Experiment 8: Atomic Spectra

Safety First!

Potential Hazards

- UV hazard. The discharge tubes produce a small amount of ultra-violet radiation. Avoid looking directly at the lamps without eye protection for extended periods of time.
- High voltage warning. The discharge lamps operate under high voltage. Care must be used when changing lamps. If there is a problem with a lamp, notify your TA and have him/her fix the equipment.

Waste Disposal

- There is no chemical waste in this experiment.

Experiment Objective(s):

- Observe and quantify the atomic spectral lines from a variety of elements.

Learning Objectives:

In this experiment you will relate the concepts of atomic energy levels to experimentally observed optical emission spectra. Additionally, you will learn the fundamentals of spectroscopy and instrumental analysis by building your very own visible spectrum spectroscope.

Background:

In preparation for this experiment you should review chapter 7 , sections 7.1 - 7.3(Bohr's Theory of the Hydrogen Atom) of your textbook, Chemistry (Chang & Goldsby), Custom Edition for IIT, 2015.

All atoms when sufficiently energized will emit light. This energy may be added by heating or as in this experiment, with a high voltage electrical current. The emitted light can then be analyzed with a spectroscope to reveal a series of colored lines which are characteristic of the difference between the energy levels of the atoms.

In this experiment you will build a simple spectroscope to view these spectral lines with surprising accuracy, study the visible line spectra of some simple atoms and relate your observations to electron transitions. In the case of the multi-electron atoms, you will not be able to relate the lines to the Bohr model because of the complexity of their spectra. You will observe and record these spectra and note the differences between elements; each element having a unique atomic spectrum much like fingerprints for people.

Experiment 8: Atomic Spectra

As shown in Figure 1, light emitted from a source, S, passes through a narrow slit which defines a thin beam of light in the shape of a ribbon. The ribbon continues in a straight line until it falls on a diffraction grating. The grating consists of a thin, transparent film on which there are very thin, parallel, ruled lines placed very close together.

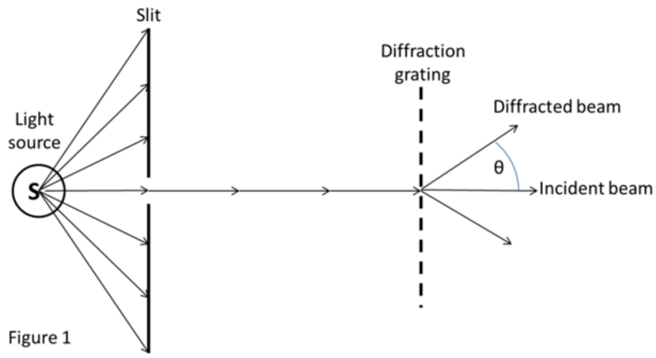


Figure 1

The ribbon of light undergoes a process called diffraction when it passes through the grating where it is deflected in a very specific way. The angle of deflection, θ, depends on two factors: the distance, d, between the lines of the grating and the wavelength, λ, of the light hitting the grating. The mathematical relationship between θ, d and λ for first order diffraction is given by the equation: $\sin\theta = \lambda/d$

The distance between grating lines is inversely proportional to the number of lines per centimeter that are scribed onto the grating. Therefore, a diffraction grating with more lines per centimeter (smaller value of d) will cause a greater deflection, θ, than a grating with fewer lines.

The wavelength of the light is related to its color and photon energy. Light with a longer wavelength (red) will be deflected more than light with a shorter wavelength (violet). If the source consists of white light (which contains all wavelengths in the visible spectrum) an observer will see a continuous spectrum of colors from red on one end with the largest angle diffraction to violet on the other end. If the source is monochromatic light (which consists of a single wavelength) an observer will see a single, sharp line at the appropriate deflection angle. If the source of light consists of two or more wavelengths of light, they will be separated by the diffraction grating. During the course of this experiment you will observe both "continuous" and "line" spectra.

