

## 11. Diffraction Grating Spectroscopy

### A. Objectives

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- Measure the wavelength of the sodium D2 line with a diffraction grating spectrometer using first-order normal incidence and second-order normal incidence.
- Measure the wavelengths of the sodium D1 and D2 lines with a diffraction grating spectrometer using the method of minimum deviation.
- Observe the spectrum of a gas in a "mystery discharge lamp." Identify the gas in the lamp from its spectrum. Measure the wavelength of one of the spectral lines of that gas.

### B. Equipment required

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1. Diffraction grating spectrometer and matching lamp platform
2. Transmission diffraction grating
3. Black cloth
4. Lighted magnifier
5. Protractor
6. Low pressure sodium lamp
7. Mystery gas discharge lamp
8. Tables of spectral lines for a number of gaseous elements

### C. Introduction

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#### 1. Review of diffraction gratings

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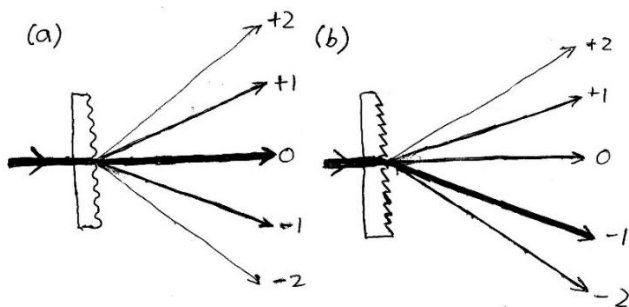


Figure 11.1. Transmission diffraction gratings. Thicker lines in the figure indicate more intense beams. (a) Transmission holographic grating. These gratings typically have a sinusoidal groove profile as shown here. (b) Transmission grating with a sawtooth groove profile. This grating is blazed to maximize the power in a first-order diffracted beam.

In the previous lab, you measured the diffraction pattern of a transmission diffraction grating, as illustrated in Figure 11.1. If an input beam of wavelength  $\lambda$  is incident on the grating at normal incidence, the diffracted beams emerge from the grating at angles  $\theta$  to the normal, where

$$d \sin \theta = m\lambda \quad (11.1)$$

and where  $d$  is the spacing between the grooves, and  $m = 0, \pm 1, \pm 2, \dots$  is the *order number*. The peak at  $\theta = 0$  is the *zeroth order peak*. The first ones to either side are the *first order diffraction peaks*. Sometimes we distinguish between these two orders as the "+1 order" and the "-1 order". Similarly, the next two peaks to either side are the *second order diffraction peaks*, the next two the *third order diffraction peaks*, and so on.

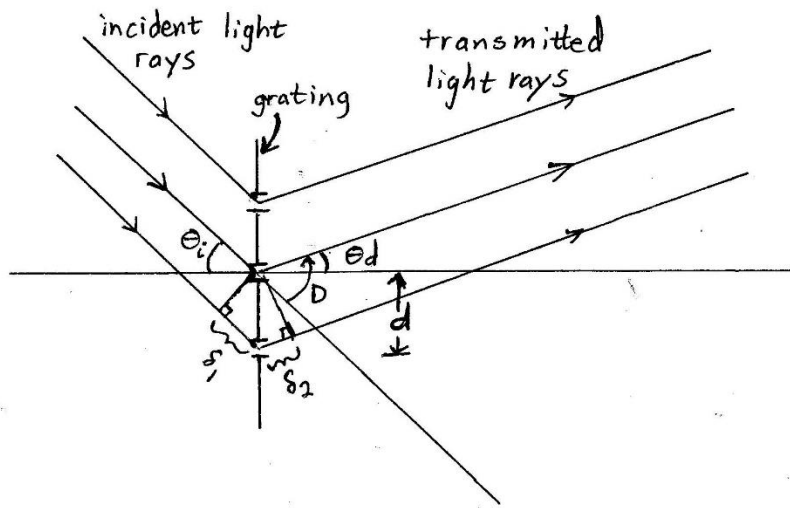


Figure 11.2. Diffraction grating used at non-normal incidence.

We can also use a grating with the incident light striking the grating at an angle to the normal  $\theta_i$ , as illustrated in Figure 11.2. In this case the diffracted beams emerge at angles  $\theta_d$  to the grating normal, where

$$d \sin \theta_i + d \sin \theta_d = m\lambda \quad (11.2)$$

Equation (11.2) is called the *grating equation*.

