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To: Dr. Frank Kowalski.
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Subject: Spectroscopy Lab.

Abstract

We used a spectrometer to measure the angles of the different wavelengths emitted from helium and sodium light sources. The wavelengths were calculated from the measured angles and were recorded for several orders for each color. The calculated wavelengths were compared to the predicted wavelengths which fell within a 95confidence interval.

1 Introduction

Using a grating spectrometer and two different diffraction gratings (300 and 600 slits/mm), we calculated the wavelengths of light emitted by two different light sources by measuring the angles of light diffraction. The first light source used was helium gas and the second was sodium. The calculated wavelengths were then compared with predicted wavelengths of the different colors of light to verify the grating equation[3].

2 Theory

In this experiment, a grating spectrometer is used to separate certain wavelengths from one beam of light. The spectrometer schematic, shown below in Figure 1, consists of a source, a slit to make the light parallel, a diffraction grating mounted on a table to separate the light, and a goniometer to read the different angles in which the light is diffracted.

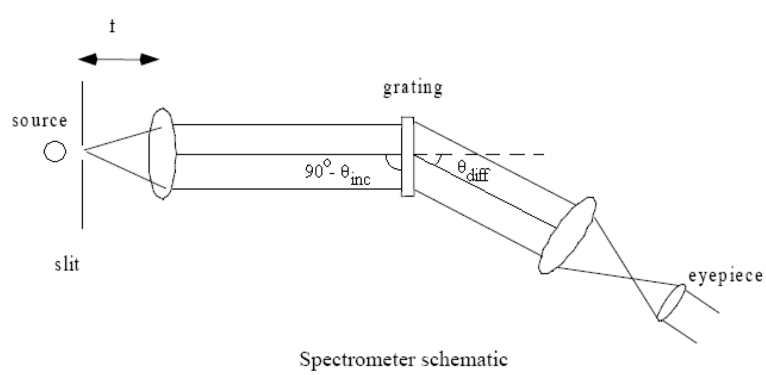

Figure 1: Spectrometer Setup

Two different types of light sources, helium and sodium, were used since different elements emits unique spectra. If the unique spectra of elements are known, an unknown can be determined by its spectrum.

3 Procedure

To begin, set up the spectrometer as shown in figure 1 with a collimator on the left, a telescope on the right and a diffraction grating in the middle that sits on the goinometer. Two diffraction gratings will be used in this lab, one with a $300\frac{slits}{mm}$ grating and another with a $600\frac{slits}{mm}$. Before taking any measurements the diffraction grating will need to be centered. To do this, set up the diffraction grating as perpendicular to the light source as you can by eye and then observe the first colored lines on either side of the zero mark on the goninometer. By recording the angle of the first light observed you can center the diffraction grating by adjusting it until the angles are equal. Also, measure and mark the center of the goinometer and place the diffraction grating on that mark to assure both gratings are the same distance away from the source.

Starting out with the $300\frac{slits}{mm}$ and using the helium light source, observe and record the angles of each of the different colors on either side of the zero mark. Try to record two-to-three orders of diffraction for each light. Next, switch out the $300\frac{slits}{mm}$ for the $600\frac{slits}{mm}$ and observe and record the angles of each wavelength of light, again trying to record two-to-three orders of diffraction. After taking the measurements for both diffraction gratings, switch out the helium light source for the sodium light source and repeat the procedure above with the 300 and 600 gratings. The sodium light will be a bright yellow light source that can make it hard to observe the different colored lines. It is helpful to have a lab partner cover the light that is not entering the collimator. Also, be sure to allow the sodium source to "warm up" for approximately 10 minutes in order to get more accurate results.