For general information, the wavelength associated with colors of visible light, refer to the textbook, Chapter 7, Section 1, Figure 7.4 on page 278.

Experiment 8: Atomic Spectra

Procedures:

Equipment and Chemicals

- Box
- Diffraction Grating (x lines/cm)
- Graph paper

Pre-lab Assignment (10pts)

Construction of the Spectroscope

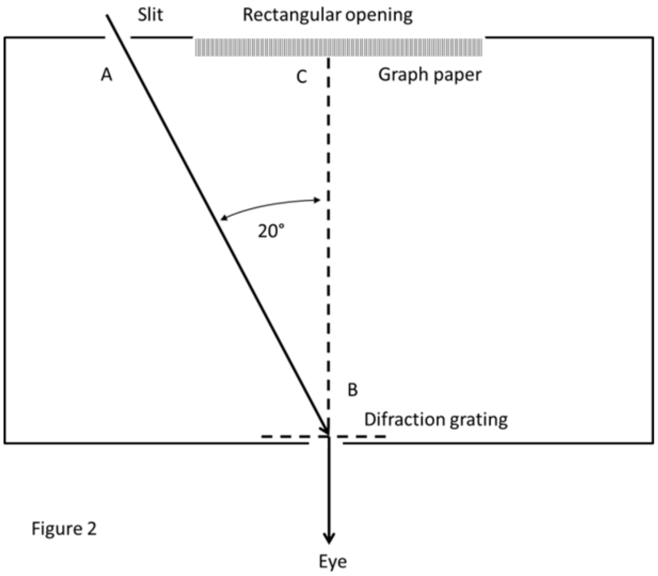


Figure 2

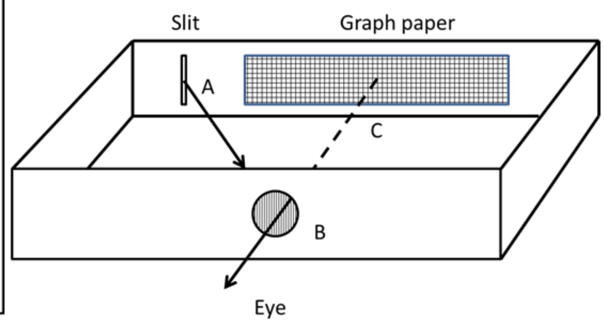


Figure 3

A top-view of the spectroscope to be constructed is shown in Figure 2 and a cross-sectional view is shown in Figure 3. You will construct the instrument at home from any sturdy box, for example a cereal box, shoe box or cigar box. The box will be oriented in a "laying-down" position where the largest faces of the box will be the top and bottom. You will make modifications to the long, narrow edges of the box to build your spectroscope.

1) In the center of one long, narrow sides cut a hole about 3/4 inch in diameter; at the point labeled B in Figures 2 and 3. This opening will serve as the eye-piece of the spectroscope.

2) Cut out a rectangle centered exactly opposite of the hole you already cut at B. The long side of the rectangle will be parallel to long edge of box; labeled C in Figures 2 and 3.

3) At a point 20° from the line BC (the line connecting the center of the eye-piece to the center of the cut-out rectangle) on the same side as the cut-out rectangle, make another hole of 1/2 inch diameter at the point labeled A in Figures 2 and 3.

4) Create a slit at point A by fastening two razor blades (CAREFULLY!) or two business cards or anything with a clean, straight edge. Orient the slit vertically and make the slit very narrow (about 0.5 mm in width).

5) Over the rectangular cut-out at C fasten a piece of graph paper which has graduated millimeter spaced lines. You might need to darken the graph paper lines with ink so that you can read them easily through the eye-piece in a dimly lit room. You will need to be able to read the scale in the laboratory with most of the lights turned off.

