vertical line of the cross hair so that it is in the middle of the slit.

7. Without moving the telescope. You should now rotate the turntable so the vernier scale tells you the telescope is lined up at 90º. (You may find it convenient to lock down the "vernier fixing screw" and make fine adjustments with the "vernier fine adjustment screw".) To understand how sensitive the vernier scale is, while looking in the telescope, turn the telescope's fine adjustment screw and notice how far the crosshairs traverse. Now look at the vernier scale and notice how many arc seconds the telescope has moved in relation the image of the slit. Notice not only the sensitivity in the movement of the telescope but how well you are able to measure its rotation. When you are done, be sure to re-center the cross-hairs on the slit.

8. Record the angle displayed in the window. This angle is your *initial zero angle*. There are windows on either side of the turntable, so be sure to use the same window throughout the whole lab. To learn how to read the vernier scales see Appendix 2 of this lab. Consult your TA or TI if you have *any* questions! It is very important to know how to read this scale properly so as not to make a mistake

Determining Grating Orientation

1. Be careful handling the grating! The emulsion is very fragile. Always handle the grating by the sides and be careful not to scratch off the emulsion when placing the grating in the holder.

2. Before we set the grating, we need to check that the orientation of the grating is perpendicular to the platform, i.e. that the etched lines are oriented vertically. To check your grating's orientation, use the supplied laser point in the lab kit and shine the laser through the grating and ***towards the wall*!** You will see the zeroth-order beam directly in front of you. When you have your grating perpendicular to the platform the ± 1st order beams will be to the left and right of the zeroth-order beam. If your 1st order lines are

above and below your zeroth-order beam, then you need to rotate your grating 90 degrees. If you have *any* questions ask your TA or TI for assistance for this is a crucial step!

3. Place the grating back into the grating holder with the emulsion side of the grating facing the Na lamp and the grating lines perpendicular to the platform. Record the number of lines/mm of your grating in *Section 4*.

Aligning the Grating

1. With the grating fixed in place, rotate the telescope exactly 90º as shown in *Figure 14.3*. As a result of this rotation, the vernier scale should now read 0º. To check this, fix the telescope in place with the telescope fixing screw and use the fine tuning screw to adjust the telescope more accurately (see Appendix 1).

2. As shown in *Figure 14.3*, rotate the grating until the slit image of the sodium light source is centered on the crosshairs (the zero order ray, i.e. the reflection of the light source itself, not a spectral line). The incident angle of the light is now certain to be 45º. If you do not see the image of the light source you may not have properly aligned your grating stage. You may see multiple images of the light source through the slit due to reflections within the grating; the brightest one in the one you should use for your alignment.

3. Fix the grating in place and make sure that the crosshairs stay centered on the light. It is *very* important the grating does not move from this position. Be careful!

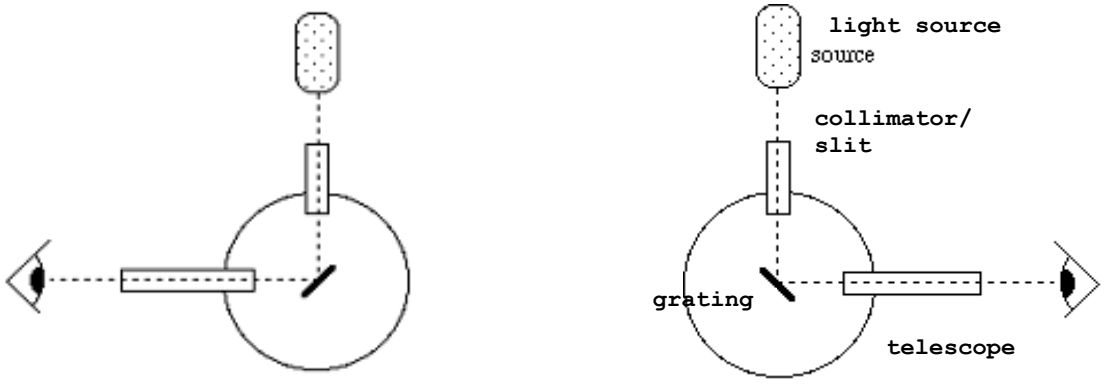

Figure 14. 3: The grating alignment setup. Depending on which venier window you read from when you set the telescope to zero degrees, you will have one or the other of these configurations.

4. Turn the *telescope* back 90º to its original position as in *Figure 14.2*. Rotate the *platform* 135º, so that the light from the source is normal to the grating with the emulsion side of the grating facing the telescope portion of the spectrometer. The crosshairs should be

centered on the slit. Record the *final zero angle*, if different. You will be using this final zero angle in all subsequent measurements with the spectrometer, as you will be subtracting it from your measured values of angle for all spectral lines.

