Determination of wavelength of LEDs using a grating spectrometer

Objectives

At the end of this activity, you should be able to:

1. learn to use a grating spectrometer
2. understand the concept behind a diffraction grating
3. determine the wavelengths of different LEDs

Introduction

A spectrometer is an instrument that separates light into its various component wavelengths using either a diffraction grating or a prism to do so.

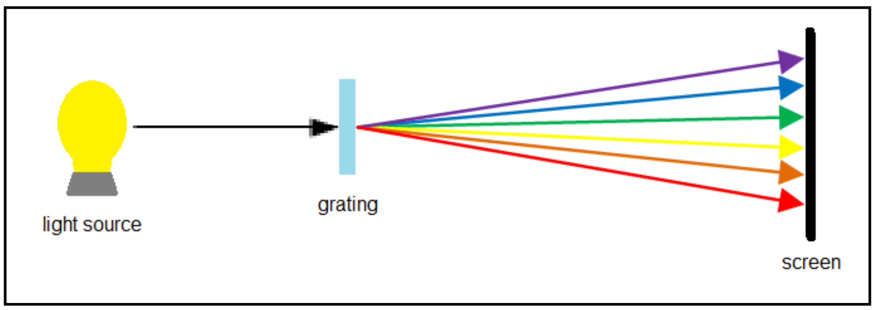


Figure 1. Schematic diagram of a spectrometer. A spectrometer works by focusing a light source into a dispersing medium (a grating or prism) which separates it into its component wavelengths, which can be viewed on a screen or through a telescope.

In this experiment, you will determine the wavelength of various Light Emitting Diodes (LED). LEDs are manufactured with a variety of colors. Some LEDs can even change color depending on the voltage supplied. However, LEDs are not really monochromatic light sources but instead produce light over a certain range with peaks at a specific wavelength. By the use of a grating spectrometer, we will be able to see the different color produced by LEDs that seem to emit only one color.

E Anguluan & M Poral, 2012

Theory

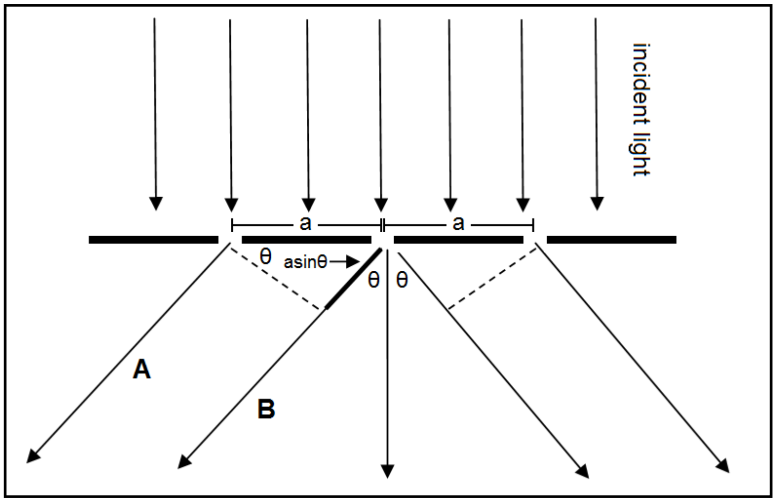


Figure 2. Schematic diagram of light passing through a diffraction grating.

A diffraction grating is an optical component which is basically a series of slits separated by a distance a. Figure 2 shows how a diffraction grating works. Consider the two rays **A** and **B** which both emerge from the grating at an angle θ. By a straightforward geometric calculation, it can be shown that the path difference between the two rays is given by $a\sin\theta$. Constructive interference, which is the overlapping of waves that results in a more amplified wave or in the present case a bright fringe (see Figure 3), can only occur if the path difference is an integral multiple of the wavelength of the emerging light. This can be mathematically represented by,

$$n\lambda = a\sin\theta \qquad (1)$$

where $n = 1, 2, 3, ...$ and λ is the wavelength of the light. In this experiment, $a = 3.3\times10^{-3}$ mm for the 300 lines/mm grating and $a = 1.66\times10^{-3}$ mm for the 600 lines/mm grating.