## The diffraction grating spectrometer

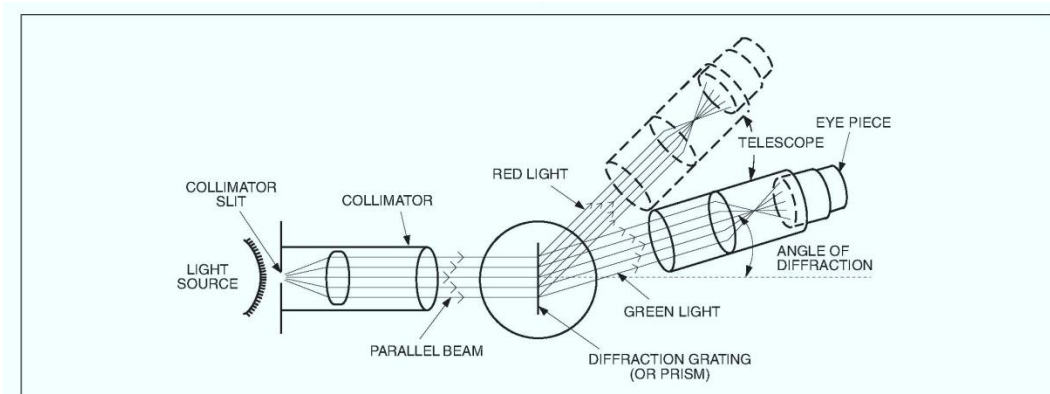


Figure 11.3. Diffraction grating spectrometer. Reproduced from the Pasco Spectrometer manual.

The *diffraction grating spectrometer*, shown in Figure 11.3, is one of the most important tools in science. It is used to measure the wavelengths of light that are contained in a light source. As shown in the figure, the light source is placed close to a collimator slit. Light emerging from the slit is collimated into a beam of parallel rays by a lens and directed onto a transmission diffraction grating. Light will then be diffracted through an angle given by the grating equation (11.2). This light is collected by a telescope on a rotating platform. If the light source contains only one wavelength, the objective lens of the telescope produces an image of the slit, which can be seen through the eyepiece. The telescope contains cross-hairs that can be used to precisely locate the slit image, or "line". The spectrometer also has a scale that reads out the angle through which the telescope has been rotated. This allows the angle of diffraction to be precisely measured, from which you can precisely determine the wavelength. If the light source contains multiple wavelengths, multiple images of the slit will be observed at different angles. A measurement of all the wavelengths in the beam determines the *spectrum* (intensity vs. wavelength) of the light source. In the spectrometer, the lenses serve the function of producing parallel light rays, so that the source and observation point can be placed relatively close to the grating.

### Discharge lamps and atomic and molecular spectra

A discharge lamp is a device in which an electrical current is passed through gas contained in a glass tube. Free electrons are accelerated by the electric field inside the tube, and collide with atoms or molecules in the gas. These collisions produce excitations of the atoms or molecules, which cause them to emit light. The electron impact can also ionize the atoms or molecules (remove an electron), and such ions can also emit light. Furthermore, the electron impacts can break apart molecules into their constituent atoms.

When the light from a discharge tube is analyzed by a diffraction grating spectrometer, it is found that the atoms or molecules do not emit light at all wavelengths. Instead, they only emit at

a discrete set of very specific wavelengths. The resulting spectra are called *line spectra*, because they appear as a set of lines in a diffraction grating spectrometer. You will learn in future courses that the line spectra occur because of quantization of the energies of atoms or molecules. It turns out that these line spectra provide information that allows you to deduce the quantum mechanical structure of the atom or molecule. Once the spectrum of a given gas has been accurately determined, the wavelengths of its spectral lines are listed in tables like the one shown in Figure 11.4.

Molecular spectra have many more lines (due to the more complex structure of the molecule) and tend to be dimmer than atomic spectra (due to the division of the emission intensity between so many lines). Of course, a discharge tube containing only an atomic gas like helium will emit only an atomic spectrum. But a discharge tube containing a molecular gas like hydrogen ( $\text{H}_2$ ) may also have a spectrum with bright atomic lines. That is because the molecules can be dissociated into atoms by electron impact, and the lines from those atoms are relatively bright.

Note that the word "line" is used in two different ways in this context. It may refer to a spectral line as discussed above, or it may refer to a groove of the diffraction grating.