4 Results

The goal for data analysis in this lab was to verify the following equation:

$$\sin\theta_{inc} + \sin\theta_{diff} = \frac{m\lambda}{d} \tag{1}$$

Where, θ_{inc} =Angle of incidence, θ_{diff}=Angle of diffraction with respect to the normal, m =order of diffraction, λ =wavelength, and d =distance between slits on the grating. This equation states that different wavelengths of light will diffract at different angles when passing through a grating. Larger wavelengths of light diffract greater than smaller angles because of their wave nature.

The equation becomes significantly simpler if $\theta_{inc} = 0$ so, for measuring the angle of diffraction of different lights it was best to put the grating perpendicular to the incident light beam. This could not be done just by inspection of the actual angle for lack of accuracy. The best way to normalize the grating was to first, look at a line of light that was diffracted from the grating on the left and right sides. The next step was to adjust the grating until the same diffracted line occurred at the same angle on the left as it was on the right. Using this grating, the light is always diffracted at two opposite angles with respect to the normal if the grating is perpendicular to the incident beam.

The errors involved in this experiment were due to precision of instruments, human errors, and due to the position of the grating.

The first instrumental error was due to the measuring limits of the goniometer, which was the table that measured the angle of diffraction. The smallest unit the instrument can measure is 0.1 degrees, so the error in this measurement is always 0.05 degrees.

The position of the grating affects the angle of diffraction if it is not perfectly centered on the goniometer. By moving the grating forward and backward from a zeroed position it was possible to quantify the error in angle due to a wrong position of the grating. The following table shows the numbers used to find this error:

Theta (degrees)	y (in)	Theta (degrees)	y(in)
20.75	zero	10.2	zero
20.75	+0.25 in	10.1	+0.5 in
20.85	+0.5 in	10.2	-0.5 in
20.85	-0.5 in	0	0

Table 1: Displacement Error for 600 and 300 slits/mm

From this analysis the error due to the position of the grating was 0.1degrees per inch for both gratings that were used.

By combining both of the errors affecting the measured angle of diffraction the total uncertainty in θ is 0.1 degrees. This number assumes the worst possible error for a possible error in displacement of 0.5 in and takes into account an error of 0.05 degrees due to the goniometer.

The last sources of error were the predicted wavelengths. The wavelengths produced from the helium lamp were experimentally measured and had no error associated with them[1]. However, the predicted wavelengths for sodium were approximated by comparing a light spectrum with the light that was seen through the telescope[2]. The error involved in this approximation was 20 nm.

Since wavelength is dependent on angle of diffraction there must be some error in calculated wavelength related to Equation 1. Since the only independent variable in this equation is θ_{diff} the error can be found by the following equation:

$$\frac{\partial \lambda}{\partial \theta} d\theta \tag{2}$$

Which, becomes:

$$\frac{d}{m} \cos\theta \tag{3}$$

The acquired data can be found in the appendix but the following graphs show the calculated wavelength with respect to angle of diffraction. The graphs also show error bars for all orders of diffraction.