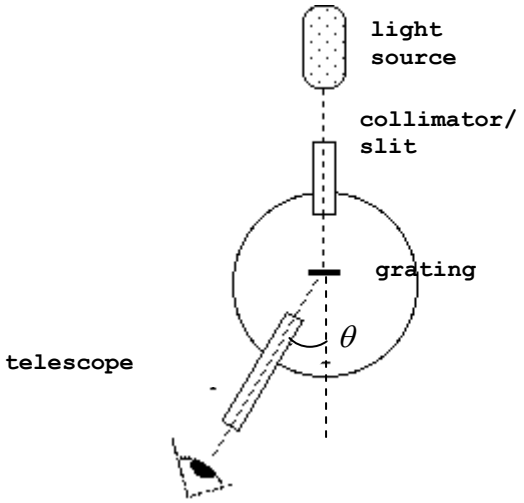

Figure 14. 4

3.2 Spectrometer Calibration

Light passing through a diffraction grating is dispersed into distinct directions, θ, given by,

$$d \sin\theta = k\lambda \qquad \textbf{Equation 14.4}$$

where *d* is the separation between the lines on the grating, *k* is an integer and referred to as the *order* of the spectral line, λ is the wavelength of light, and the angle, θ, is measured from the normal to the grating as in *Figure 14.4*. In this part of the experiment you will determine your grating separation by measuring the angle at which the sodium D spectral lines appear. The sodium D lines are a pair of yellow spectral lines, a "doublet", that have wavelengths of 589.0nm and 589.6nm. You should be able to resolve the doublet, and thus measure a distinct angle for each spectral line.

Procedure

1. Start with the telescope set to the *final zero angle* position. Move the telescope to the left until you come across the first pair of yellow lines. This angle will be the first order

spectrum value (k = 1). Record the angles of the two lines in the doublet in *Table 14.2.* (If you are having difficulty resolving the doublet, it might be because your light source is too close to the slit giving lines that are too bright. Try moving the lamp further from the slit.)

2. Now measure the first order position(s) in the opposite direction (the right side). Record this angle(s) in *Table 14.2.* You should now be able to determine the grating spacing of your particular grating, using *Equation 14.4* and the average first order angle(s) of the sodium line(s). You do not need to measure the second order lines (k = 2).
3. In filling out *Table 14.2*, the *Measured Angle* is the number read from the vernier scale, the *Difference Angle* is the positive angle difference of the *final zero angle* and the *Measured Angle*, and the *Average Angle* is the average of the two *Difference Angles*. *Average Angle* is the value you use to calculate the grating separation according to *Equation 14.4.*

3.3 Balmer Series

Now you should be able to accurately measure the Balmer series for atomic hydrogen. You should be able to measure the first and second order for three Balmer lines: a violet line, an indigo line, and a red line. See *Figure 14.5* for a picture of the relationship between first (k = 1) and second (k = 2) orders.

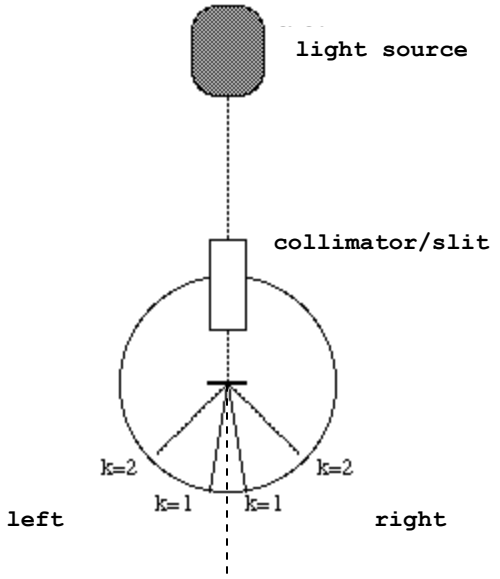

Figure 14. 5

Procedure

1. Replace the sodium lamp with the hydrogen lamp. Make sure that the center of the hydrogen bulb aligns well with the spectrometer slit. This will maximize the intensity of the spectral lines. You will need to protect your line of sight from all stray light to clearly see and measure the violet lines. It may be helpful to carefully drape black cloth around your hydrogen lamp or over your spectrometer to prevent any unneeded light from entering the spectrometer or from interfering with your ability to view the spectrum.

2. Record the angles at which each spectral line appears. You should measure both first and second orders on both the left and right sides of the zero angle of the red, violet and indigo lines, for a total of 12 measurements. Record your data in *Table 14.3*

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Setup Materials Confirmation: TA/TI Signature _____
(Return all lab materials to original state to match image reference before Post-Lab will be accepted)

EXPERIMENT 14

The Atomic Spectrum of Hydrogen

4. Post-Laboratory Work [20 pts]

4.1 Alignment & Calibration [6pts]

Initial Zero Angle: _____ Final Zero Angle: Grating: _____

_____ **Table 14.2** (3pts)

Spectral Line	Measured Angle	Difference Angle	Wavelength (nm)	Order, k	Grating Separation, *d* (nm)	$\bar{d}$ (*nm*)
Left, Line 1						
Right, Line 1						
Left, Line 2						
Right, Line 2						

1. Show an example calculation of how you determined the grating spacing, *d*, using data from *Table 14.2*. Calculate an average value for *d*. (1pt)

