Analysis of several light sources through simple diffraction setups

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Abstract

The properties of light can be determined by letting it pass through an obstacle with width that is comparable to its wavelength, otherwise known as diffraction. This experiment aimed to determine the wavelength of a monochromatic light, and the Rydberg constant for the hydrogen spectra by letting light pass through a diffraction grating of specified line density. The average measured wavelength for red laser is 686nm. This value is slightly above the theoretical laser wavelength range of 660 nm to 680 nm. The measured Rydberg's constant is $1.04 \times 10^7 m^{-1}$ which is 4.9% from the theoretical value.

Keywords: Diffraction, monochromatic light sources, Rydberg constant

1. Introduction

When light, a plane wave, pass through an obstacle with a width that is comparable to its wavelength λ, it gets bent, thus producing radially propagating electromagnetic waves. These waves interfere with each other, either constructively or destructively depending on which point in space is being considered. Once projected onto a screen that is of distance l from the source, an interference pattern will manifest on the screen which effectively shows maxima and minima as a demonstration of interference. The relation,

$$d \sin\theta = n\lambda \tag{1}$$

where d is the distance between two obstacles, a grating for example, θ_n is the angle from the zeroth maximum to the nth maximum, n is the order of the maximum and λ is the wavelength of the light source. Shown in Figure 1 is a schematic diagram showing the physical meaning of the described parameters.

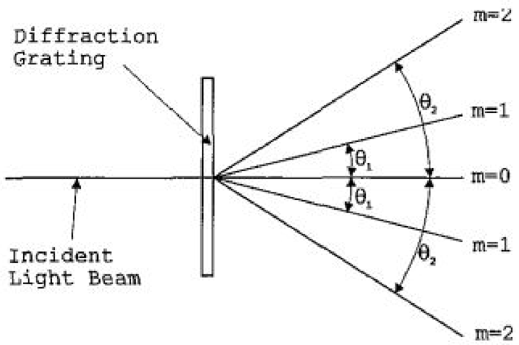

Figure 1: Schematic diagram describing the diffraction of a monochromatic light source

By taking the distance between the screen and the source, and the distance of the nth maximum from the zeroth maximum, the angle prescribed in Equation (1) can be calculated by using the expression,

$$\theta_n = \tan^{-1}\left(\frac{l_n}{L}\right) \tag{2}$$

where l_n is the distance between the nth maximum and the zeroth maximum, and L is the distance between the screen and the source.

The aim of this experiment was to use the previously discussed concepts in determining the wavelength of a monochromatic light source, observing and characterizing the spectra of an atom, and determining the Rydberg constant according to hydrogen's atomic spectra. Also, the limitations of the setup used in this undertaking was criticized in terms of measurement errors.

2. Methodology

The first part of the experiment dealt with the diffraction of monochromatic light when it passes through a grating. The monochromatic light source used in this experiment is a red laser with wavelength specification of $\lambda = 660 - 680$nm. The grating, with line density of 300 lines per millimeter, was placed 62.0 cm away from a screen. The position of the first and second maxima with respect to the zeroth maximum was recorded. The experimental wavelength was determined by using Equation (1) and (2).

Shown in Figure 2 is a setup that was assembled in order to observe and characterize the spectra of hydrogen that was diffracted through a grating with 300 lines per millimeter.

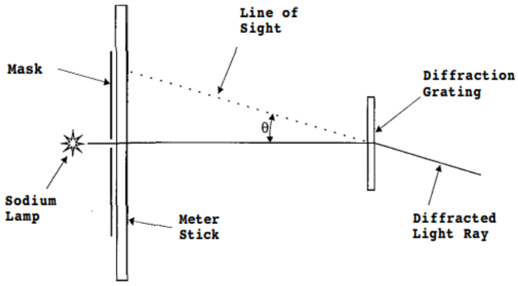

Figure 2: Setup for determining the wavelength via diffraction grating

In this setup, the diffraction grating was placed 62.0 cm away from the hydrogen lamp, with the meter stick mounted onto two iron stands by attaching it to iron clamps. The elevation of the meter stick was precisely aligned to the diffraction grating. The resulting diffraction phenomenon was observed by looking through the diffraction grating. The distance between the spectral lines and the zeroth maximum was measured and recorded for each color and order. Through this dataset, the Rydberg constant (R_H) was determined by using the relation,

$$\frac{1}{\lambda} = R_H\left(\frac{1}{2} - \frac{1}{n^2}\right) \tag{3}$$

which describes the transition of hydrogen's emission lines. The experimental Rydberg constant was compared with the theoretical.

3. Results and Discussion

In the first part of the experiment, the wavelength of the laser light was determined by making it pass through a diffraction grating. The angle of diffraction was determined for the first and second order diffraction. Table 1 shows experimental wavelength of red laser for each order. The average measured wavelength is 686nm and is above the theoretical range of wavelengths which is 660nm to 680nm.

	Measured wavelength (nm)
1^{st} Order	684
2^{nd} Order	692

Table 1: Measured wavelengths for red laser

In the second part of the experiment, the wavelengths of the light in the hydrogen spectrum were measured. The light from the hydrogen source was made to pass through a 300 lines/mm grating and the angle of diffractions in first and second order diffraction were measured for each light spectra?. Table 22 shows the measured wavelength and the theoretical wavelength [1] and the relative error of the measured wavelength. The value of the wavelength and the Rydberg's constant is the average of the values obtained for the 1^st and 2^{nd} order. The average of the measured Rydberg's constant, $1.04 \times 10^7 m^{-1}$, gives a 4.9% error from its theoretical value [2] which is $1.097 \times 10^7\, m^{-1}$. The percent error in the table is the relative uncertainty of the measured Rydberg's constant. Most values obtained in the experiment are close to the theoretical counterpart. All percent errors except that of violet are less than 5%. For the case of the violet spectra, the violet line observed has a large width which affects the measurement values. The line observed by the experimenters is probably made of two line spectra of hydrogen, the violet and the blue

Color	Theoretical wavelength(nm)	Measured Wavelength(nm)	Rydberg's Constant (m^{-1})	Percent error
Violet	410.2	452.8	9.94×10^6	9.4%
Cyan	486.1	502.5	1.06×10^7	3.27%
Red	656.3	669.8	1.075×10^{10}	2.03%

Table 2: Wavelengths and Rydberg Constant for Hydrogen Spectra

spectra.

The wavelengths and the Rydberg's constant have a percent error that is less than 10%. The error is attributed to the methodology used to obtained the said values. The method approximates the angle of diffraction through estimating the position on which the line spectra coincides with the ruler. This gives inaccurate results since the measurement was based on the experimenter's estimation of the position of line spectra on the ruler. The measuring materials used also has high uncertainty. The use of more accurate methods such as spectroscopy will give more accurate results. The instruments used in spectroscopy has higher accuracy which can measure the angle of diffraction up to the 1 minute.

4. Summary and Conclusion

The average wavelength for red laser is 686 nm. This value is slightly above the theoretical wavelength range. For the hydrogen spectrum, the measured Rydberg's constant is 1.04 m^{-1} which is 4.9% from the theoretical value, 1.09%. The wavelengths of the hydrogen spectrum have percent errors all less than 10% from their theoretical values. The methodology and materials used specifically, estimation of the position of the line spectra on the ruler, account the errors in the measured data. The use of other methods such as spectroscopy will give a more accurate results because of the accuracy of the measuring instruments and the decrease in estimation error.

References

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