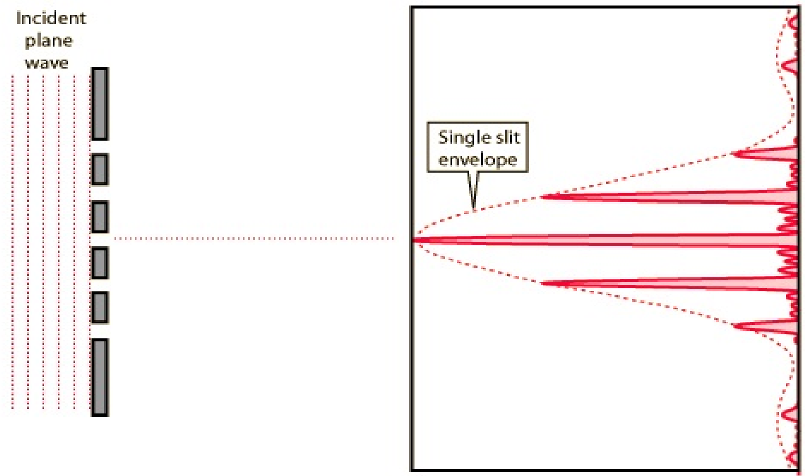


Figure 3. *Interference pattern formed on a viewing screen by multiple slits.* The intensity peaks are the points where constructive interference occurred. (Image taken from: http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/imgpho/muls5.gif)

The consequence of this is that light with a certain wavelength will be bent at a specific angle upon emergence from the grating. As such, if the diffraction grating is illuminated by a light source that is composed of various wavelengths, the component wavelengths will be separated or bent into specific angles resulting in a spectrum of wavelengths. The grating spectrometer is used to scan through these possible angles of diffraction and to get the wavelength of the emerging light by using the more explicit equation given by:

$$\lambda = \frac{a\sin\theta}{n} \tag{2}$$

Materials

spectrometer

diffraction grating
(300 or 600 lines/mm)