2. Calculate the uncertainty in grating separation, Δd, using the standard deviation of your two (or four) values for *d*. Hopefully you were able to resolve four! (2pts)

4.2 Balmer Series [14pts]

Table 14.3 (3pts)

Spectral Line	Order	Measured Angle	Difference Angle	Average Angle	k	Wavelength (nm)	**Average Wavelength (nm)**
Red, Right	First						
Red, Left	First						
Red, Right	Second						
Red, Left	Second						
Violet, Right	First						
Violet, Left	First						
Violet, Right	Second						
Violet, Left	Second						
Indigo, Right	First						
Indigo, Left	First						
Indigo, Right	Second						
Indigo, Left	Second						

3. Show the calculation for how you found the wavelength of the *first* order *violet* line. (1pt)

4. Show the calculation for how you found the wavelength of the *second* order *red* line. (1pt)

5. Calculate the uncertainty in wavelength, $\Delta\lambda$, for the *first* order *indigo* line using error propagation. Use the uncertainty in grating separation that you determined in Question #2 and estimate a value for the uncertainty in angle, $\Delta\theta$, which you must convert to radians. Use the *Average Angle* in computing the tangent. Use this value of $\Delta\lambda$ later for the red and violet lines. In this case, the equation for propagation is, (2pts)

$$\left(\frac{\Delta\lambda}{\lambda}\right)^2 = \left(\frac{\Delta d}{d}\right)^2 + \left(\frac{\Delta\theta}{\tan\theta}\right)^2 \qquad \textbf{Equation 14.5}$$

6. Show the calculation for the theoretical Balmer wavelength for n = 3 using *Table 14.1* and *Equation 14.2*. (1pt)

7. Show the calculation for the theoretical Balmer wavelength for n = 4. (1pt)

8. Show the calculation for the theoretical Balmer wavelength for n = 5. (1pt)

9. Are the theoretical Balmer wavelengths consistent with your measured wavelengths (and uncertainties)? Why or why not? (2pts)

10. Ordinary hydrogen has a nucleus consisting of one proton. However, naturally occurring hydrogen contains a small amount of *deuterium*, hydrogen having a nucleus consisting of one proton and one neutron. If deuterium existed in sufficient quantity in your source to produce observable spectral lines, would you expect to resolve its lines from those of ordinary hydrogen with our equipment? Let the neutron mass be equal to the proton mass, and let the proton mass be about 1840 times greater than the electron mass.(2pts)

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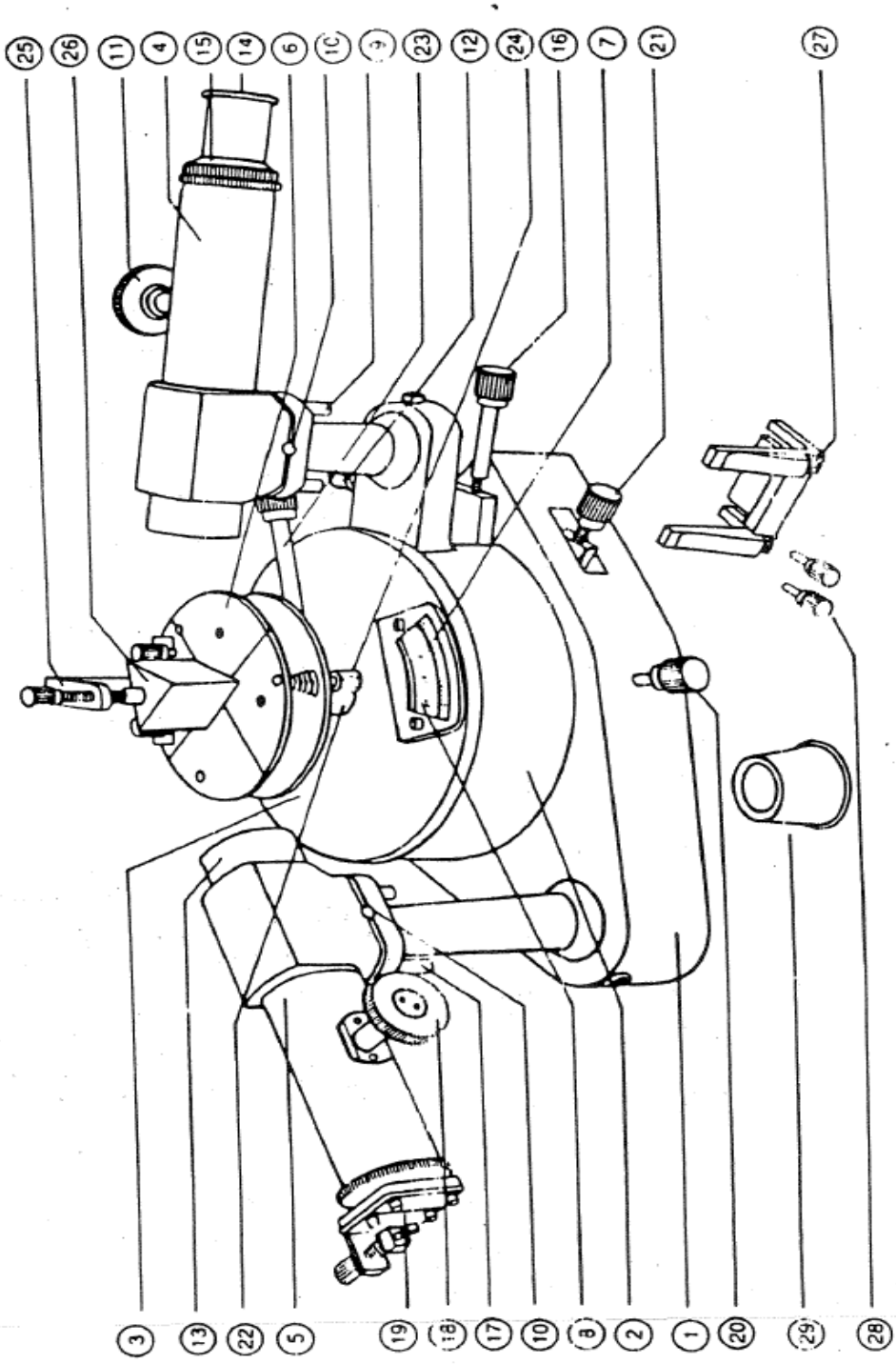
Appendix 1