6) **Proper alignment of the grating is critical to the success of the instrument.** The diffraction grating has an orientation; the grating lines must be parallel to the slit. Mount the diffraction grating by taping it on the inside of the box covering the eye-piece. Close the box and examine your alignment by observing a white light source through the eye-piece/grating. (Note that many fluorescent lights are not white light sources and only contain certain color of the spectrum.)

You should be able to manipulate the instrument until you see that the light coming in from the slit is diffracted into a continuous spectrum superimposed on the graph paper. The entire spectrum from red to violet should fit onto the graph paper. Ignore any additional (second order) spectra that you may see on the box sides as long as you can see one complete “rainbow.”

If you see no spectrum, try removing the grating and remounting it rotated 90°. If the spectrum is not completely on the graph paper adjust the position of the slit or enlarge the graph paper rectangle. When your spectroscope satisfies these criteria, it should be ready for the laboratory experiments.

(Optional Modifications: The inside of the box may be coated with black flat paint or black paper to remove glare. You may also wish to put an extra sheet of paper or your hand behind the graph paper since too much light may enter and make the spectra difficult to see).

In this particular spectroscope model, light from the slit hits the grating at an angle and is deflected as it passes through. To an observer looking through the grating the IMAGE of the slit appears on the graph paper. This is a virtual image. The grating is not reflecting any light and therefore there is no real image on the graph paper.

Experiment 8

Name___________________ **Partner(s)**_________________________

Procedure

SAFETY:

- UV hazard. The discharge tubes produce a small amount of ultra-violet radiation. Avoid looking directly at the lamps without eye protection for extended periods of time.
- High voltage warning. The discharge lamps operate under high voltage. Care must be used when changing lamps. If there is a problem with a lamp, notify your TA and have him/her fix the equipment.

A. Calibration

1. Observe the mercury vapor arc lamp through you spectrometer.
2. DO NOT attempt to mark the lines on the graph paper!
3. Decide on one graph line to be called zero mm and remember it.
4. Measure the position of each mercury line to the nearest 0.1 mm (if possible) on the graph paper relative to the zero line you have chosen. (If you choose a zero mark in the middle of the spectrum, assign one direction positive values and the other direction negative values on the millimeter scale).
5. In the calculations section, you will plot your data points and draw a straight line to fit the data. The slope of the line will give you the conversion between your millimeter scale and the wavelength of the light in nanometers. The y-intercept will give you the wavelength of light at your chosen zero mark. Each spectroscope will have a unique calibration.

B. Observation of Continuous Spectrum – White Light

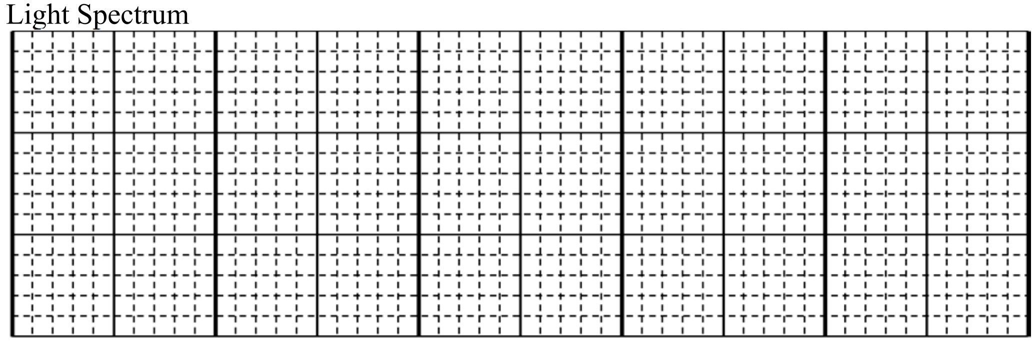
1. Observe the spectrum of white light generated by an incandescent light bulb or sunlight. N.B. Fluorescent light is NOT the same as white light.
2. Sketch your observations on the graph. Note the placement of your chosen zero mm line and where the colors change from purple to blue to green to yellow to red.