LED box

magnifying glass

iron rod

clamps

Procedure

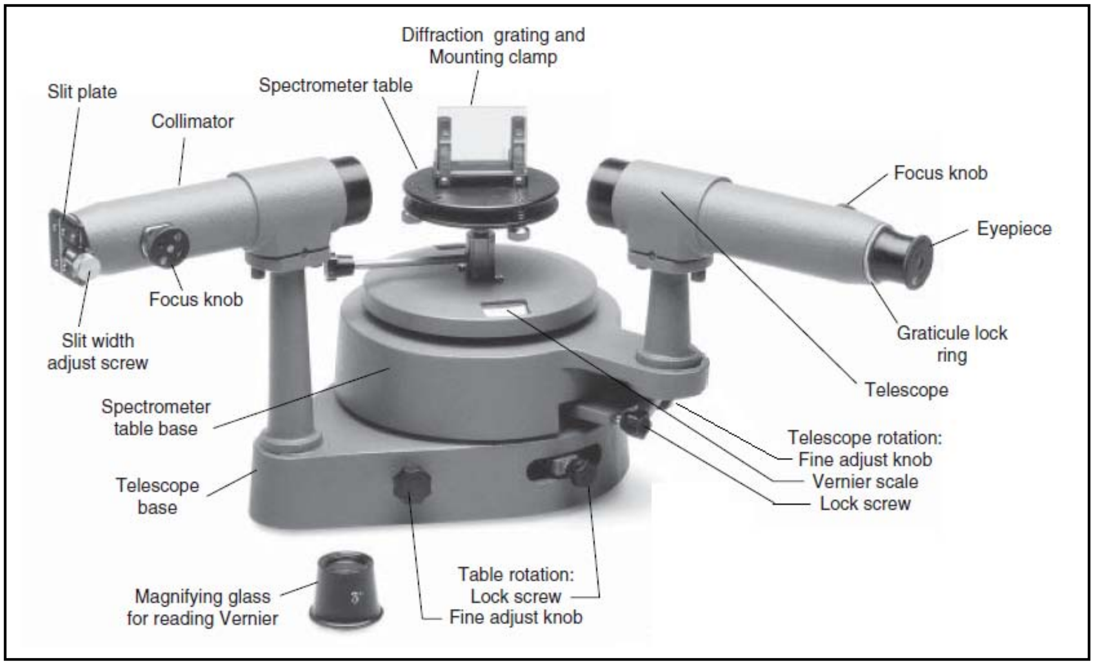


Figure 4. Parts of the spectrometer. (Image taken from: Instruction Manual and Experiment Guide for the PASCO scientific Model SP-9268A)

A. Preparing the Spectrometer for Use

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.

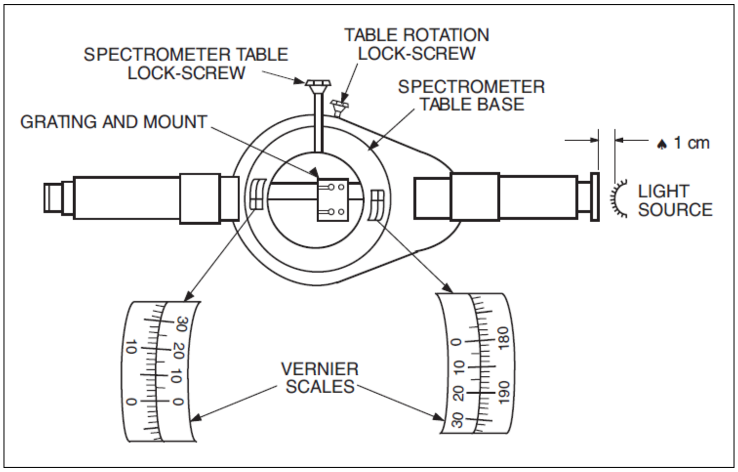
1. Place the spectrometer on a flat surface. Loosen the eyepiece by rotating the graticular lock ring. Rotate the graticule until the cross-hairs are focused and one of the cross-hairs is vertical.

2. Focus the telescope at infinity. Loosen the telescope rotation lock screw to be able to move the telescope. Focus the telescope on a distant object by adjusting the telescope focus knob.

3. Align the telescope directly opposite the collimator. Use the slit width adjust screw to partially open the slit aperture. Look through the eyepiece and find the slit aperture. Focus the collimator at slit aperture by adjusting the collimator focus knob or changing the rotation of the telescope if necessary. **Do not change the focus of the telescope.**

4. Tighten the telescope rotation lock screw. Align the vertical cross-hair with a fixed edge of the slit aperture by adjusting the telescope rotation fine adjust knob. The slit width can be adjusted for a clear, bright image.

5. Setup the light source and diffraction grating as shown in the figure below. Place the diffraction grating on the mounting clamp. Loosen the table rotation lock screw and align the lines on the spectrometer table with the telescope and collimator. Using the iron rod and clamps, position the light source (LED box) approximately 1 cm away from the slit plate. Align the light source with the center of the slit aperture.



6. Make the zero diffraction angle reading. Look through the eyepiece and find a bright slit image (undiffracted beam). Align the edge of the slit image with the vertical cross-hair. Measure the angle of diffraction (see below, *How to Measure Angles of Diffraction*). This is the zero diffraction angle, θ_0. To check if the image that you see is of zero diffraction, slightly tilt the telescope to the left or right, you must be able to see identical spectra on either side. **Note: Every time the spectrometer table is rotated or moved, the zero diffraction angles changes, and have to be measured again.**