1. Spectrometer Base
2. Turn Table
3. Turn Table Cover
4. Telescope
5. Collimator
6. Prism Table
7. Circular Main Scale
8. Vernier Scale
9. Telescope Levelling Screws
10. Horizontal Pin
11. Telescope Focussing Knob
12. Telescope Fine Adjustment Screw
13. Converging Lens
14. Ramsden Eye Piece
15. Crosswire Assembly
16. Telescope Fixing Screw
17. Collimator Levelling Screw
18. Collimator Focussing Knob
19. Slit
20. Vernier Fine Adjustment Screw
21. Vernier Fixing Screw
22. Receptacle
23. Prism Table Fixing Screw
24. Prism Table Levelling Screw
25. Prism Holder
26. Prism (supplied separately)
27. Diffraction Grating Holder
28. Screws for Diffraction Grating Holder
29. Hand Magnifier

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Appendix 2

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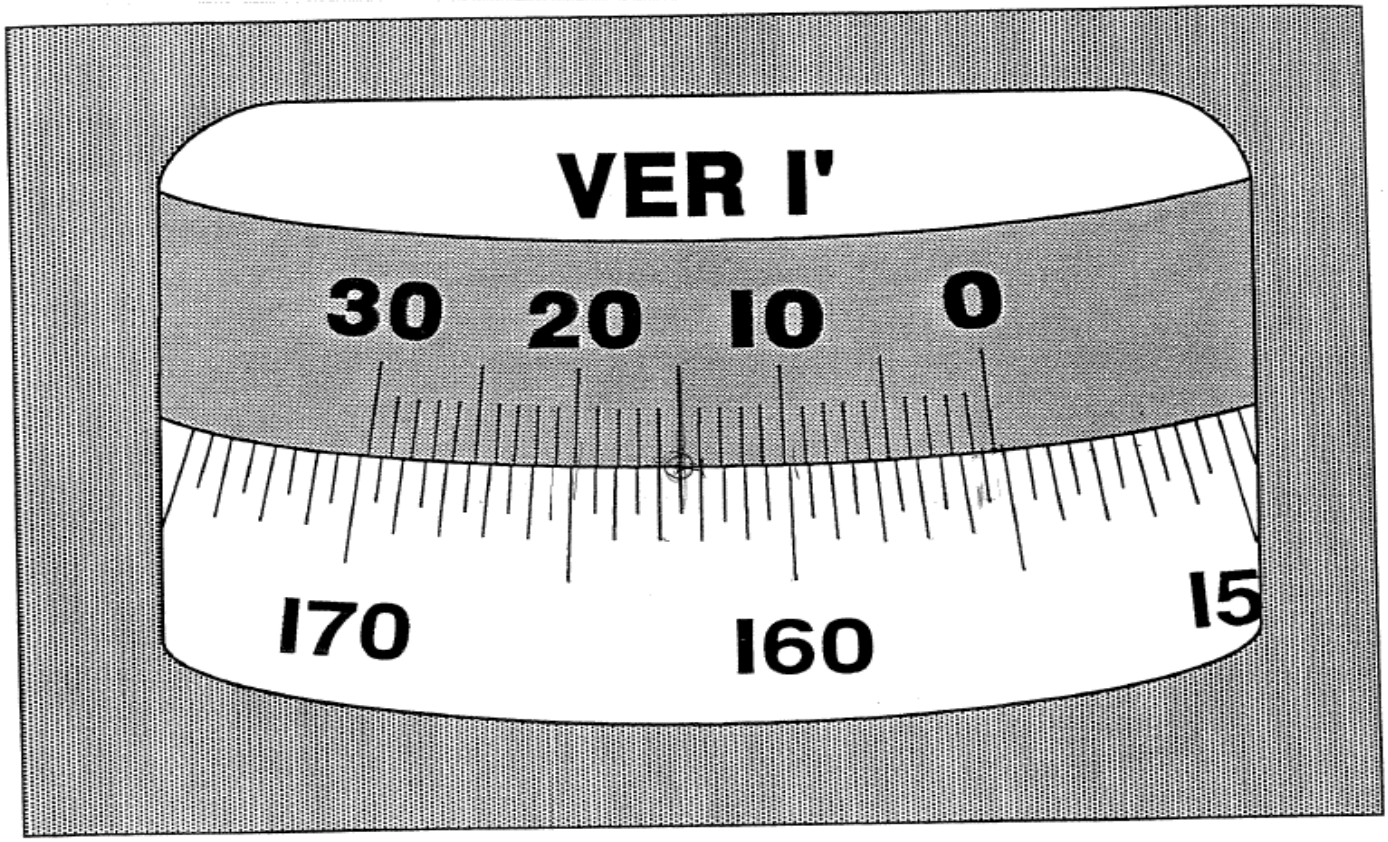
Reading the Vernier Scales



