VALENCIA COLLEGE

Experiment 9:
Emission Spectra

Version 5

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The light emission of a gas arc-lamp as well as the flame emission spectra of different salt solutions are used to visualize the quantification of energy in the atom. Students will develop an understanding of the electromagnetic spectrum, as well as the ideas of absorption and emission of light by molecules. Students will be able to correlate the energy of the light emitted to the wavelength and frequency of those emissions.

Objectives

- Observe the emission spectra of gases in discharge tubes.
- Observe the light emitted by solutions of cations in a flame.
- Obtain wavelength values from a calibration graph.

Learning Outcomes

- Student will be able to relate wavelength and frequency of electromagnetic radiation to its speed.
- Student will be able to calculate the energy of a photon.
- Student will be able to compare the energies of the electron to the different energy levels of the hydrogen atom.
- Students will measure the emission spectra of different light sources.
- Students will learn how to measure the emitted light using a spectrometer.

Definitions

- **electromagnetic spectrum-** the entire range and scope of frequencies of electromagnetic radiation and their respective, associated photon wavelengths
- **frequency (ν)** - cycles per unit time; for example, wave crests per second in electromagnetic energy
- **ground state** – lowest energy state possible for the electrons in an atom
- **quanta** – a discrete quantity of energy proportional in magnitude to the frequency of the radiation it represents
- **visible spectrum** – region of the electromagnetic spectrum that can be perceived by the human eye
- **wavelength (λ)** - the distance of one wave; for example, crest-to-crest length

Techniques

- Proper use of a diffraction grating spectroscope
- Use of a gas discharge lamp and power supply
- Use of inoculation loop for flame test
- Technique 9: Using a Bunsen burner

Introduction

As a chemist for Light Me Up Fireworks, you did marvelous work identifying the reason for some fireworks failure. As a result, you were promoted to group lead in the research and development (R&D) new products division. Your team has been tasked with identifying colors and combinations for fireworks and other illumination products. A second chemistry team has provided you with materials to study. These materials consist of salts and you must study their light emission properties, with emphasis of the color, intensity, and duration of those emissions. This first prototyping will lead to combinations of different materials for use in novel products for fireworks, flame dyes, and light emitters.

Light is what we define as electromagnetic radiation. It is determined by waves of mutually perpendicular electric and magnetic fields. Any charged particle in the presence of an electric field will feel a force. As particles interact with that force, light can be seen as a form of energy. Light can be described by two principal properties: the wavelength and the frequency.

The wavelength (λ) is the distance between adjacent analogous points in a wave, and it is measured in units of length such as meters (Figure 1). The frequency (ν) can be described as the number of cycles, or wave crests, that pass through a point in a given period of time. The frequency has units of cycles per second, or 1/s (s^{-1}). The SI unit for frequency is the hertz, Hz and 1 Hz = 1 s^{-1}. Light in vacuum travels at the speed of 2.998×10^8 m/s. That value is considered a constant, described with the symbol c. The frequency and the wavelength of light are inversely proportional to each other, and related to the speed of light by the following relationship:

$$c = \lambda\nu \qquad \textbf{\textit{Equation}}\ 1$$

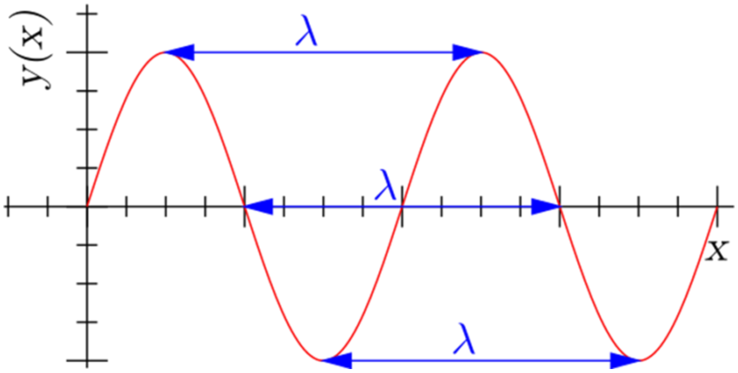

Figure 1. *Wavelength can be defined as the distance between two equivalent points in a wave. As the wave propagates, the frequency can be described as how many waves pass through a point in a period of time. Figure by Richard F. Lyon, under Wikipedia Commons License, 2009.*