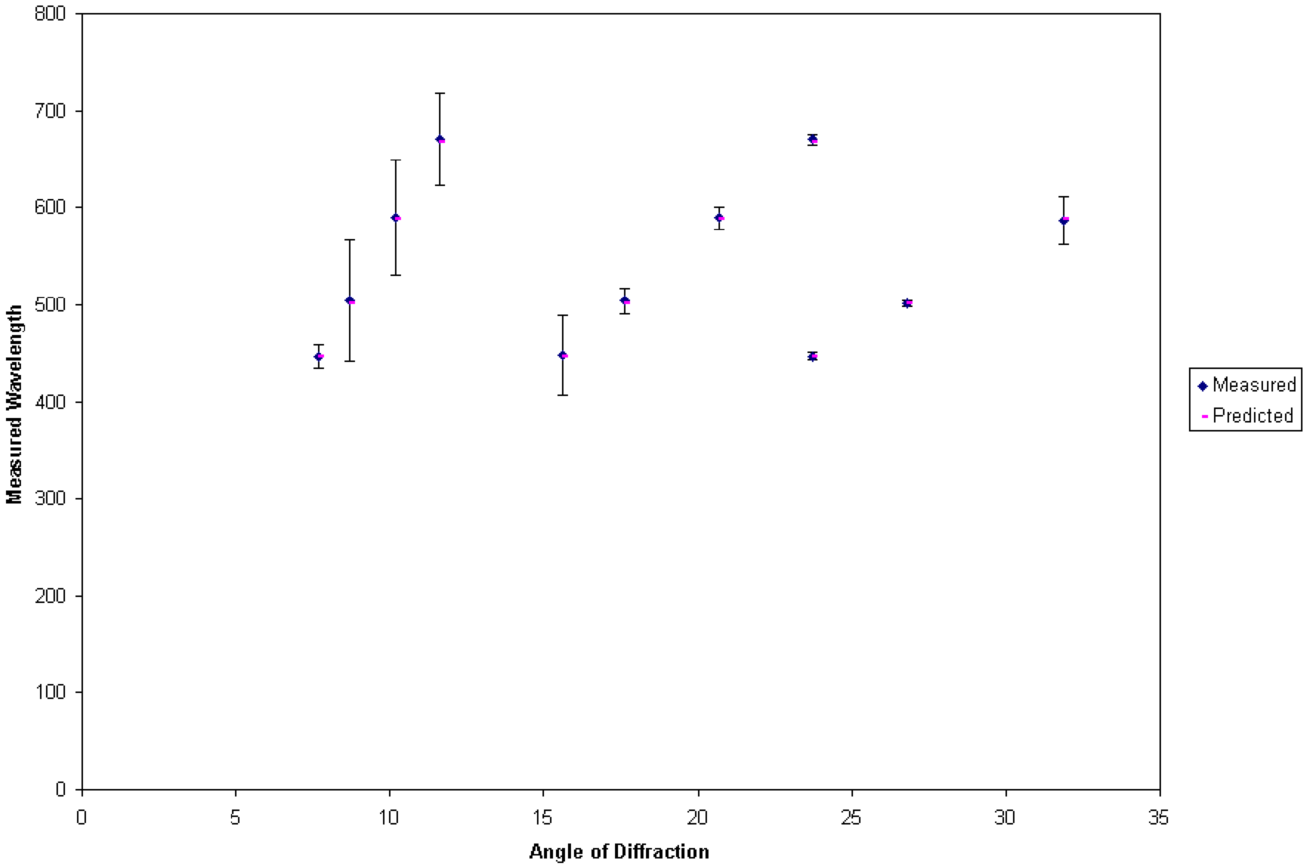

Figure 2: Helium for 300 slits per mm

This graph shows that all of the values for wavelength that were calculated were very close to the predicted wavelengths. For every diffraction the calculated wavelength fell in the 95 percent confidence interval.