The relative rotational positions of the telescope base and the table base are measured using the vernier scales.

First, find where the zero point of the vernier scale aligns with the degree plate and record the value. If the zero point is between two lines, use the smaller value. (In the above photograph, the zero point on the vernier scale is between the 155 ° and 155 ° 30' marks on the degree plate, so the recorded value is 155 °.)

Now use the magnifying glass to find the line on the vernier scale that aligns most closely with any line on the degree scale. (In the picture, this is the line corresponding to a measurement of 15 minutes of arc.) Add this value to the reading recorded above to get the correct measurement to within 1 minute of arc (that is, 155 ° + 15' = 155 ° 15').

Important: Notice that the vernier scale measures only the relative positions of the table and telescope rotating bases. When using the scales to measure angles of diffraction, first align the vertical cross-hair of the graticule with the fixed edge of the slit image for the undeflected beam. Then read the vernier scale. This is the zero point reading. All successive measurements (measured with the cross-hair on the fixed edge of the diffracted slit images) are meaningful only with respect to that zero point. If the table base is rotated, the zero point changes.

155°15'

166 + 12/60

PASCO scientific

TA or TI Signature _____ 14 of 14

Equipment Setup

Leveling the Spectrometer

For accurate results, the diffracting element must be properly aligned with the optical axes of the telescope and collimator. This requires that both the spectrometer and the spectrometer table be level.

1. Place the spectrometer on a flat surface. If necessary use paper or 3 X 5 cards to shim beneath the wood base until the fixed-base of the spectrometer is level.
2. Level the spectrometer table by adjusting the three thumbscrews on the underside of the table.

Focusing the Spectrometer

1. While looking through the telescope, slide the eyepiece in and out until the cross-hairs come into sharp focus. Loosen the graticule lock ring, and rotate the graticule until one of the cross-hairs is vertical. Retighten the lock ring and then refocus if necessary.
2. Focus the telescope at infinity. This is best accomplished by focusing on a distant object (e.g.; out the window).
3. Check that the collimator slit is partially open (use the slit width adjust screw).
4. Align the telescope directly opposite the collimator as shown in Figure 3.

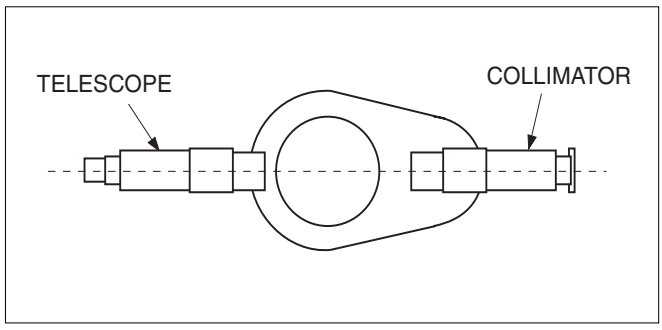


Figure 3 Align the Telescope directly opposite the Collimator

5. Looking through the telescope, adjust the focus of the collimator and, if necessary, the rotation of the telescope until the slit comes into sharp focus. ***Do not change the focus of the telescope.***
6. Tighten the telescope rotation lock-screw, then use the fine adjust knob to align the vertical line of the graticule with the fixed edge of the slit. If the slit is not vertical, loosen the slit lock ring, realign the slit, and retighten the lock ring. Adjust the slit width for a clear, bright image. Measurements of the diffraction angle are always made with the graticule line aligned along the fixed edge of the slit, so a very narrow slit is not necessarily advantageous.

NOTE: When the telescope and collimator are properly aligned and focused, the slit should be sharply focused in the center of the field of view of the telescope, and one cross-hair should be perpendicular and aligned with the fixed edge of the slit. If proper alignment cannot be achieved with the adjustments just described, you will need to realign the spectrometer as follows.

