THE DIFFRACTION GRATING SPECTROMETER

Purpose

      a. To study diffraction of light using a diffraction grating spectrometer

      b. To measure the wavelengths of certain lines in the spectrum of the mercury arc lamp.

Theory

      Diffraction grating is a thin film of clear glass or plastic that has a large number of lines per (mm) drawn on it. A typical grating has density of 250 lines/mm. Using more expensive laser techniques, it is possible to create line densities of 3000 lines/mm or higher. When light from a bright and small source passes through a diffraction grating, it generates a large number of sources at the grating. The very thin space between every two adjacent lines of the grating becomes an independent source. These sources are coherent sources meaning that they emit in phase waves with the same wavelength. These sources act independently such that each source sends out waves in all directions. As shown in Fig. 1, on a screen a distance D away, points can be found whose distance differences from these sources are different multiples of λ causing bright fringes. One difference between the interference of many slits (diffraction grating) and double slit experiment is that a diffraction grating makes a number of principle maxima along with lower intensity maxima in between. The principal maxima occur on both sides of the central maximum for which a formula similar to double slit interference holds true which is given by

Fig. 1. Diffraction of light from a grating.

$$d\,Sin\,\theta_n = n\,\lambda\,, \qquad \text{where n = 1, 2, 3, ………..} \qquad (1)$$

      In this equation, d is the spacing between every two lines (*same as every two sources*). If there are N lines per mm of the grating, then d, the space between every two adjacent lines or (every two adjacent sources) is

$$d = \frac{1}{N}\ \text{(mm)} \qquad\qquad (2)$$

      Based on Eq. 1, if the light source has different colors (different wavelengths), shorter wavelength color will have smaller diffraction angle compared to longer wavelength for the same order of principle maximum. Thus we will see a spectrum in such case. The angular spacing for different colors will increase for higher order maxima.

      In this lab, you will use a spectrometer to study diffraction from a grating and measure the wavelengths of certain lines in the spectrum of different lamps including a mercury arc lamp.
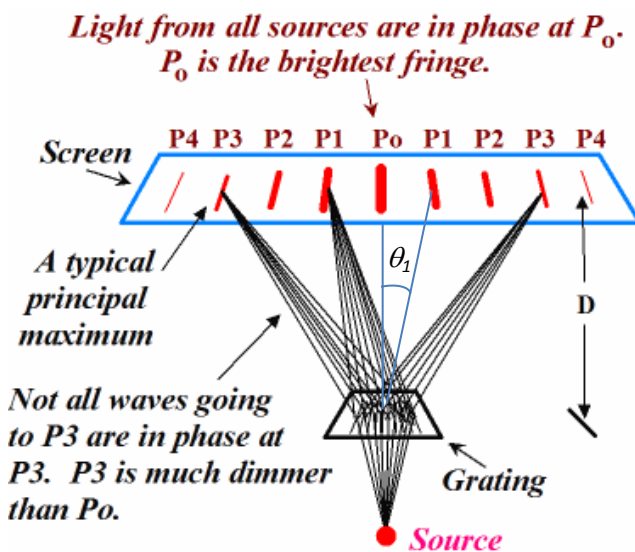
Apparatus

Spectrometer, grating and holder, mercury arc lamp, sodium lamp (optional), various discharge tubes and accessories, table lamp.

Description of Apparatus

Spectrometer has application in a wide range of areas including to determine the constituents of stars, to investigate the structure of the atom. You will using a simple but high precision student spectrometer similar to the picture shown in Fig. 2, which consists of three basic components; a collimator, a diffraction grating, and a telescope.
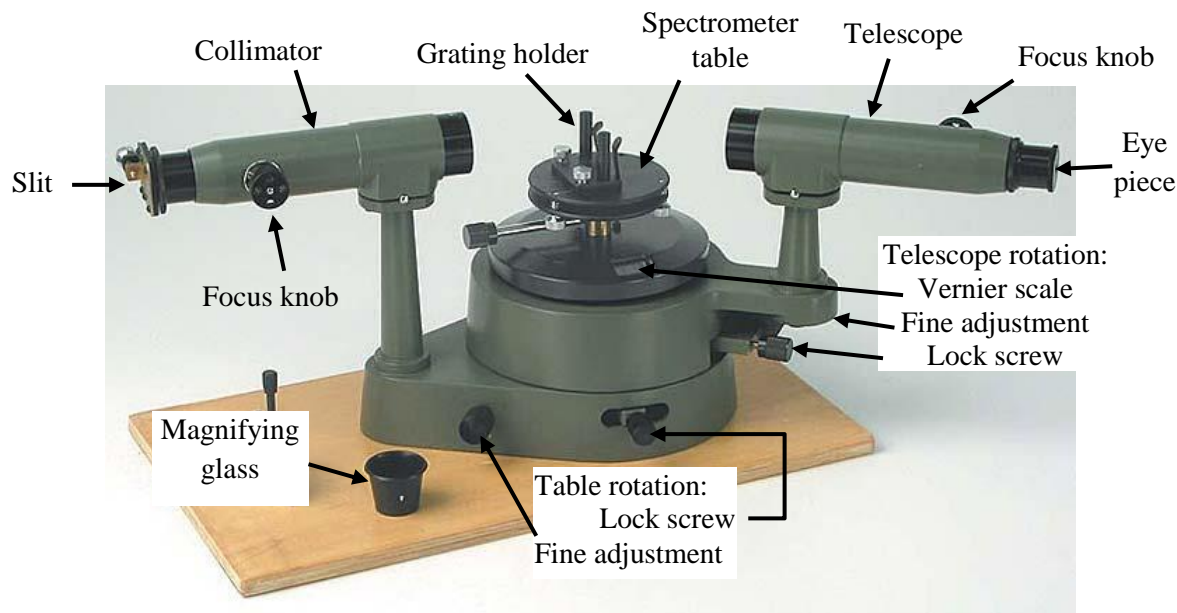
Fig. 2: Spectrometer and its components.