Tables of atomic line spectra are widely used in science. For example, Figure 11.4 shows a table for atomic argon. The first column in the table gives a semi-quantitative measure of the relative intensity of the lines. You can be pretty sure that a line listed as having an intensity of 1100 will be much brighter in the spectrometer than one listed as having an intensity of 150, as long as it is in the visible part of the spectrum. However you cannot expect that the ratio of intensities will be exactly 1100/150. That is because the relative brightness of lines depends on the details of the specific discharge tube such as its gas pressure, current, tube voltage, *etc.* The second column gives the wavelength of each line in units of Angstroms ( $\text{\AA}$ ).  $1 \text{ \AA} = 10^{-10} \text{ m}$ . When you view spectrometer lines by eye, you can of course only see lines in the visible part of the spectrum, which extends from about 4000  $\text{\AA}$  (deep violet) to about 7000  $\text{\AA}$  (deep red). So, for this lab you can ignore the parts of the tables for wavelengths outside this range. The third line of the table gives a Roman numeral that tells you whether that line comes from the neutral atom or one of its ions. The numeral I indicates that the line is from the neutral atom (*e.g.* Ar). The numeral II indicates that it is from the singly ionized atom (*e.g.*  $\text{Ar}^+$ ). The numeral III indicates that it is from the doubly ionized atom (with two electrons missing, *e.g.*  $\text{Ar}^{++}$ ), and so on. The tables for the neutral atom (I) and the singly ionized atom (II) are often given together, like the one in Figure 11.4. The reason is that spectra are often observed in gas discharges, and such discharges often have significant contributions from both neutral and singly ionized atoms.

ARGON (Ar)								
Z = 18								
Ar I and II								
Ref. 190, 203, 204, 219, — E.F.W.								
Intensity	Wavelength							
Vacuum								
30	487.227	II	50	3582.355	II	300	4735.906	II
50	490.650	II	70	3588.441	II	800	4764.865	II
30	490.701	II	7	3606.522	I	550	4806.020	II
30	519.327	II	25	3622.138	II	150	4847.810	II
30	542.912	II	20	3639.833	II	50	4865.910	II
200	543.203	II	35	3718.206	II	800	4879.864	II
70	547.461	II	70	3729.309	II	70	4889.042	II
70	556.817	II	50	3737.889	II	20	4904.752	II
70	573.362	II	150	3765.270	II	35	4933.209	II
30	576.736	II	50	3766.119	II	200	4965.080	II
70	580.263	II	20	3770.369	I	50	5009.334	II
30	583.437	II	20	3770.520	II	70	5017.163	II
70	597.700	II	25	3780.840	II	70	5062.037	II
30	602.858	II	25	3803.172	II	20	5090.495	II
30	612.372	II	50	3809.456	I	100	5141.783	II
500	661.867	II	7	3834.679	I	70	5145.308	II
30	664.562	II	70	3850.581	II	5	5151.391	I
200	666.011	II	35	3868.528	II	15	5162.285	I
1000	670.946	II	35	3925.719	II	25	5165.773	II
3000	671.851	II	50	3928.623	II	20	5187.746	I
70	676.242	II	25	3932.547	II	20	5216.814	II
30	677.952	II	70	3946.097	II	7	5221.271	I
30	679.218	II	7	3947.505	I	5	5421.352	I
200	679.401	II	35	3948.979	I	10	5451.652	I
200	718.090	II	20	3979.356	II	25	5495.874	I
3000	723.361	II	35	3994.792	II	5	5506.113	I
500	725.548	II	50	4013.857	II	25	5558.702	I
70	730.930	II	50	4033.809	II	10	5572.541	I
200	740.269	II	20	4035.460	II	35	5606.733	I
200	744.925	II	150	4042.894	II	20	5650.704	I
70	745.322	II	50	4044.418	I	10	5739.520	I
20	802.859	I	100	4052.921	II	5	5834.263	I
100	806.471	I	200	4072.005	II	10	5860.310	I
60	806.869	I	70	4072.385	II	15	5882.624	I
30	807.218	I	25	4076.628	II	25	5888.584	I
40	807.653	I	35	4079.574	II	50	5912.085	I
50	809.927	I	25	4082.387	II	15	5928.813	I
120	816.232	I	150	4103.912	II	5	5942.669	I
70	816.464	I	300	4131.724	II	7	5987.302	I
80	820.124	I	35	4156.086	I	5	5998.999	I
120	825.346	I	400	4158.590	I	5	6025.150	I
120	826.365	I	50	4164.180	I	70	6032.127	I
150	834.392	I	35	4179.297	II	35	6043.223	I
100	835.002	I	50	4181.884	I	10	6059.372	I
100	842.805	I	100	4190.713	I	20	6059.372	I
180	866.800	I	50	4191.029	I	7	6098.803	I
150	869.754	I	200	4198.317	I	10	6105.635	I
180	876.058	I	400	4200.674	I	100	6114.923	II
180	879.947	I	25	4218.665	II	10	6145.441	I
150	894.310	I	25	4222.637	II	7	6170.174	I
1000	919.781	II	25	4226.988	II	150	6172.278	II
1000	932.054	II	100	4228.158	II	10	6173.096	I
1000	1048.220	II	100	4237.220	II	10	6212.503	I
500	1066.660	I	25	4251.185	I	5	6215.938	I
Air			200	4259.362	I	25	6243.120	II
5	2420.456	II	100	4266.286	I	7	6296.872	I
10	2516.789	II	70	4266.527	II	15	6307.657	I
10	2534.709	II	150	4272.169	I	7	6369.575	I
15	2562.087	II	550	4277.528	II	20	6384.717	I
25	2891.612	II	20	4282.898	II	70	6416.307	I
200	2942.893	II	100	4300.101	I	25	6483.082	II
100	2979.050	II	25	4300.650	II	15	6538.112	I
50	3033.508	II	70	4309.239	II	15	6604.853	I
50	3093.402	II	200	4331.200	II	25	6638.221	II
8	3200.37	I	50	4332.030	II	20	6639.740	II
20	3243.689	II	100	4333.561	I	50	6643.698	II
25	3293.640	II	25	4335.338	I	5	6660.676	I
20	3307.228	II	25	4345.168	I	5	6664.051	I
7	3319.34	I	800	4348.064	II	25	6666.359	II
25	3350.924	II	50	4352.205	II	100	6677.282	I
7	3373.47	I	25	4362.066	II	35	6684.293	II
25	3376.436	II	50	4367.832	II	150	6752.834	I
25	3388.531	II	200	4370.753	II	5	6756.163	I
7	3393.73	I	70	4371.329	II	15	6766.612	I
7	3461.07	I	50	4375.954	II	20	6861.269	II
70	3476.747	II	150	4379.667	II	150	6871.289	I
20	3478.232	II	50	4385.057	II	5	6879.582	I
50	3491.244	II	70	4400.097	II	10	6888.174	I
100	3491.536	II	400	4400.986	II	50	6937.664	I
70	3509.778	II	150	4426.001	II	7	6951.478	I
70	3514.388	II	50	4430.189	II	7	6960.250	I
70	3545.596	II	50	4430.996	II	10000	6965.431	I
70	3545.845	II	20	4433.838	II	150	7030.251	I
7	3554.306	I	50	4439.461	II	10000	7067.218	I
100	3559.508	II	35	4448.879	II	100	7068.736	I
100	3561.030	II	100	4474.759	II	25	7107.478	I
70	3576.616	II	200	4481.811	II	25	7125.820	I
25	3581.608	II	100	4510.733	I	1000	7147.042	I
			20	4522.323	I	15	7158.839	I
			20	4530.552	II	70	7206.980	I
			400	4545.052	II	15	7265.172	I
			20	4564.405	II	7	7270.664	I
			400	4579.350	II	2000	7272.936	I
			400	4589.898	II	35	7311.716	I
			15	4596.097	I	25	7316.005	I
			550	4609.567	II	5	7350.814	I
			7	4628.441	I	70	7353.293	I
			35	4637.233	II	100	7372.118	I
			70	4657.901	II	20	7380.426	II
			15	4702.316	I	10000	7383.980	I
			20	4721.591	II	20	7392.980	I
			550	4726.868	II	15	7412.337	I
			50	4732.053	II	10	7425.294	I
						12	769.15	I
						Ar III		
						Ref. 367, 372, 373, 375 — E.F.W.		
						Intensity	Wavelength	
							Vacuum	