Realigning the Spectrometer

Under normal circumstances, the spectrometer will maintain its alignment indefinitely. However, if the spectrometer can not be properly focused, as described above, it may be necessary to adjust the optical axes of the collimator and telescope, as follows:

1. The telescope and collimator pivot about a fulcrum on their respective mounting pillars (See Fig 4). Use the aluminum rod provided with the accessory equipment to adjust the leveling screws. Loosen one as the other is tightened until the unit is level and secure.

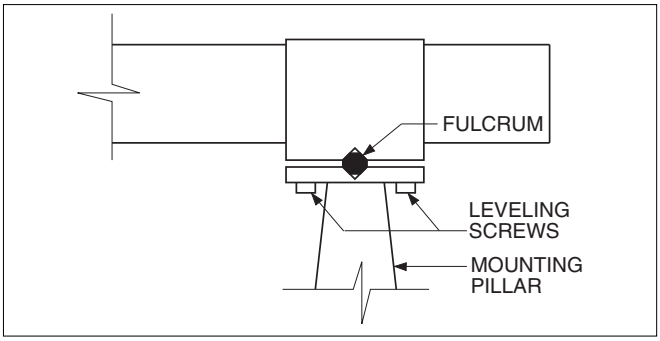


Figure 4 Leveling the Telescope and Collimator

2. The mounting pillars of the telescope and collimator can be rotated by using an Allen wrench to loosen the screws that attach the pillars to their respective bases. To loosen the screw for the collimator, the spectrometer must be removed from the wood base.

3. To be sure both optical units are square to the axis of rotation, follow the focusing procedure described above, adjusting the mounting pillars as necessary so the slit image is well centered in the viewing field of the telescope.

Measuring Angles of Diffraction

When analyzing a light source, angles of diffraction are measured using the vernier scales. However, the scales only measure the relative rotational positions of the telescope and the spectrometer table base. Therefore, before making a measurement, it's important to establish a vernier reading for the undeflected beam. All angles of diffraction are then made with respect to that initial reading (see Fig 5).

To obtain a vernier reading for the undeflected beam, first align the vertical cross-hair with the fixed edge of the slit image for the undeflected beam. Then read the vernier scale. This is the zero point reading (θ_0).

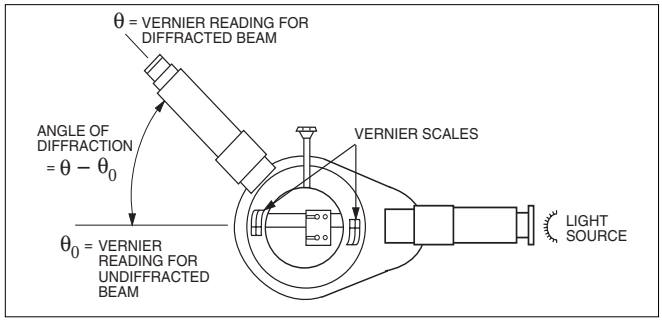


Figure 5 Measuring an Angle of Diffraction

Now rotate the telescope to align the vertical cross-hair with the fixed edge of a deflected image. Read the vernier scale again. If this second reading is θ, then the actual angle of diffraction is $\theta - \theta_0$. If the table base is rotated for some reason, the zero point changes, and must be remeasured.

Reading the Vernier Scales

To read the angle, first find where the zero point of the vernier scale aligns with the degree plate and record the value. If the zero point is between two lines, use the smaller value. In Figure 6, below, the zero point on the vernier scale is between the 155 ° and 155 ° 30' marks on the degree plate, so the recorded value is 155 °.

Now use the magnifying glass to find the line on the vernier scale that aligns most closely with any line on the degree scale. In the figure, this is the line corresponding to a measurement of 15 minutes of arc. Add this value to the reading recorded above to get the correct measurement to within 1 minute of arc: that is, 155 ° + 15' = 155 ° 15'.

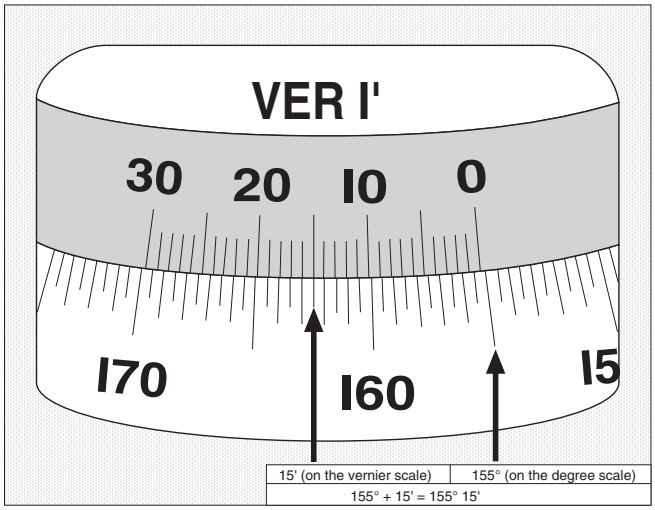


Figure 6 Reading the Vernier Scales

Using the Diffraction Grating

IMPORTANT: The Diffraction Grating is a delicate component. Be careful not to scratch the surface and always replace it in the protective foam wrapping when it is not being used.