Data and Observations

Table 1: Visible Mercury Spectral Lines

Color	Wavelength	Position on Spectroscope (mm)
yellow	578.0 nm	
green	546.1 nm	
blue	435.8 nm	
violet	404.7 nm	

White Light Spectrum



Experiment 8 **Name**___________________ **Partner(s)**_________________________

C. Observation of Simple Line Spectrum – Hydrogen lamp

1. Observe the spectrum from a hydrogen gas discharge tube.
2. Draw the position of each line that you observe and your chosen zero millimeter mark.
3. In the calculation section, you will calculate the wavelength of each line observed.

Hydrogen Line Spectrum

D. Observation of Multi-electron Line Spectra – Helium, Neon, Argon, and Krypton

1. Observe the spectra, one at a time, from a helium gas discharge tube, neon gas discharge tube, krypton gas discharge tube and argon gas discharge tube.
2. Draw the position of the most intense lines of each spectrum as well as your chosen zero millimeter mark.

Helium Line Spectrum

Experiment 8 **Name**____________________ **Partner(s)**__________________________

Neon Line Spectrum

Argon Line Spectrum

TA Signature:_________________

Experiment 8

Name__________________ **Partner(s)________________________**

Krypton Line Spectrum

Fluorescent Light Spectrum

E. Identifying unknown elements in a fluorescent light

1. Observe the spectrum from a fluorescent light source. There should a faint continuous background rainbow (similar to the white light from part B) which you may disregard.
2. Draw the position of the most intense lines of each spectrum as well as your chosen zero millimeter mark.
3. Compare the position of these lines to the other spectra (He, Ne, Ar, Kr and Hg) to identify the elements in a fluorescent light.

Experiment 8

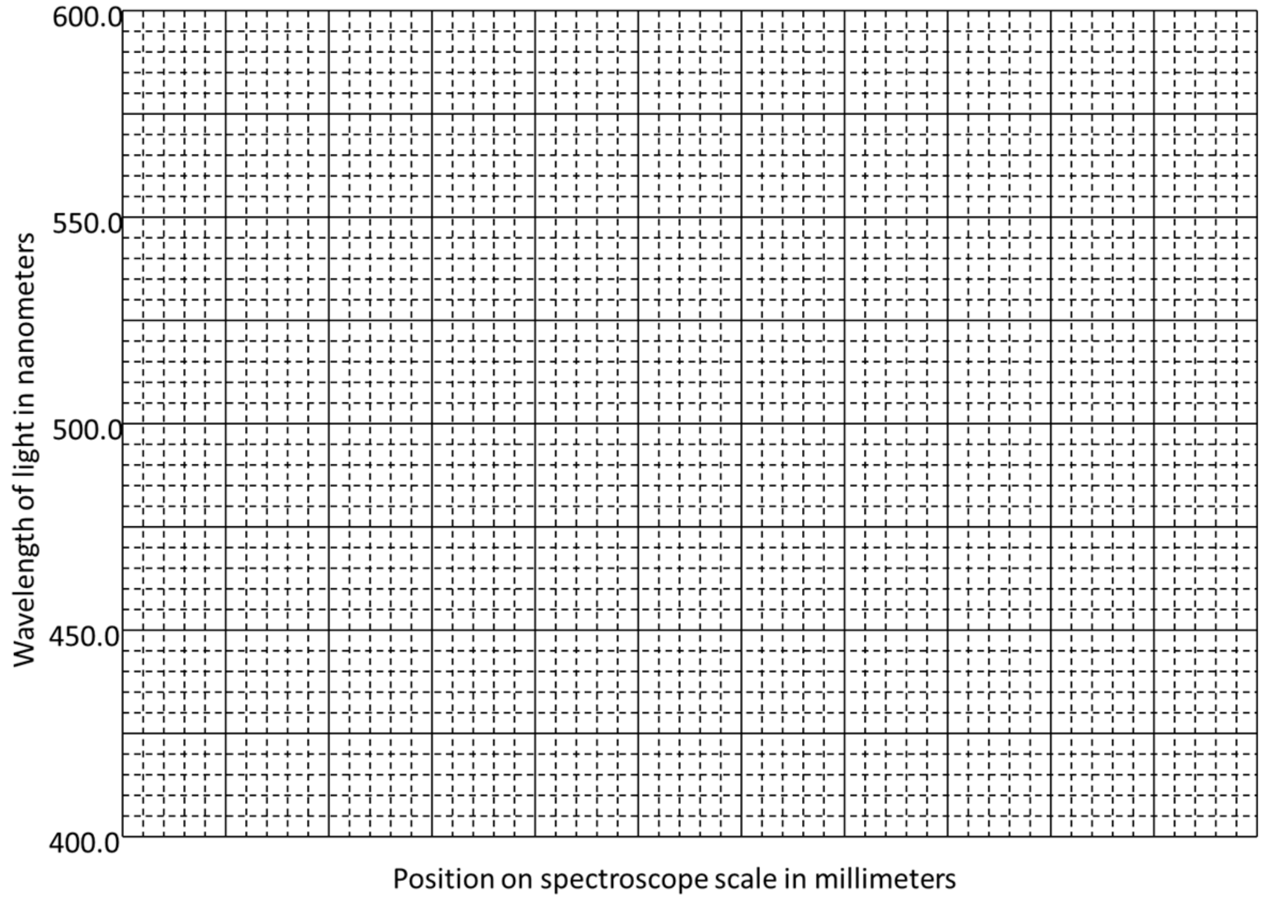
Name____________________ **Partner(s)**__________________________