The spectrum of a gas discharge can be used to determine the chemical composition of the gas. In order to do this, you just compare the observed wavelengths of the spectral lines to those in the line tables of various possible atomic or molecular constituents. A good match between the observed and tabulated lines will tell you that a given atom or molecules is present in the gas.

## **D. Experimental procedure**

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At the start of your lab section, please turn your sodium lamp on, so that you do not have to wait for it to warm up later. It takes about 10 minutes to warm up. The reason is that very little of the sodium will be in the vapor phase when you first turn it on, because its vapor pressure is very low at room temperature. The sodium lamp contains a small pressure of neon gas. This allows the discharge to start even though there is almost no sodium vapor at first. When you start the lamp, it will have a reddish color, which is coming from the neon gas. Once the lamp starts running, it begins to get hotter. At the higher temperature, the sodium will vaporize. As this happens, sodium becomes the dominant atom in the discharge, and the lamp color changes to orangish-yellow, which is coming mainly from sodium atoms.

### **Diffraction grating**

In this lab you will use a 600 line/mm transmission diffraction grating. This grating is blazed to produce a high intensity in one of the two first-order diffracted beams. We have mounted the grating next to a glass window in an aluminum frame, with the grating surface facing the window. Thus, only flat glass surfaces face outward, and the delicate grating surface is protected from fingerprints and scratches. As always, you should handle optics with care. But, if you do accidentally get a fingerprint on a glass surface of this assembly, we can clean it off.