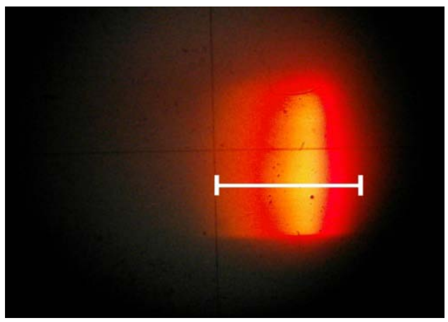
7. Make sure that the grating is perfectly aligned. A perfectly aligned grating would give the same diffraction angles for corresponding slit images on both sides of the undiffracted beam. Look for images of the same color on both sides of the undiffracted beam and align the edge with the vertical cross-hair. Measure the angle of diffraction for both images and compare. If the angles are different, use the table rotation fine adjustment knob to align the diffraction grating perpendicular to the collimator beam. Repeat steps 6 & 7 until the angle readings are correct to within one minute of arc. **Note: Actual angle of diffraction = $\theta - \theta_0$, where θ is the angle reading for the diffracted image.**

8. Note the final zero diffraction angle reading on *Data Table 1*.

B. Determination of Wavelength

1. Now that the grating is aligned and zero diffraction angle reading has been made, you can now determine the wavelength of an LED. Rotate the telescope to a side and look for the first order diffraction spectrum. Measure the angles of diffraction for the start and end of a high intensity spectrum (see figure below). Repeat this step for the second and third order spectrum. Record angle measurements in Data Table 1.

2. Get the approximate peak for each order n = 1, 2, 3, by solving for the midpoint of each pair of angle measurements and recording this in Data Table 2. Get the average peak and compare with the wavelength range for each LED taken from literature.



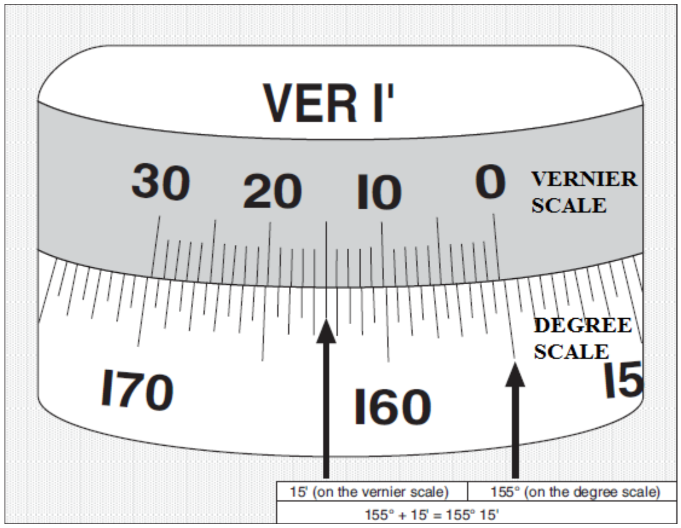
Measure the angles of diffraction for the start and end of a high intensity spectrum as shown with a white line in the figure.

How to Measure Angles of Diffraction

1. Align vertical cross-hair with the edge of an image. Use a magnifying glass to read the Vernier scales.

2. Find where the zero-point of the Vernier scale aligns with the degree scale. If the zero point is in between two lines on the degree scale, choose the smaller reading. Record this as the degree reading.

3. Find the line on the Vernier scale aligned most closely to any line on the degree scale. This corresponds to the number of minutes of a degree (1/60). Add this to the degree reading. Refer to the image below.



(Image taken from: Instruction Manual and Experiment Guide for the PASCO scientific Model SP-9268A)

References

Student Spectrometer: Instruction Manual and Experiment Guide for the PASCO scientific Model SP-9268A (January 1991)

Name	Date Submitted	Date Performed	Score
Group Members			
Instructor		Section	

WORKSHEET: Determination of Wavelength of LEDs

Data Summary

Data Table 1. Diffraction angles for different LEDs

LED no.	observed color	n = 1		n = 2		n = 3	
		$\theta - \theta_0$	λ (nm)	$\theta - \theta_0$	λ (nm)	$\theta - \theta_0$	λ (nm)
1							
2							
3							
4							
5							
6							

zero diffraction angle, θ_0 : _______________

Data Table 2. Average peak wavelengths of different LEDs.