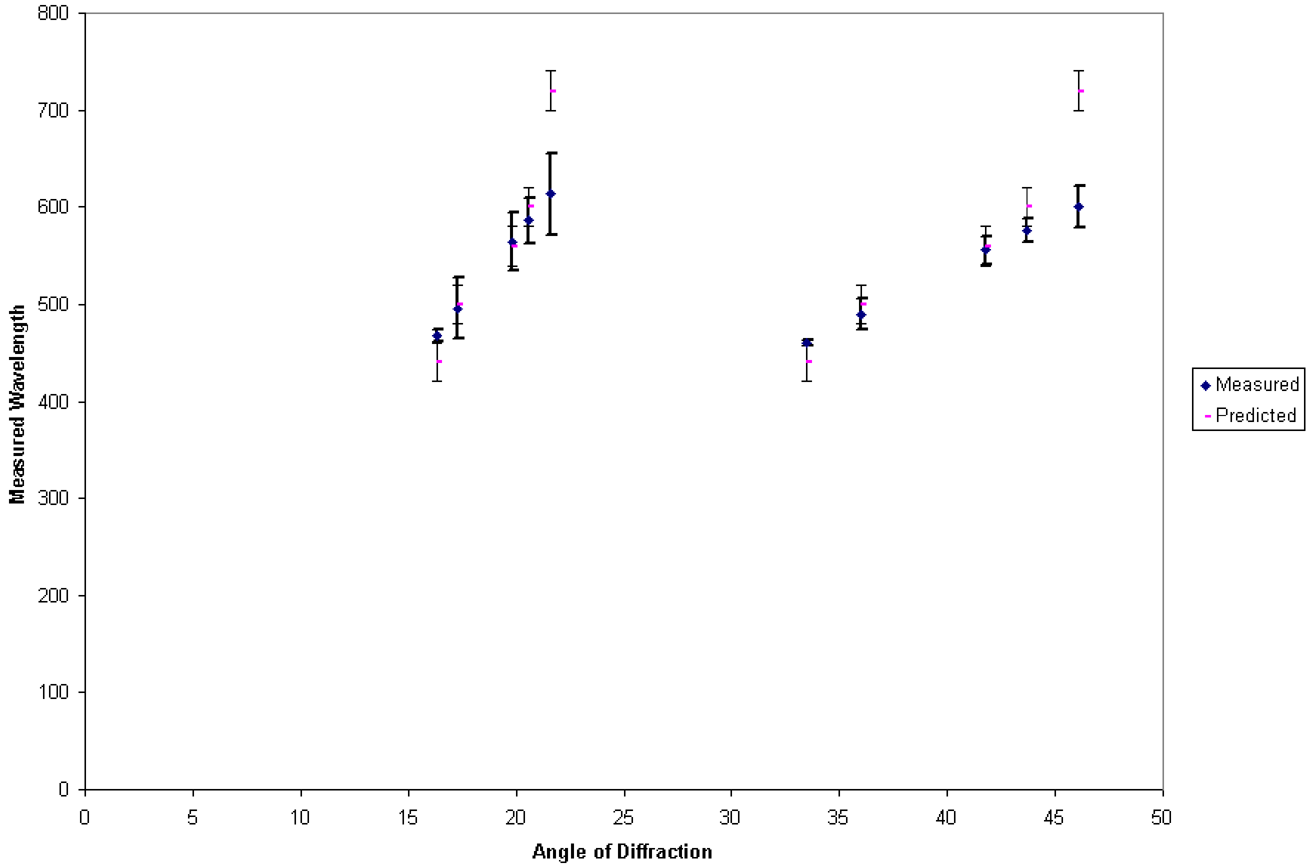

Figure 3: Sodium for 600 slits per mm

This graph shows that most of the calculated wavelengths were close to the predicted wavelengths but some did not fall in the 95 percent confidence interval. This graph contains error bars for the predicted wavelengths unlike the first because of the manner in which they were determined. All calculations fell in the 95 percent confidence interval except for the red light diffractions at the end of each order.

5 Discussion

This experiment confirmed that the equation relating wavelength to diffraction is accurate and is an excellent way to find the spectra of light. All measurements except for two fell in the 95 percent confidence range. The two measurements which did not fall in this range were correct but the method used to predict the wavelengths was not a reliable method. This could have been improved by using accurate data tables with predetermined values for wavelengths as was done for the Helium spectrum. Another way to reduce error in this experiment would be to attach the grating to a more accurate device so it could be better centered on the goniometer. This experiment was very educational in the methods of spectroscopy and was very successful.

References

[1] Author-R. Nave, Atomic Spectra, http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/atspect.html, date accessed, October 6, 2007.

[2] Spectrum.jpg, http://wfc3.gsfc.nasa.gov/MARCONI/images-basic/spectrum.jpg, date accessed, October 6, 2007.

[3] Spectroscopy.pdf, http://ticc.mines.edu/csm/wiki/images/d/d2/Spectroscopy.pdf, date accessed, September 30, 2007.