Exp: Atomic Emission Spectroscopy

Objectives

- To observe and compare spectra of several light sources with a spectrometer

- To determine the atomic spectra of hydrogen and helium in the visible region and compare experimentally determined spectral lines with lines calculated using the Rydberg equation

Prior Reading

Consult your Burdge textbook for background material on electromagnetic radiation and atomic spectra in chapter 6, sections 1, 2 and 3. Review the wave characteristics of light and the relationship of frequency (or wavelength) to energy as expressed in the equations

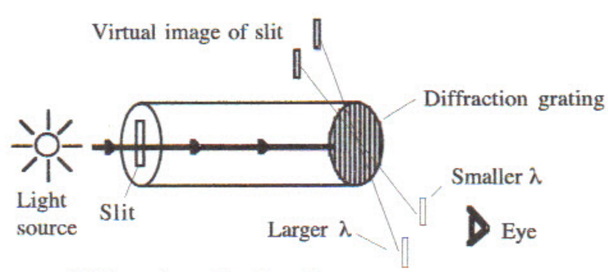
$$\lambda\nu = c \quad \text{and} \quad E = h\nu = hc/\lambda$$

Introduction

Much of our knowledge concerning atoms and molecules comes from investigations of the interactions of electromagnetic radiation (*i.e.,* light) with matter. Energies and frequencies of electromagnetic radiation correspond to energy changes and frequencies of motion within atoms and molecules. Spectroscopy in the ultraviolet and visible regions of the spectrum yields information about the electronic structure of atoms and molecules, whereas studies in the infrared and microwave region provide data on vibrations and rotations in molecules.

There are two general types of spectroscopy—emission and absorption. In emission spectroscopy, samples of matter are "excited" by heating or passing an electrical current through the sample. As the sample returns to the ground state, electromagnetic radiation is emitted. A study of the emitted light yields information about energy levels and changes within the atom. In absorption spectroscopy, electromagnetic radiation is passed through a sample, and information about its structure is obtained by analysis of the wavelengths of light that are absorbed by the sample. This experiment focuses on emission spectroscopy and the diffraction of light.

In the first part of this experiment, you will use a spectroscope to view the spectrum of various light sources. In a spectroscope, light passes through a diffraction grating which is a piece of glass or plastic which has closely and evenly spaced lines on its surface. This grating bends or "diffracts" the light passing through it, and constructive and destructive interference of the diffracted waves leads to a spectrum of the light. A spectroscope is illustrated below.



Diffraction Grating Spectroscope

In the second part of this experiment, you will measure wavelengths of visible light emitted by hydrogen and helium discharge tubes. In a discharge tube, an electric current is passed through a sample of pure hydrogen or helium. As the excited atoms and molecules lose the absorbed energy, they emit light of specific wavelengths. The setup, shown in the Experimental Procedure, allows you to obtain measurements that lead to the determination of the wavelengths of the emitted light. The equation used in these determinations is

$$n \lambda = d \sin\theta$$

where n represents the order number; λ, the wavelength of the emitted light; d, the distance between rulings on the grating; and θ, the angle of the diffracted light from the observer. In this experiment, you will consider what is called first–order spectra where n = 1. Units of the measurements are selected so that the wavelength will be expressed in nanometers (nm).
[Note: You will be using trigonometry to determine $\sin\theta$, and you may want to refresh your memory about tangents and sines.]

Experimental Procedure

• **Spectra of various light sources**

Use a spectroscope to observe the spectrum emitted by an **incandescent bulb**. Sketch a diagram of the spectrum on the data sheet indicating the various colors present.

Repeat this observation of the spectrum of an incandescent bulb with a red filter placed over the end of the spectroscope. Next observe the spectrum of an incandescent bulb with a blue filter over the end. Record these results on the data sheet and note the effects of each filter.

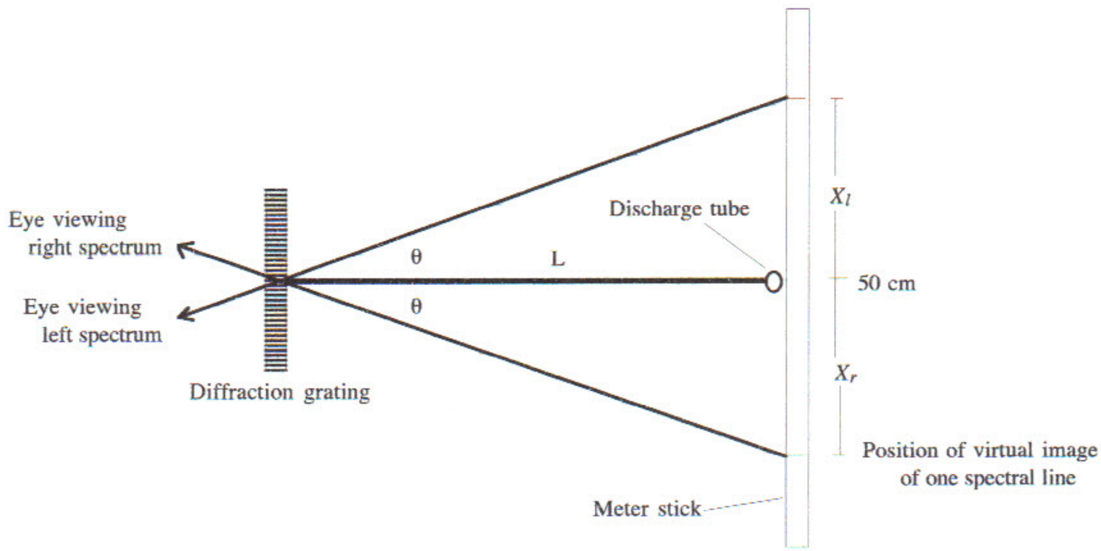
Use a spectroscope to observe the spectrum emitted by the **fluorescent lights** in the laboratory. Record these results on the data sheet and note any differences between the spectra of fluorescent and incandescent bulbs.