LED no.	peaks (nm)			Average peak	Expected range of λ
	n = 1	n = 2	n = 3		
1					
2					
3					
4					
5					
6					

Questions

1. Justify taking the average/midpoint when computing for the peak. How does the spectrum of an LED look like?

2. In the computation of wavelength, the slits in the diffraction grating are assumed to have no width. In reality, the slits have a finite width. Discuss the effect of this theoretical consideration in your results.

3. A 600 lines/mm diffraction grating is illuminated by a yellow light from a sodium vapor lamp. This light contains two closely spaced lines (the well-known sodium doublet) of wavelengths 589 nm and 589.59 nm. At what angles will the first order maxima occur for these wavelengths?

4. A light which is known to be composed of red light (632.8 nm) and blue light (420 nm) is used to illuminate a 300 lines/mm diffraction grating. If a viewing screen is placed 1 meter from the diffraction grating, what is the separation distance between the **second order** red and blue fringes formed at the screen?

Name TEST RUN & INSTRUCTOR’S REFERENCE	Date Submitted	Date Performed	Score
Group Members			
Instructor		Section	

WORKSHEET: Determination of Wavelength of LEDs

Data Summary

Data Table 1. Diffraction angles for different LEDs

LED no.	Observed color	n = 1		n = 2		n = 3	
		$\theta - \theta_0$	λ (nm)	$\theta - \theta_0$	λ (nm)	$\theta - \theta_0$	λ (nm)
1	Violet	6° 29’	372.617	13° 29’	384.718	21° 7’	396.295
		7° 48’	447.861	15° 30’	440.943	22° 38’	423.316
2	Blue	7° 11’	412.647	15° 10’	431.686	24° 8’	449.748
		9° 17’	532.345	16° 59’	481.9543	25° 3’	465.750
3	Yellow	9° 33’	547.497	19° 44’	557.111	28° 59’	533.011
		10° 4’	582.490	20° 38’	581.437	29° 55’	548.614
4	Orange	9° 34’	548.444	20° 16’	571.543	31° 29’	574.476
		10° 7’	579.655	21° 7’	594.443	32° 30’	591.030
5	Orange-yellow	10° 4’	576.820	19° 59’	590.859	29° 33’	542.501
		10° 30’	601.377	21° 24’	602.047	30° 9’	552.492
6	Red	10° 32’	603.265	21° 59’	617.656	29° 36’	546.116
		11° 7’	636.264	22° 52’	641.170	31° 10’	569.282

zero diffraction angle, θ_0 : 0° 32’

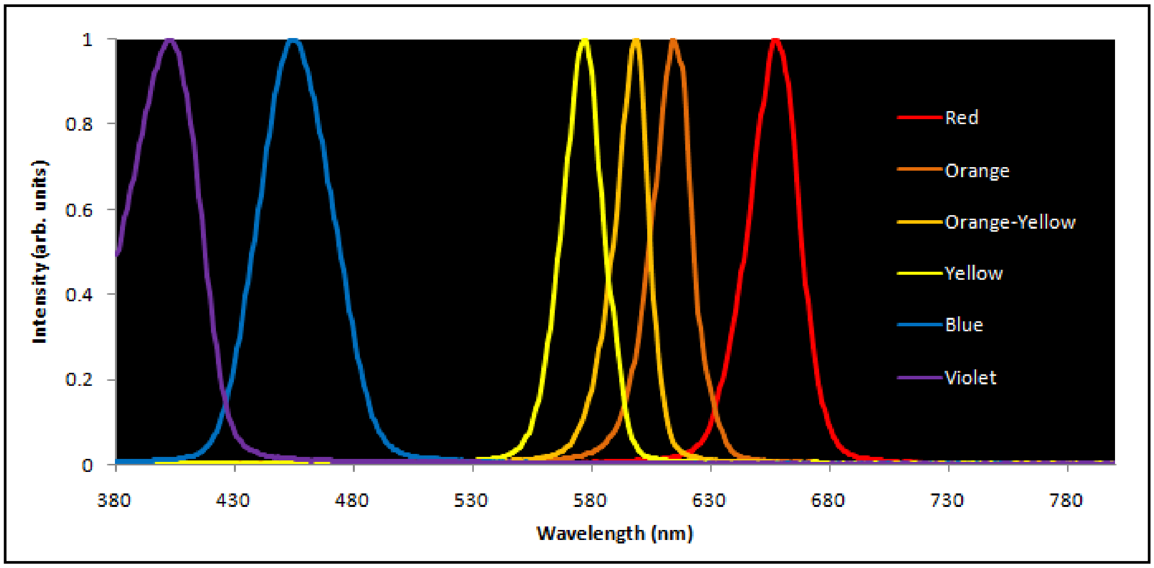
Data Table 2. Average peak wavelengths of different LEDs.