### **Grating spectrometer**

Next, familiarize yourself with the grating spectrometer. We have several different models of spectrometer in the lab, but they are very similar in construction. The spectrometer components are illustrated in Figure 11.5. Light enters the spectrometer through a slit. The width of the slit can be changed with an adjustment screw. A wide slit will allow more light into the interferometer, possibly making weak lines easier to see. A narrow slit will make the lines sharper, which will allow closely spaced lines to be more easily distinguished from each other.

The slit and collimator are fixed to the spectrometer base. The telescope and grating are mounted on independently rotating bases. Each base can be rotated by hand. In addition each base has a fine adjustment screw and a locking screw. With the locking screw tightened, a base can be moved through a very small change in angle with the fine adjustment screw. Finally, each of the two bases has a vernier scale for reading off the angle. Instructions for reading a vernier scale are given in Figure 11.6.

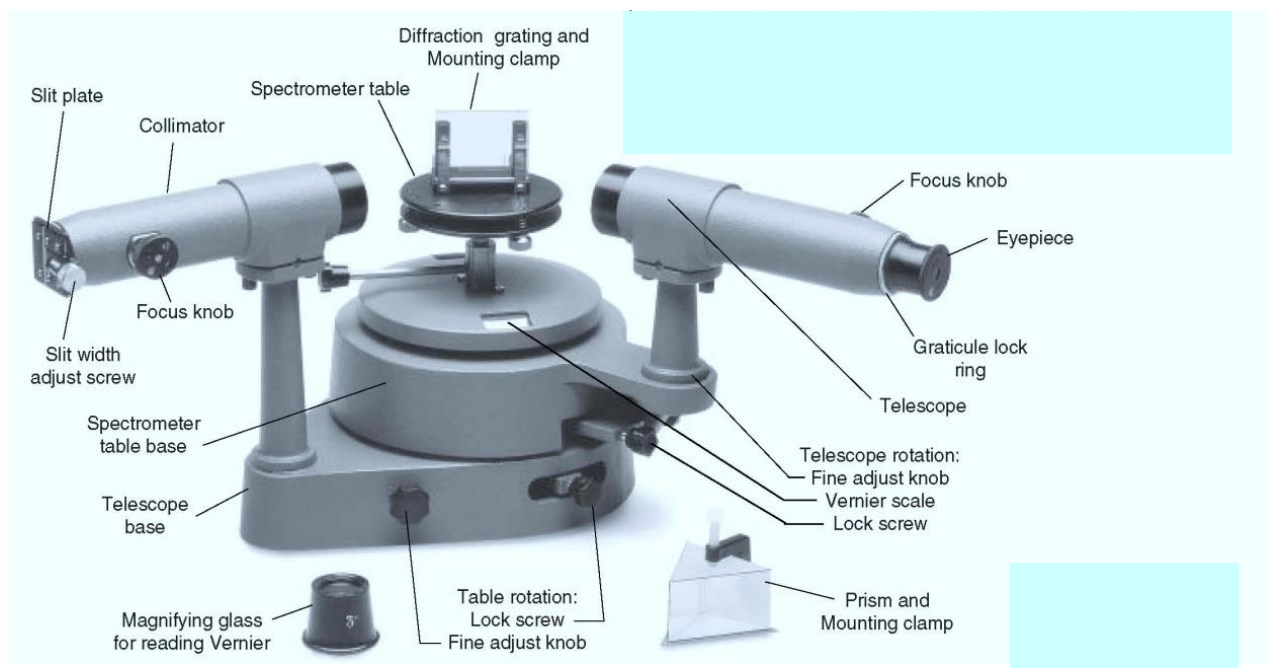


Figure 11.5. Diffraction grating spectrometer. Reproduced from the Pasco spectrometer manual.

Spend some time familiarizing yourself with the spectrometer controls for your spectrometer. Observe the opening and closing of the slit with the slit width adjustment knob. Determine which knob locks down the grating table, and which locks down the telescope. With these knobs unlocked, experiment with the rotation of the grating table and the rotation of the telescope. With these knobs locked, determine which knobs produce fine adjustments of the grating and telescope angles. Observe the effects of these small rotations on the vernier angular scales, and make sure you know how to precisely read the angle from the vernier scales. (Refer to Figure 11.6.)

To read the vernier scale, it may help to use the magnifier. When you pull open the magnifier, an LED will automatically turn on, and can be used to illuminate the scale making it easier to read. *Whenever you're done using the magnifier, please close it so that the LED turns back off and you don't run the batteries down.*

### Set up the spectrometer and observe the sodium D lines

In this part of the lab you will measure the wavelength of the *sodium D lines*. These are perhaps the most well-known lines in atomic spectroscopy. We are starting with these lines because the sodium spectrum is very simple and very bright, being dominated by these two lines. The two lines are very close together in wavelength, so they may appear to be a single line until you set the slit width to be small.



