Using the Spectrometer

Introduction

When an atom is stimulated it can respond by emitting a spectrum of light. The spectrum comprises discrete wavelengths whose values are characteristic of the particular atom, which, from a practical perspective, provides a way of indentifying the atom. In principle, one collects light from the stimulated atom, then passes it through a prism or diffraction grating to separate the light into its constituent wavelengths. One such device for this purpose is the spectrometer. A brief but informative discussion of the spectrometer, including definitions of technical terms related to the spectrometer, can be found in the Wikipedia, the online Free Encyclopedia.

The spectrometer used in this experiment is shown in Fig. 1. It consists of a collimator for focusing light from the source, a diffraction grating for dispersing light of different wavelengths, a telescope for viewing the various wavelengths of light, and a vernier scale for measuring the angles at which each wavelength is dispersed. If the diffraction grating is oriented so that the normal to the plane of the grating makes an angle α to the incident beam of light, as shown in Fig. 3, then the angles θ_m and θ'_m, associated with the m–th intensity maxima $(m = 0, 1, 2 \dots)$ to the left or right of the central maximum are related to the wavelength λ of the incident light according to

$$m\lambda = d\sin(\alpha) + d\sin(\theta_m - \alpha)\,, \tag{1}$$

and

$$m\lambda = -d\sin(\alpha) + d\sin(\theta'_m + \alpha) \tag{2}$$

where d is the spacing between lines in the grating. Combining Eq's 1 and 2 one can show that

$$m\lambda = d\sin(\phi_m)\left[1 - \frac{\sin^2(\alpha)}{\cos^2(\phi_m)}\right]^{\frac{1}{2}} \tag{3}$$

and

$$\tan(\alpha) = \frac{\sin(\delta_m)\cos(\phi_m)}{1 - \cos(\delta_m)\cos(\phi_m)}\,, \tag{4}$$

where

$$\phi_m = \frac{\theta'_m + \theta_m}{2} \tag{5}$$

and

$$\delta_m = \frac{\theta'_m - \theta_m}{2}\,. \tag{6}$$

Color	Wavelength [nm]	Relative Intensity
dark blue	447.1	100
blue	471.3	40
blue-green	492.2	50
green	501.5	100
yellow	587.6	1000
bright red	667.8	100
red	706.5	70

Table 1: The wavelengths and relative intensities of spectral lines of helium shown in Fig. 2.

If $\alpha \approxeq 0$ then Eq's 3 and 4 may be approximated by

$$\lambda = \frac{d}{m}\sin(\phi_m) \tag{7}$$

and

$$\alpha = \frac{\delta_m \cos(\phi_m)}{1-\cos(\phi_m)}\ , \tag{8}$$

both of which are accurate to first order in α.

The purpose of this experiment is to identify specific wavelengths in the helium spectrum, to determine their precise values, and to compare them to accepted values.

Figure 1: Experimental setup. In the foreground is a flashlight, behind which is the spectrometer. To the right of the spectrometer is the power supply with the helium discharge tube mounted across its high voltage connectors.

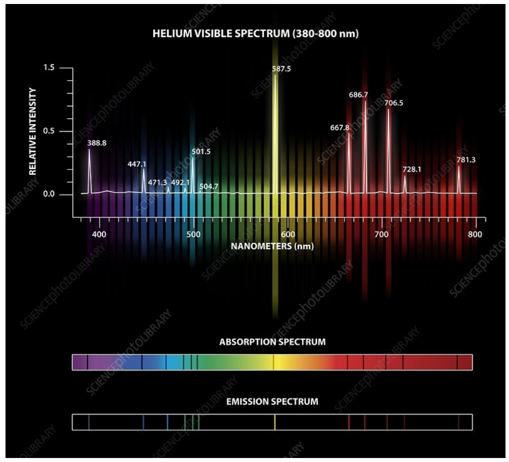

Figure 2: The Helium Spectrum. The visible lines of the helium spectrum are shown. The wavelengths of the prominent lines are given in table1.

Procedure

Seven prominent spectral lines of helium are shown in Fig. 2. The accepted values of their wavelengths are given in Table 1. The three spectral lines of particular interest in this experiment are the dark blue, the yellow, and the red. Note the location of each with respect to other lines in the spectrum. To determine the wavelengths of these spectral lines proceed as follows.

1. Turn on the power supply to which is attached the helium discharge tube.
2. Align the telescope so that the cross hairs in the eyepiece are centered on the light emerging from the collimator tube. Adjust the platform on which the diffraction grating is placed so that the $0°$ marking on the vernier aligns with an angular marking on the scale between the $35°$ and $325°$.[1]
3. Attach the diffraction grating to the platform on the spectrometer. The normal to the plane of the grating should be aligned with the direction of the beam, i.e. α should be close to zero. If the diffraction grating is positioned properly, the angles θ_m and θ'_m are approximately equal, i.e. they should not differ by more than a degree.
4. Identify the $m = 1$ maxima of the dark blue, the yellow, and the red (not bright red) spectral lines to the left of the collimating tube.
5. Measure their respective angles and report them as $\theta_{l,1}$ in Table 2. Note: Because of the vernier scale angles can be measured to an accuracy of $.1°$.

[1]For some spectrometers, this may not be possible.

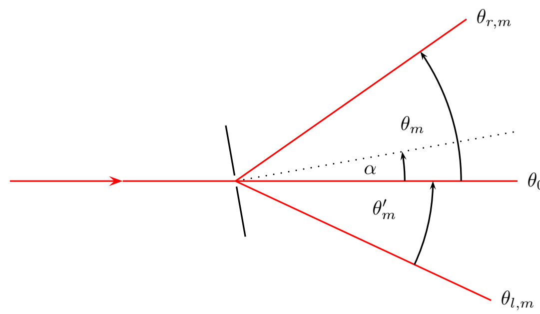

Figure 3: A depiction of the m–th maximum for monochromatic light being dispersed by a diffraction grating. The angle α is the angle the normal to the diffraction grating makes with respect to the incident beam of light. The quantity θ_0 is the angular coordinate of the zeroth order maximum. The quantities $\theta_{l,m}$ and $\theta_{r,m}$ are the angular coordinates of the m–th order maxima to the left and right of the zeroth order maximum.

6. Perform the corresponding measurements for the $m = 1$ maxima to the right of the collimating tube and report their values as $\theta_{r,1}$.

7. Calculate ϕ_1 for each spectral line. According to Fig. 3 one can re-express Eq. 5 as

$$\phi_1 = \frac{|\theta_{l,1} - \theta_{r,1}|}{2} \, . \tag{9}$$

   Report their values in Table 2.

8. Using Eq. 7 with $m = 1$ and $d = 1.6667 \times 10^3$ nm, calculate the experimental value of each wavelength and report them in Table 2.

9. Calculate the fractional deviation of each wavelength and report the values in Table 2. The fractional deviation F is defined as

$$F = \frac{|\lambda_{\text{exp}} - \lambda_{\text{accepted}}|}{\lambda_{\text{accepted}}} \, . \tag{10}$$

	$\theta_{l,1}$ [deg]	$\theta_{r,1}$ [deg]	ϕ_1 [deg]	λ_{exp} [nm]	$\lambda_{\text{accepted}}$ [nm]	F
Dark Blue						
Yellow						
Red						

Table 2: Data and Calculations