Light enters through a narrow slit positioned at the focal point of the collimating lens. The light leaving the collimator is therefore a thin, parallel beam, which ensures that all the light from the slit strikes the diffraction grating at the same angle of incidence. The grating diffracts the light of different color light at different angles. The telescope is focused at infinity to collect the parallel diffracted beam of light and can be rotated at very precisely measured angles. There are two Vernier readings on two opposite sides on the table, Vernier A and B. You can treat these two reading as measured by two different scales. The Vernier reading has least count of 1' [$(1/60)^\circ$]. To aid viewing the Vernier scale reading a magnifying glass is provided. The table and the telescope can be fine adjusted by tightening the lock screw and rotating the fine adjustment knobs.

The Diffraction Grating is a delicate component. It has a large number of lines per (mm) drawn on it. Be careful not to touch or scratch the surface of the grating.

Procedure

Part I. Setting up the Spectrometer

1. Turn on the mercury lamp. It may take some time to glow properly. Inspect the spectrometer and identify its parts. Make sure your spectrometer is placed with properly leveled. There are three screws under the table to adjust the level.
2. Now, look through the eye piece of the telescope and slide the eyepiece in and out until the cross-hairs come into sharp focus. You may bring one of the cross-hair to vertical position.
3. Focus the telescope at infinity by rotating focus knob. This is best accomplished by focusing on a distant object (e.g.; out the window).
4. Now, align the telescope directly opposite the collimator. View the slit through the telescope, rotate the telescope slightly if necessary, you should see some light if the slit is open partially. Adjust the focus knob of collimator to make the sharp image of the slit. **Do not change the focus of the telescope.** Finally, narrow down the slit as much as possible and fine adjust the focus if necessary.
5. Set the telescope so that the point of intersection of the cross hairs is symmetrically placed within the very narrow slit image. Record the readings of both Verniers (A and B) with the telescope in this position and record in Table 1. Now shift the telescope slightly, and again bring back the intersection of the cross hairs to the center of the slit image, and record a second set of Vernier readings. This reading gives the zero position of the telescope for the undeflected beam of light.

   Fig. 3 gives an example of how 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 3, the zero point on the vernier scale is between the 155 ° and 155 ° 30' marks on the degree plate, so the main scale reading 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 main scale reading recorded above to get the correct measurement to within 1 minute of arc, i.e., 155 ° + 15' = 155 °15'.
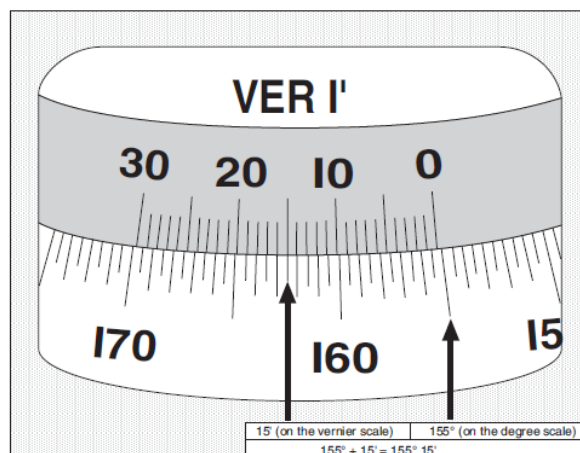

   Fig. 3: Reading the Vernier Scale.

6. Now, place the diffraction grating on the holder and mount on the circular grating table so that the grating faces the collimating lens. Record the number of lines per mm (or inch) on the grating. The grating should be perpendicular to the light beam and the lines on the grating should be parallel to the vertical slit. In order to check if they are vertical or not, rotate the telescope away from the center. You should see beautiful spectrum of light on both sides. If the position of the spectra are up and down from the field of view in the telescope, the grating is not well aligned. Adjust the three screws under the circular plate to align the grating.

Part II. Wavelength of Mercury lines

1. You are now ready for the measurement. In normal condition alignment of the spectrometer does not change. You should lock the table rotation as you are moving only telescope. The mercury light source should be about one centimeter from the slit. What is the color of the light you see?