## 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  $155^\circ$  and  $155^\circ 30'$  marks on the degree plate, so the recorded value is  $155^\circ$ .

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,  $155^\circ + 15' = 155^\circ 15'$ .

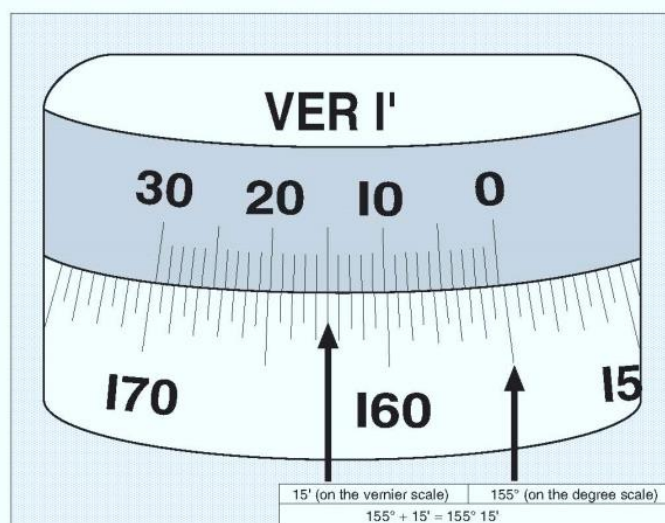


Figure 11.6. Reading the vernier scale. Reproduced from the Pasco spectrometer manual.

To observe these lines, complete the following steps:

- 1) In this first step you will look through the telescope at something far away (at least 15 feet). To do this, set the spectrometer on the upper level of the lab bench, so that you can at the other end of the room through the telescope. Alternatively, you may take the spectrometer out of the lab, set it on one of the file cabinets at the end of the hallway next to the windows, and look out the window at the building across the street. If there is a grating in the spectrometer, remove it and put it back into its protective case. Rotate the telescope to an angle such that you can see through it to your distant object. You should see a vertical cross hair. Make sure that the cross



hair is accurately vertical. If necessary, you can unlock the cross hair with a ring near the eyepiece, rotate it, and lock it back down. Make sure that the cross hair is in sharp focus. To do this, pull the eyepiece in or out.

2) Adjust the telescope focus knob until the distant object becomes clear and sharp. This adjusts the telescope focus to be approximately at infinity, which is important for proper operation of the spectrometer. From this point on, do not touch the focus of the telescope.

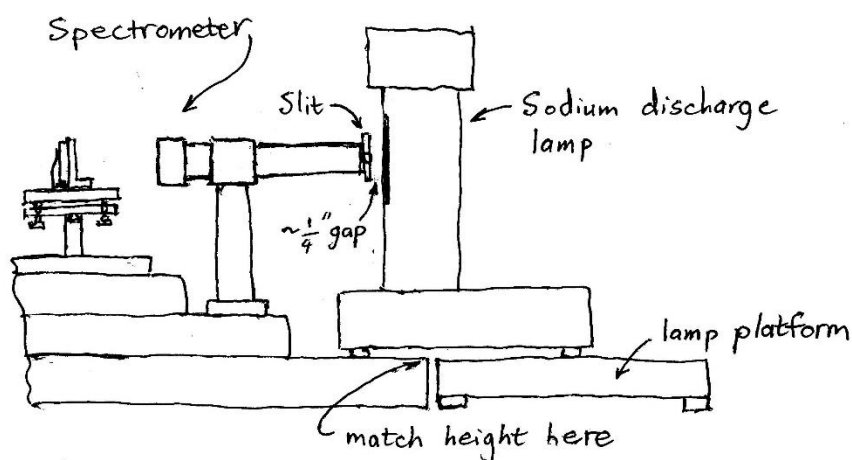


Figure 11.7. Correct placement of the sodium discharge lamp and lamp platform.

3) Bring the spectrometer back into the lab. Then, place the lamp platform next to your spectrometer platform. The different models of spectrometers have different height platforms, and we have made different height lamp platforms to match. **Please make sure that your lamp platform matches the height of your spectrometer platform, as shown in Figure 11.7.**

Otherwise, you may not be able to get a stable placement of your lamp next to your slit. Place your sodium lamp on the platform so that its light output aperture is close to the spectrometer slit (within about one cm) and lined up with the collimator.