Aligning the Grating

To accurately calculate wavelengths on the basis of diffraction angles, the grating must be perpendicular to the beam of light from the collimator.

1. Align and focus the spectrometer as described earlier. The telescope must be directly opposite the collimator with the slit in sharp focus and aligned with the vertical cross-hair.

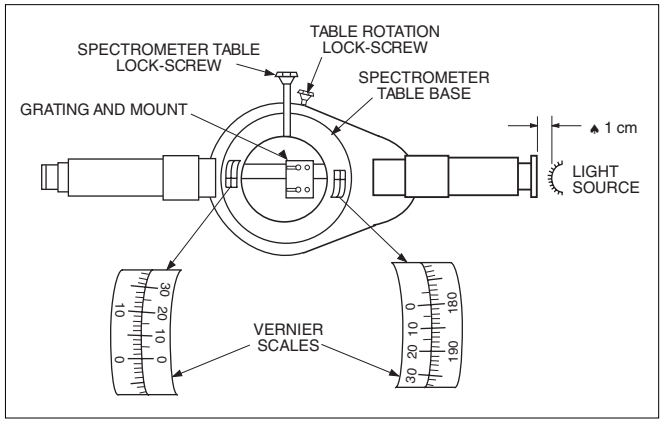


Figure 7

Perform steps 2-5 with reference to Figure 7.

2. Loosen the spectrometer table lock-screw. Align the engraved line on the spectrometer table so that it is, as nearly as possible, colinear with the optical axes of the telescope and the collimator. Tighten the lock-screw.
3. Using the thumbscrews, attach the grating mount so it is perpendicular to the engraved lines.
4. Insert the diffraction grating into the clips of the mount. To check the orientation of the grating, look through the grating at a light source and notice how the grating disperses the light into its various color components. When placed in the grating mount, the grating should spread the colors of the incident light horizontally, so rotation of the telescope will allow you to see the different colored images of the slit.
5. Place a light source (preferably one with a discrete spectrum, such as a mercury or sodium lamp) approximately one centimeter from the slit. Adjust the slit width so the slit image is bright and sharp. If necessary, adjust the height of the spectrometer table so the slit image is centered in the field of view of the telescope.

IMPORTANT: Stray light can obscure the images. Use the spectrometer in a semi-darkened room or drape a sheet of opaque material over the spectrometer.

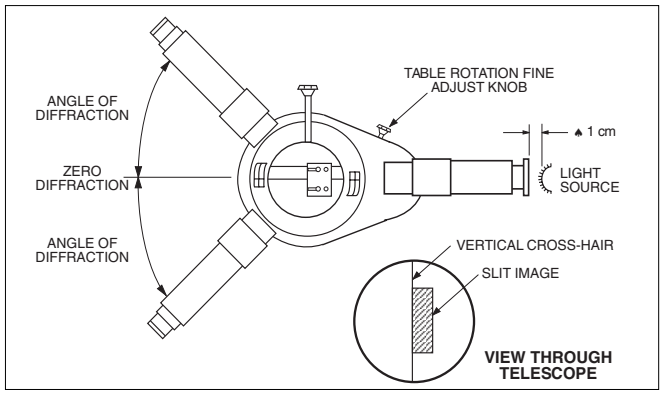


Figure 8

Perform steps 6-9 with reference to Figure 8.

6. Rotate the telescope to find a bright slit image. Align the vertical cross-hair with the fixed edge of the image and carefully measure the angle of diffraction. (See the previous section, *Measuring Angles of Diffraction*.)
7. The diffraction grating diffracts the incident light into identical spectra on either side of the line of the undiffracted beam. Rotate the telescope back, past the zero diffraction angle, to find the corresponding slit image. Measure the angle of diffraction for this image.
8. If the grating is perfectly aligned, the diffraction angles for corresponding slit images will be identical. If not, use the table rotation fine adjust knob to compensate for the difference (i.e.; to align the grating perpendicular to the collimator beam so the two angles will be equal).

9. Repeat steps 6-8 until the angles for the corresponding slit images are the same to within one minute of arc.

Making the Reading

Once the grating is aligned, do not rotate the rotating table or its base again. Diffraction angles are measured as described in the previous section, *Measuring Angles of Diffraction*. (Since the vernier scales were moved when the spectrometer table was adjusted, the point of zero diffraction must be remeasured).

Wavelengths are determined according to the formula:

$$\lambda = \frac{a \sin \theta}{n}$$

where λ is the wavelength; a is the distance between lines on the diffraction grating

($a = 1.66 \times 10^{-3}$ mm for the 600 line/mm grating;

θ is the angle of diffraction; and n is the order of the diffraction spectrum under observation.

Using the Prism

Advantages and Disadvantages

A prism can also be used as the diffracting element in a spectrometer since the index of refraction of the prism (and therefore the angle of refraction of the light) varies slightly depending on the wavelength of the light.