LED no.	peaks (nm)			Average peak (nm)
	n = 1	n = 2	n = 3	
1	410.239	412.831	409.805	410.958
2	472.496	456.820	457.749	462.355
3	564.994	569.274	540.812	558.360
4	564.050	582.993	582.753	576.598
5	589.099	596.453	547.497*	592.776
6	619.765	629.413	557.700*	624.589

*not included in computation of average peak; third order spectra very faint

***Error*.**

LED no.	Observed color	Average peak (nm)	Expected range of λ (nm)	Actual peak (nm)	% error
1	Violet	410.958	384 – 421	402.7	2.051
2	Blue	462.355	436 – 472	454.3	1.773
3	Yellow	558.360	567 – 587	577.4	3.298
4	Orange	576.598	590 – 606	598.6	3.676
5	Orange-yellow	592.776	605 – 624	614.4	3.520
6	Red	624.589	645 – 669	657.2	4.962



Emission spectra of the LEDs used in the experiment.

Possible sources of error include: imperfect alignment of grating and other optical elements; and inconsistent alignment of vertical cross-hair with image.

Answers to Questions:

1. Justify taking the average/midpoint when computing for the peak. How does the spectrum of an LED look like?

   See figure above, *Emission spectra of LEDs used in the experiment*.

2. In the computation of wavelength, the slits in the diffraction grating are assumed to have no width. In reality, the slits have a finite width. Discuss the effect of this theoretical consideration in your results.

   The finite width of the slits is the reason why the observed light is a broad spectrum. If the slit width is narrower, the spectrum produced will be narrower also.

3. A 600 lines/mm diffraction grating is illuminated by a yellow light from a sodium vapor lamp. This light contains two closely spaced lines (the well-known sodium doublet) of wavelengths 589 nm and 589.59 nm. At what angles will the first order maxima occur for these wavelengths?

$$\theta_1 = \sin^{-1}\left(\frac{(589)(1)}{1.66\times10^{-3}mm}\right) = \boxed{20.78°} \qquad \theta_2 = \sin^{-1}\left(\frac{(589.59)(1)}{1.66\times10^{-3}mm}\right) = \boxed{20.82°}$$

4. A light which is known to be composed of red light (632.8 nm) and blue light (420 nm) is used to illuminate a 300 lines/mm diffraction grating. If a viewing screen is placed 1 meter from the diffraction grating, what is the separation distance between the second order red and blue fringes formed at the screen?

$$\theta_{red} = \sin^{-1}\left(\frac{(632.8)(2)}{3.3\times10^{-3}mm}\right) = 22.55°$$

$$\theta_{blue} = \sin^{-1}\left(\frac{(420)(2)}{3.3\times10^{-3}mm}\right) = 14.75°$$

$$x_{red} = (1m)\tan(\theta_{red}) = 0.415m$$

$$x_{blue} = (1m)\tan(\theta_{blue}) = 0.263m$$

$$\text{separation distance} = x_{red} - x_{blue} = \boxed{0.152m}$$