Open up the slit so that it is 1 or 2 mm wide. Rotate the telescope until it is directly opposite the collimator. At this point the telescope, collimator, slit, and sodium lamp should all lie along a straight line. Look through the telescope. You should see an image of the slit. Move the focus adjustment of the **collimator** so that the slit comes into sharp focus. **Do not move the focus adjustment of the telescope.** Experiment with the slit width adjustment so that you can see what it does. Take note of which edge of the slit is the fixed edge, and which one moves. **You will take all measurements from the fixed slit edge.**

4) Adjust the position of the sodium lamp to maximize the brightness of the slit image.

5) Make sure that the fixed edge of the slit and the vertical cross hair are parallel. If necessary, the slit, cross hair, or both can be unlocked, rotated into the desired orientation, and then locked back down.

6) Adjust the slit width to give a clear, bright slit image. Measurements will be taken from the fixed slit edge, so a narrow slit width doesn't necessarily improve the precision of the measurements. However, a narrow slit will be useful for distinguishing closely spaced lines from each other.

7) Put the diffraction grating assembly into the grating mount. Loosen the grating base lock screw, and rotate the grating platform so that the grating is perpendicular to the input beam from the collimator, as best you can judge by eye. It may help to set the protractor up against the grating mount for this adjustment. Tighten the grating base lock screw.

8) Rotate the telescope platform until you can see images of the slit from one of the first-order diffracted beams. You should see slit images, also called *lines*, of several different colors. Each of these is the first order diffracted beam from a different spectral line. **The strong yellow line is the sodium D line.**

9) Rotate the telescope in the opposite direction until you can see the lines from the other first-order diffracted beam. One of the first-order diffracted beams will be brighter than the other due to the blaze of the grating. Determine which one is the brighter one. You can change which one is brighter by flipping over the grating. You don't need to worry about which one you're using for now.

10) Reduce the slit width until you see the sodium D line split into two separate lines. The larger wavelength line is called the "D1 line" and the smaller wavelength line is called the "D2 line".

**Accurately measure the wavelength of the sodium D2 line using normal incidence diffraction in both first and second order.**

The most straightforward way to make a first-order, normal incidence diffraction measurement of the wavelength would be to set the angle of incidence to  $0^\circ$  (as you did in step 7), measure the diffraction angle  $\theta_1$  of one of the first order lines, and use that measured diffraction angle to determine the wavelength from the normal incidence equation (11.1). However, to get a very accurate measurement this way, it is necessary that the angle of incidence is set very accurately. This is difficult to do, and so we won't try to do that any better than you can do by eye in this lab. Without that, this measurement would not be very accurate.

However, it turns out that as long as the angle of incidence is close to  $0^\circ$ , you can get an accurate measurement of the wavelength using equation (11.1) as long as you *take the diffraction angle  $\theta$  equal to the average diffraction angle of the two first-order beams*. So, carry out this measurement as follows.

11) Rotate the telescope platform so that you can see the undiffracted (zero-order) image of the slit. Align the fixed edge of the slit with the vertical cross hair, and read the telescope angular position from its vernier scale. Call this angle  $\theta_0$ . Then, rotate the telescope and repeat this procedure with one of the first-order diffracted D2 lines. Call this angle  $\theta_+$ . From this, determine

the diffraction angle  $\theta_{1+} = \theta_+ - \theta_0$ . Repeat this measurement with the other first-order diffracted D2 line, and determine the diffraction angle  $\theta_{1-}$  for that line. Then, compute the average diffraction angle  $\theta_1 = (\theta_{1+} + \theta_{1-}) / 2$  of the two first-order lines from your measurements, and use that in equation (11.1) to determine the wavelength of the D2 line. Note that you'll get  $d$  from the stated number of lines/mm on the grating.

At this point, check with your instructor to see whether you've gotten close to the correct wavelength (within about 40 Å). (With careful measurement, accuracy better than 10 Å is feasible with these spectrometers.) If you haven't gotten close to the correct wavelength, work to improve your measurement until you get within about 40 Å of the correct wavelength. Then proceed to the next step.

12) Repeat step 11 using the second-order diffracted beams.

*Question for your report:* what are the reasons, if any, to prefer a measurement in second order over a measurement in first order? What are the reasons, if any, to prefer a measurement in first order?