Calculations

1) Calibration

- Plot the data points from Procedure Part A.
- Fit a line to the data points.
- Find the slope of the line. The slope will convert millimeters on the spectroscope scale to nanometers of wavelength. Its units are nm/mm.
- Find the y-intercept of the line. This is the wavelength that corresponds to the zero mark on your spectrometer.
- You will use these values to determine the wavelengths of the colors and lines you have observed.

Sample Calculations



Slope of Line, m	
Y-intercept, b	

Experiment 8

Name___________________ **Partner(s)**_________________________

2) Hydrogen Line Spectrum – Balmer Series

- For each line you recorded in Part C of Procedure, record the position on the spectroscope in mm.
- Convert your measurements from mm on the spectroscope to nm of wavelength, λ, using the conversion factors from Part 1 of Calculations.
- Use the equation, E = hc/λ, where h is Planck's Constant and c is the speed of light to find the energy associated with each atomic line.
- Use the Rydberg Equation;

$$\Delta E = R_H\left(\frac{1}{{n_f}^2} - \frac{1}{{n_i}^2}\right)$$

  where $n_f = 2$ for the Balmer series to calculate the Rydberg constant in Joules.
- Find the average value of Rydberg Constant.

Table 2: Visible Hydrogen Spectral Lines

Color	n_i	position (mm)	λ (nm)	ΔE (J)	R_H (J)
Red	3				
Blue-green	4				
Purple	5				
4th line (?)	6				

Average value of R_H ___________

TA Signature:________________

Experiment 8: Atomic Spectra

Post-Lab Questions (10pts)

1. By comparing the spectra of the different gas discharge lamps to the fluorescent light what elements are present in the fluorescent bulb? (3pts)

2. Using the Rydberg equation of the Bohr model of the hydrogen atom: (4pts)

a) For the transition of an electron from energy level n = 7 to n = 3 find

i) The change in energy ______________

ii) The wavelength of the photon emitted ______________

iii) The part of spectrum to which it belongs ______________

b) For the transition of an electron from energy level n = 2 to n = 1 find

i) The change in energy ______________

ii) The wavelength of the photon emitted ______________

iii) The part of spectrum to which it belongs ______________

c) Which transition has a larger energy?

3. List two features of the entrance slit of the spectrometer and explain why they are important? (3pts)