A prism refracts the light into a single spectrum, whereas the grating divides the available light into several spectra. Because of this, slit images formed using a prism are generally brighter than those formed using a grating. Spectral lines that are too dim to be seen with a grating can often be seen using a prism.

Unfortunately, the increased brightness of the spectral lines is offset by a decreased resolution, since the prism doesn't separate the different lines as effectively as the grating. However, the brighter lines allow a narrow slit width to be used, which partially compensates for the reduced resolution.

With a prism, the angle of refraction is not directly proportional to the wavelength of the light. Therefore, to measure wavelengths using a prism, a graph of wavelength versus angle of refraction must be constructed using a light source with a known spectrum. The wavelength of unknown spectral lines can then be interpolated from the graph.

Once a calibration graph is created for the prism, future wavelength determinations are valid only if they are made with the prism aligned precisely as it was when the graph was produced. To ensure that this alignment can be reproduced, all measurements are made with the prism aligned so that the light is refracted at the angle of minimum deviation.

The Angle of Minimum Deviation

The angle of deviation for light traversing a prism is shown in Figure 9. For a given wavelength of light traversing a given prism, there is a characteristic angle of incidence for which the angle of deviation is a minimum. This angle depends only on the index of refraction of the prism and the angle (labeled A in Figure 8) between the two sides of the prism traversed by the light. The relationship between these variables is given by the equation:

$$n = \frac{\sin\left\{\frac{A+D}{2}\right\}}{\sin\frac{A}{2}}$$

where **n** is the index of refraction of the prism; A is the angle between the sides of the prism traversed by the light; and D is the angle of minimum deviation. Since **n** varies with wavelength, the angle of minimum deviation also varies, but it is constant for any particular wavelength.

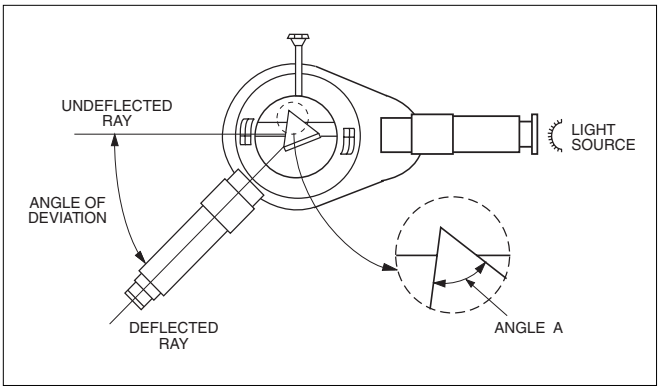


Figure 9 Angle of Deviation

To Measure the Angle of Minimum Deviation:

1. Align and focus the spectrometer as described earlier.
2. Use the two thumbscrews to attach the prism clamp to the spectrometer table and clamp the prism in place as shown in Figure 10.
3. Place the light source a few centimeters behind the slit of the collimator. (It may be helpful to partially darken the room, but when using the prism this is often not necessary.)

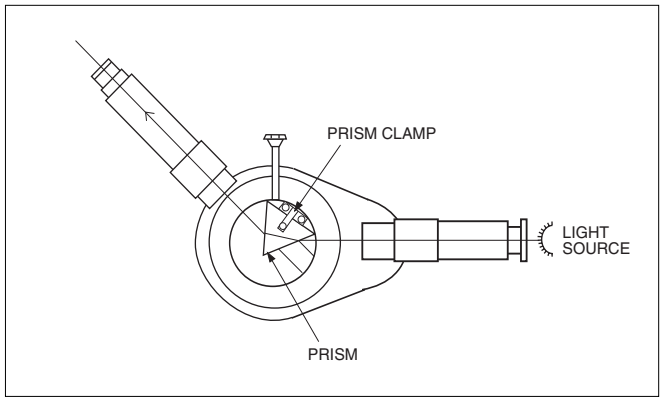


Figure 10 Mounting the Prism

4. With the prism, it is generally possible to see the refracted light with the naked eye. Locate the general direction to which the light is refracted, then align the telescope and spectrometer table base so the slit image can be viewed through the telescope.
5. While looking through the telescope, rotate the spectrometer table slightly back and forth. Notice that the angle of refraction for the spectral line under observation changes. Rotate the spectrometer table until this angle is a minimum, then rotate the telescope to align the vertical cross-hair with the fixed edge of the slit image. Use the fine adjust knobs to make these adjustments as precisely as possible, then measure the telescope angle using the vernier scale.
6. Without changing the rotation of the spectrometer table, remove the prism and rotate the telescope to align the cross-hair with the fixed edge of the undiffracted beam. Measure the angle on the vernier scale. The difference between this angle and that recorded for the diffracted spectral line in step 5, is the angle of minimum deviation. Notice that, since the determination of the angle of minimum deviation for each spectral line requires rotational adjustments of the spectrometer table, the angle of the undeflected beam must be remeasured for each line.