### Measure the wavelengths of the sodium D1 and D2 lines with the method of minimum deviation

There is another way to work around the problem of grating alignment: the *method of minimum deviation*. To see how this method works, first note that with some trigonometry, we can rewrite the grating equation (11.2) as

$$2d \sin\left(\frac{\theta_i + \theta_d}{2}\right) \cos\left(\frac{\theta_i - \theta_d}{2}\right) = m\lambda \quad (11.3)$$

The total deviation angle between the input and diffracted beams is  $D = \theta_i + \theta_d$ , as illustrated in Figure 11.2. Thus, we can rewrite equation (11.3) as

$$2d \sin\left(\frac{D}{2}\right) \cos\left(\frac{\theta_i - \theta_d}{2}\right) = m\lambda \quad (11.4)$$

Angles involving the rotation angle of the grating in its mount, such as  $\theta_i$  and  $\theta_d$ , are difficult to measure accurately. However, we can eliminate these angles from our measurement. To do this, we notice that  $D$  has a minimum when  $\theta_i - \theta_d = 0$ . Thus, for this *minimum deviation angle*  $D_{\min}$ ,

$$2d \sin\left(\frac{D_{\min}}{2}\right) = m\lambda \quad (11.5)$$

To make a measurement with minimum deviation, you view the first order diffracted beam, and then rotate the grating mount so as to minimize  $D$ . This can be done as precisely as you can measure the angle with the view of the slit and cross hair. That deviation angle is equal to  $D_{\min}$ ,

which can then be used together with equation (11.5) to determine the wavelength. You measure  $D_{\min}$  in the same way as you measured  $\theta_{1\pm}$  in the normal incidence method in step (11).

13) Measure the wavelength of both the sodium D1 and the sodium D2 line using the method of minimum deviation in first order. Note that you only need to do this in one of the two first order beams. Compare your results to the accepted value of these wavelengths.

*Question for your report:* You should have found that you can measure wavelengths with far greater accuracy with the grating spectrometer than with two slit interference fringes as in Experiment 9. What factors account for this greater accuracy?

### **Hints for increasing the intensity of the lines**

Your lines from the sodium lamp should be very bright, but the lines from the “mystery lamp” in the next step may not be. If you have a line that is dim, there are several things you can do to make it appear brighter. One is to turn off the room lights. Another is to drape a black cloth over the discharge lamp (but not blocking the light going into the spectrometer). These steps will reduce the stray light so that your eye adapts to the darkness and the lines appear to be brighter. (But, making the room too dark might make it hard to see the vertical cross hair, so there is a compromise to be struck between making the spectral lines visible and making the cross-hair visible.) It may also help to re-position the discharge lamp, or to open up the slit. Another thing to try is to work with the diffraction order that is brightest due to the blaze of the grating. These steps should not be necessary for the sodium measurements, but they may be helpful for the following section.

### **Measurement of lines of the spectrum of a "mystery gas", and determination of the gas species.**

You are supplied with another discharge lamp. This lamp contains a gas with bright atomic lines. (The gas is either an atomic gas, or a molecular gas for which the brightest lines are atomic lines.) This lamp is labelled with a number, but not the gas species. Be sure to record this identifying number in your lab book, and to include it in your lab report.

Replace the sodium lamp with the "mystery gas" discharge lamp, and position the glass discharge tube as close as you can to the spectrometer slit. Plug the lamp in and turn it on. These lamps do not require time to warm up.

Observe the spectrum of your mystery gas in the spectrometer. Using spectral measurements of your choice, determine which gas is in the tube.

The gas will be one of these:

Hydrogen	Helium	Argon	Neon	Mercury
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In order to identify the gas, you should compare your observed spectrum with the tables of the spectra that are provided with this lab. These are also posted on Canvas.

When you are confident that you have identified the gas, check with your instructor to see whether you've gotten it right. If you have mis-identified the gas, try again.

Once you're sure you have the correct gas identification, measure the wavelength of at least one spectral line of your gas. In your report, indicate which spectral line you believe that you have observed from the spectral lines table.

### **Suggestions**

Ignore the parts of the tables with wavelengths shorter than 3900 Å and longer than 7800 Å, because your eye can't see those wavelengths. Take note of color vs. wavelength – violet near 4000 Å, blue near 4800 Å, green near 5400 Å, yellow near 5900 Å, and red near 6400 Å. This will help you to quickly assess the approximate wavelength of any given line.

When looking at the tables, be sure to take note of the intensities – the most intense lines should match the intensities given in the table.

It might not work to just measure the wavelength of one line and match that to a line in the table. The reason is that your measurement will probably only be accurate to something like 10 or 20 Å, and more than one gas may have a line within 10 or 20 Å of your measured line's wavelength. In this case, you will need to take other features of the spectrum into account, such as the relative intensity of lines, the positions of other strong lines, or the density of strong lines. In other words, the overall pattern of the strong lines is an important identifying factor.

You don't have to measure the wavelength of each and every line you refer to in your determination – whatever combination of measurement and qualitative observation that allows you to determine the gas is sufficient.

You need to identify the gas before leaving the lab, because you'll probably need to consider the overall pattern of strong lines, not just the wavelengths of one or two lines. Once you leave the lab, it will be too late to check whether any unmeasured features of your spectrum match up with the lines in the table.

- END OF EXPERIMENT 11 -