Use a spectroscope to observe the spectrum of a **sodium lamp** and record your observations on the data sheet.

Use a spectroscope to observe the spectra of **hydrogen** and **helium discharge tubes**. Indicate on the data sheet the color of the lines that you observe.

• **Determination of wavelengths of hydrogen and helium spectral lines**

The laboratory benches have several setups of hydrogen and helium discharge tubes placed in front of a meter stick and about 90–100 cm from a diffraction grating as shown in the figure below. The discharge tube should be vertical with the meter stick placed behind the thin portion of the tube and exactly at the 50–cm mark on the meter stick. The grating is also directly across from the 50–cm mark so that a line connecting the grating to the discharge tube would be perpendicular to the meter stick.



Schematic Diagram of Apparatus for Determination of λ's

Accurately measure the distance from the discharge tube to the diffraction grating (L) and then turn on the discharge tube. Also record the value of the number of lines per cm of the grating you use. This number is found on the grating slide.

With the laboratory darkened, view the spectrum through the grating, looking both to the right and left on the meter stick to see the spectrum. Have your laboratory partner move paper clips along both sides of the meter stick until the clips coincide with the lines of the spectrum. You should be able to identify the spectral lines by the colors that appear on both sides of the meter stick. Record the distances **both** to the right (X_r) and left (X_l) of the 50–cm mark on the meter stick for each colored line that you observe. These left and right values should agree within a few millimeters. Determine and record the average (X_{avg}) of these distances for each line that you observe.

Record the spectral lines for **both** the hydrogen and helium discharge lamps in the tables on the data sheet.

Apply trigonometric principles to the values of X_{avg} and and L (the length of the dispersion grating from the discharge tube) and calculate $\tan\theta$. Then determine $\sin\theta$ from trigonometric tables or your calculator for each spectral line. Consult the figure for the setup for the discharge tube for the lengths and angles involved.

Lastly calculate the wavelength of each spectral line using the relationship

$$n\,\lambda = d\,\sin\theta$$

where n = 1 for a first–order spectra. The value of the grating spacing "d" is the reciprocal of the number of lines per cm ruled on the grating. Record the measured and calculated values in the appropriate columns on the data sheet.

Atomic Spectroscopy

Pre-Laboratory Questions:

Name: ______________________

Date: ______________________

1. Which part of the visible spectrum represents light with the longer wavelengths and which with the shorter wavelengths?

2. If a grating has 14,200 lines per inch, what is the spacing between the lines in **nanometers** (nm)?

3. Calculate the energy associated with

   a. a red photon ($\lambda = 600$ nm)

   b. a mole of red photons ($\lambda = 600$ nm)

Atomic Spectroscopy

Data & Results:

Name: ______________________

Lab Partner: ________________

Date: ______________________

I. Spectra of various light sources

A. Spectrum of an incandescent bulb

No filter

with red filter

with blue filter

What is the effect of the filters?

B. Spectrum of fluorescent light

What are the observed differences between the spectra of an incandescent bulb and a fluorescent light?

C. Spectrum of sodium light

D. Spectrum of discharge tubes

hydrogen

helium

II. Determination of wavelengths of hydrogen and helium spectral lines

A. Hydrogen spectra (first order spectra where n = 1)

Grating (lines per inch) = ____________ L = ____________

d = ____________________

Color of Line	X_r	X_l	X_{avg}	tan θ	sin θ	λ (nm)

B. Helium spectra (first order spectra where n = 1)

Grating (lines per inch) = ____________ L = ____________

d = ____________________

Color of Line	X_r	X_l	X_{avg}	tan θ	sin θ	λ (nm)

Atomic Spectroscopy

Post-Laboratory Questions:

Name: ______________________________

Date: ______________________________

1. Which color of visible light is diffracted the most and which the least?

2. Compare the wavelengths of the visible spectral lines of hydrogen that you measured to the values calculated using the Rydberg equation, shown below, for the Balmer series of transitions where n_1 is 2 and n_2 is 3, 4 or 5.

$$1/\lambda = R[1/(n_1)^2 - 1/(n_2)^2]$$

where $R = 1.10 \times 10^7\ m^{-1}$

n_2	$1/\lambda$	λ (nm)	λ (nm)
3			
4			
5			

3. Explain the origin of the line spectra in terms of what is taking place with the atom for hydrogen.

4. How would the position of a spectral line change as:

   a. the distance L between the grating and the light source is increased?

   b. the separation d between the the lines of the grating is increased?