EXPERIMENT - 12

Aim of the experiment: Determination of wavelengths of some prominent spectral lines of mercury light using a plane transmission diffraction grating spectrometer (*use Table-1 only, for this purpose*).

Converse to the above-mentioned aim, we may equally well try and estimate the number of lines per millimeter of the diffraction grating provided to us, using known wavelengths of some prominent spectral lines of mercury light. (*use Table-2 only, for this purpose*).

Apparatus required: Plane transmission grating, grating holder, college spectrometer, mercury vapor lamp and its power supply, reading lens, torch.

Principle:
When a beam of light is made to pass through a plane transmission grating, it gets diffracted in a plane perpendicular to the diffraction grating plate and the grating rulings. Its diffraction pattern has the central principal maximum of highest intensity and several other secondary maxima. The diffraction of nth maximum is given by:

$$(a + b)\, sin\theta = n\lambda$$

$$or, \qquad \lambda = \frac{sin\theta}{nN}$$

where,
λ is the wavelength of a particular spectral line and θ is its angle of diffraction
a is the width of each slit and b is the width of the opaque space between two constructive sites.
$(a + b)$ is the grating constant or grating element
$N = 1/(a + b)$ is the number of rulings per unit length
n is the order of diffraction pattern or lines. For example, $n = 1$ corresponds to the *first order* diffraction lines, $n = 2$ is for *second order*, and so on.

The diagrams show how light is diffracted when a well collimated beam of light is incident normally onto a plane transmission diffraction grating.

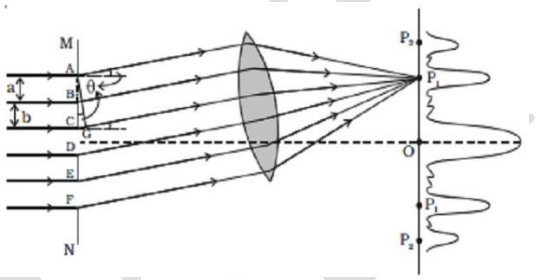

Fig-1. Diagram showing normally incident beam in a grating and the light intensity distribution of the diffracted beam

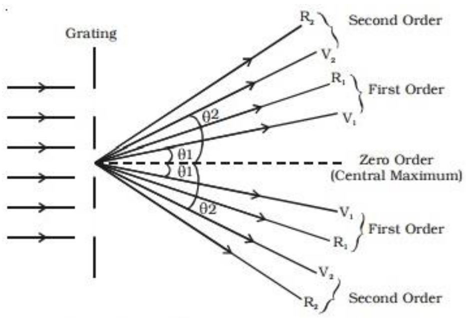

Fig-2. Diagram showing angular dispersion of white light into 1st and 2nd order spectrum of component colors by a diffraction grating.

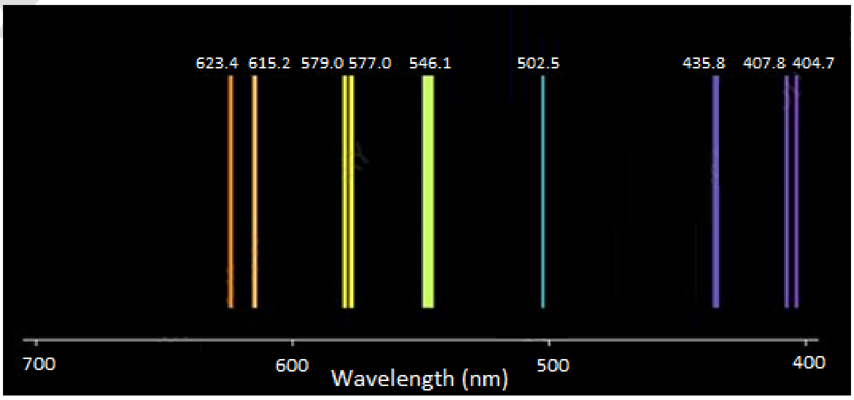

Fig-3. Spectral lines of mercury

Procedure and precautions:

1. Place your spectrometer outside the dark room on a table adjacent to a window and focus the telescope to a very distant object, preferably, at the leaves of a distant tree. Bring them to sharp focus by adjusting the telescope focusing knob. Once done, your telescope is adjusted for receiving parallel rays. DO NOT DISTURB THIS KNOB ANY FURTHER, THROUGHOUT THE EXPERIMENT. If at all focusing is required, use the collimator focusing knob.
2. Now, bring your spectrometer to an appropriate location in the dark room. Note that there is a fairly wide slit in the housing of a mercury vapor discharge lamp.
3. Place your spectrometer in front of this slit in such a way that the adjustable slit of the collimator receives enough light. Ensure that the collimator is exactly in line with the light source by looking directly through the collimator objective.
4. Follow the process for rough levelling, alignment and optical levelling as outlined in the relevant sections of *appendix-A*.
5. Bring the telescope in line with the collimator directly facing each other.
6. View through the eyepiece of the telescope and adjust its position so that the slit image is at the center of the field of view. Make the collimator slit as thin as possible so that you see just a sharp thin line. This is the direct ray. Focus the instrument using the collimator focusing knob in case you feel the need for it ever, during the experiment. *Do not disturb the telescope focusing knob!*
7. Place the grating on the prism table exactly at the center, such that it is perpendicular to the light beam from the collimator and the rulings are perpendicular to the prism table. For this you may use the grating holder. Make sure to keep the holder frame towards the collimator else it might obstruct the 2^{nd} order diffracted lines that emerge at larger angles from the direct ray.
8. While viewing through the eyepiece push the telescope gradually to one side, in its allowed plane of movement. Discrete spectral lines of various colors starting from violet through red will appear one after the other, and they will be sufficiently bright. These are the 1^{st} order diffracted lines. Keep moving the telescope in the same direction, and all the lines appear again in the same sequence, but with much diminished intensity and with slightly enhanced angular separation. These are the 2^{nd} order diffracted lines. Beyond this you may be able to view a few lines of the 3^{rd} order as well, provided you are in a completely dark room with almost no stray light marring your experiment. However, that's not important for this experiment.
9. Remember that we have moved the telescope to only one side of the direct ray. All the colors that appear while moving towards one side of the direct ray appear on the other side as well, in the same sequence (like a mirror image).
10. To start making measurements, position the telescope crosshair exactly onto the spectral line of interest and read the MSR and VSR from both the windows i.e., window I and II. This gives the current angular position of the telescope that can be recorded on the observation table appropriately. Make sure not to mix up or process the readings of window I with those of window II.
11. Repeat step 10 for all the spectral lines of interest, to populate the observation table. Proceed with the data processing and calculations to obtain the results as desired.

Note:

1. Make sure not to mix up the observations of the two Vernier windows. Reading of Vernier window-1 is to be processed with those of the same window, for any position of the telescope. Same will hold for Vernier window-2.
2. During this experiment if a need is felt for refocusing, invariably the collimator focusing knob is to be used for the purpose.

Observations:

Obtaining the LC of the spectrometer that we are using:

$1 \text{ MSD is } = 0.5 \text{ deg}$

$60\ VSD\ coincide\ with\ 59\ MSD$

$\therefore 1\ VSD = \frac{59}{60}\ MSD$

$30\ VSD\ coincide\ with\ 29\ MSD$

$\therefore 1\ VSD = \frac{29}{30}\ MSD$

By definition, the least count or the Vernier constant of an instrument is defined as:

$LC = 1\ MSD - 1\ VSD$

$\therefore LC = 1\ MSD - \frac{59}{60}\ MSD$

$or, \quad LC = \left(1 - \frac{59}{60}\right)\ MSD$

$or, \quad LC = \left(1 - \frac{59}{60}\right) 0.5 \text{ deg}$

$or, \quad LC = \left(\frac{1}{120}\right) \text{deg}$

$LC = 1\ MSD - 1\ VSD$

$\therefore LC = 1\ MSD - \frac{29}{30}\ MSD$

$or, \quad LC = \left(1 - \frac{29}{30}\right)\ MSD$

$or, \quad LC = \left(1 - \frac{29}{30}\right) 0.5 \text{ deg}$

$or, \quad LC = \left(\frac{1}{60}\right) \text{deg}$

Note that there are some spectrometers having 60 VSD coinciding with 59 MSD and others having 30 VSD coinciding with 29 MSD. Hence, exercise due care while determining the least count of your instrument, in particular.