    For better observation you should turn off the room light and cover the light from the source so that light is passing only through the slit. Use a table lamp when you need to take data.

2. From the center position, turn the telescope about 19° to the right or left until you see the first order green line. Adjust the telescope such that the cross-hair coincides at the center of the green line. For fine adjustment, you can tighten the lock screw of the telescope and rotate the fine adjustment screw. Now read the position of the telescope from both Vernier readings and record in Table 2. Difference between this reading **from Vernier A** and the reading for undeflected beam **from Vernier A** gives you the first order diffraction angle for green light. (Similarly the difference between this reading **from Vernier B** and the reading for undeflected beam **from Vernier B** also gives you the first order diffraction angle for green light.)

3. Now, unlock the telescope and turn the telescope to the other side from the center until you see the first order green line. It should be positioned approximately same angle. With fine adjustment as in the previous step, read the position of the telescope from both Verniers and record in Table 2. If the grating is well aligned, the angles on both side should be very close.

4. Repeat the previous steps 2 and 3 to measure the diffracting angles on both sides for all other visible lines in first order for Mercury light. Take the reading from ONLY one of the Vernier scales A or B and record in Table 3.

5. Repeat the previous steps 2 and 3 for all the visible lines in **Second order** for Mercury light. Take the reading from ONLY one of the Vernier scales A or B and record in Table 4.

6. Check for any visible lines in the third order.

Part III. Spectra of different elements

Examine the spectra of various discharge tubes, including sodium, neon and hydrogen from the spectrometer, and record your qualitative observations with sketch of number of lines and colors observed for each light source. Do not measure the wavelengths.

There is a poster in the lab room showing spectrum from lots of different elements. The spectrum for a particular element is a fingerprint of the element. Look at the poster and check if you observed all the spectral lines shown for the elements you observed.

Computation

From the reading in Table 1, take the average of the zero position of the telescope for Vernier A and B. You will need these values later to determine the diffracting angles.

From the reading in Table 2, determine the diffracting angles **from Vernier A** for green line in first order on both sides and take the average. This is the difference between the reading for first order position and zero position. Note that the angle cannot be negative and pay attention if the zero line has crossed when you move the telescope. Similarly,

determine the diffracting angles **from Vernier B** for green line in first order on both sides and take the average. Calculate the average angle from both sides.

Now, calculate the wavelength of green line using the values of diffracting angle and grating spacing in Eq. 1. Express the wavelength in nm.

Similarly, calculate the diffracting angles on both sides and take the average and tabulate the values in Table 3 for other first order lines. Calculate the wavelength in nm.

Similarly, from the readings in Table 4 for second order lines, determine the diffracting angles on both sides and take the average. Calculate the wavelength in nm.

Compare your results with the accepted wavelengths of mercury lines given below. Tabulate your results along with the accepted values.

Wavelengths of Spectral Lines

Mercury		
Wavelength (nm)	Color	Intensity
404.7	Violet	Very Bright
407.8	Violet	Weak
435.8	Blue-Violet	Bright
491.6	Blue-Green	Weak
546.1	Green	Very-Bright
577.0	Yellow	Bright
579.1	Yellow	Bright

Hydrogen		
Wavelength (nm)	Color	Intensity
486.1	Blue-Green (H_β)	Weak
656.3	Red (H_α)	Bright
Sodium		
589.0	Yellow (D_2)	Bright
589.2	Yellow (D_1)	Bright

Questions

1. Compute the longest wavelength for which your grating will form a third-order image.

2. You made two determinations of the wavelength of the bright green mercury line, one based on the first order interference and the other based on the second order interference. Which one do you think is more precise? Explain why.

3. Why is the wavelength of the spectral lines that seem same color have slightly different wavelength when emitted by different element?

4. List some diffraction phenomena in your daily life experience.

5. What do think, how the spectrum from sunlight in the spectrometer look like in the spectrometer? Give your thought comparing the spectrum with the white light from merc

Data Sheet

Date experiment performed:

Name of the group members:

Number of lines on grating, N =   d = 1/N =

Table 1. Zero position reading

	Vernier A	Vernier B
Trial 1		
Trial 2		
Average (θ_o)		

Table 2. Green line in first order

	Vernier A			Vernier B		
	Reading	θ_o	angle (θ_1)	Reading	θ_o	angle (θ_1)
On right side						
On left side						
		Average (θ_1)			Average (θ_1)	

Average θ_1 = λ (green) =   (nm)

Table 3. First order spectrum for other colors using only one Vernier reading

θ_o from Table 1 =

	On left side		On right side		Average	wavelength
Color	Reading	angle (θ_1)	Reading	angle (θ_1)	θ_1	λ (nm)

Table 4. Second order spectrum using only one Vernier reading

θ_o from Table 1 =

	On left side		On right side		Average	wavelength
Color	Reading	angle (θ_2)	Reading	angle (θ_2)	θ_2	λ (nm)