Table-1: Spectrometer readings for the determination of wavelengths of prominent spectral lines in the mercury spectrum produced by a plane transmission diffraction grating at normal incidence.

Order	Vernier Window	Color	Standard values Wavelength (nm)	Position of Telescope											Difference between actual and obtained λ
				Left side spectrum				Right side spectrum							
				MSR	VSR	VSRxLC	Total	MSR	VSR	VSRxLC	Total	2θ	θ	λ	
				(deg)		(deg)	(deg)	(deg)		(deg)	(deg)	(deg)	(deg)	(nm)	%
0	I	White	Composite												
	II	White													
1	I	Yellow	577.0												
		Green	546.1												
		Blue	435.8												
		Violet	404.7												
	II	Yellow	577.0												
		Green	546.1												
		Blue	435.8												
		Violet	404.7												
2	I	Yellow	577.0												
		Green	546.1												
		Blue	435.8												
		Violet	404.7												
	II	Yellow	577.0												
		Green	546.1												
		Blue	435.8												
		Violet	404.7												

Table-2: Table for the determination of the number of lines per unit length of the grating.

Order	Vernier Window	Color	Wavelength λ (nm)	Position of Telescope										
				Left side spectrum				Right side spectrum						
				MSR	VSR	VSRxLC	Total	MSR	VSR	VSRxLC	Total	2θ	θ	N
				(deg)		(deg)	(deg)	(deg)		(deg)	(deg)	(deg)	(deg)	(nm)
0														
1	I	Yellow	577.0											
		Green	546.1											
		Blue	435.8											
		Violet	404.7											
	II	Yellow	577.0											
		Green	546.1											
		Blue	435.8											
		Violet	404.7											
2	I	Yellow	577.0											
		Green	546.1											
		Blue	435.8											
		Violet	404.7											
	II	Yellow	577.0											
		Green	546.1											
		Blue	435.8											
		Violet	404.7											
													Average =	

Calculations:

We may use the following relation to calculate the wavelength of light diffracted at an angle θ

$$\lambda = \frac{sin\theta}{nN}$$

where, $N = \frac{1}{(a+b)}$ lines / m

Results and Discussion:

At this stage we realize that we have determined the wavelength of light of a particular color at least twice using the 1st order lines and twice using the 2nd order. Hence, we have four values of λ for a color. It is by all means possible to compute their average, their standard deviation and standard error. The final results may be reported using the following format.

The wavelength of *yellow line of mercury* as determined by the diffraction grating experiment is,

$$\lambda = (\ avg\ value \pm standard\ error)\ nm$$

The percentage error in its determination is

$$\lambda = \frac{|avg\ value - 577.0|}{577.0} \times 100\%$$

The wavelength of green line of mercury as determined by the diffraction grating experiment is,

$$\lambda = (\ avg\ value \pm standard\ error)\ nm$$

The percentage error in its determination is

$$\lambda = \frac{|avg\ value - 546.1|}{546.1} \times 100\%$$

The wavelength of blue line of mercury as determined by the diffraction grating experiment is,

$$\lambda = (\ avg\ value \pm standard\ error)\ nm$$

The percentage error in its determination is

$$\lambda = \frac{|avg\ value - 435.8|}{435.8} \times 100\%$$

A brief conclusion regarding elegance of the method in determining the wavelength of light using the method of diffraction of light may by incorporated, with a special reference to the accuracy and precision incurred may be also be elaborated upon.