In an atom, the electrons are arranged in specific energy levels. At room temperature, those electrons are at the lowest energy state possible, called the ground state. Energy in the form of electricity, heat, or light may be used to excite electrons in atoms to higher energy levels. As the electrons return to their ground state, the excess energy can be emitted as light. The energy emitted is quantized. Quantized means that the light is emitted in small, discrete packets. The energy of these "packets" of light cannot be an arbitrary number. Instead, the light emitted will have a specific energy determined by the difference between the energy levels of the excited level and the lower energy level. The energy of each of these packets is related to the frequency, and thus to the wavelength, by the following relationship:

$$E = h\nu = h\frac{c}{\lambda} \qquad \textbf{Equation } 2$$

where h is a Planck's constant and has a value equal to 6.626 x 10^{-34} J·s.

It is possible to observe the emitted light with the "naked eye" or through a spectroscope when its wavelength is in the visible portion of the electromagnetic spectrum. The electromagnetic spectrum covers a broad range of wavelengths ranging from 10^{-15} m (gamma rays) to 10^{5} m (radio waves). Although the visible region of the spectrum only covers the range from approximately 400 nm (blue) to 700 nm (red), many of the electronic transitions in atoms happen within that range. Because the wavelengths of the light emitted correspond to specific transitions between energy levels, different atoms will have a unique set of wavelengths in which they emit light. This results in different elements having a unique emission pattern or spectrum. We can use this spectrum as a method for the identification of an element.

In the laboratory, emission spectra can be produced by using gas discharge tubes (Figure 2). A small amount of gas is placed in an evacuated tube with electrodes at both ends. A high voltage power supply causes electrons to travel from one electrode to the other at very high velocity. When the electrons collide with the gas molecules, the molecules may be split into atoms, and electrons in the atoms may be excited to higher energy levels.

Similarly, a hot flame can be used to excite electrons in atoms or ions in solution. The flame color of a solution containing a metal ion is a characteristic property of the ion and may be used for identification.

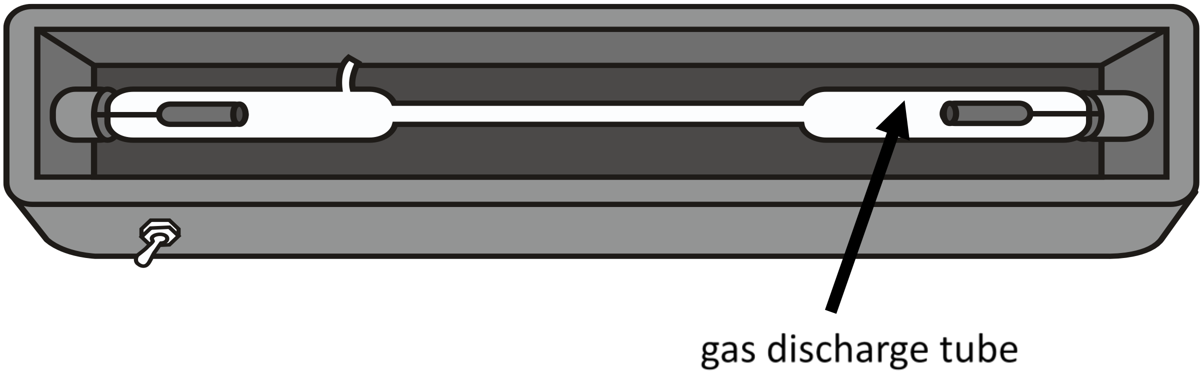

Figure 2. *Correct setup of the gas discharge tube in the high voltage power supply.*

The light emitted by excited atoms and ions always appears to be a single color when observed by the human eye. If the color of the emission is red, possibly red is the only color emitted by the atoms or ions. But the emission may appear to be red when other colors as well as red are emitted. A spectroscope makes it possible to see what colors of light are actually emitted by a light source. The light from an ordinary light bulb is white. Looking at white light through a prism or spectroscope shows that all colors of the rainbow are emitted (Figure 3). The spectroscope has either a prism or grating which separates the various colors of light in space so that they can be observed. In this experiment, you will use a diffraction grating spectrometer. It consists of a thin film of plastic with thousands of very closely spaced lines etched in its surface. As the light waves pass through it, the waves diffract causing a separation of the colors (wavelengths) that composed the incoming light beam.

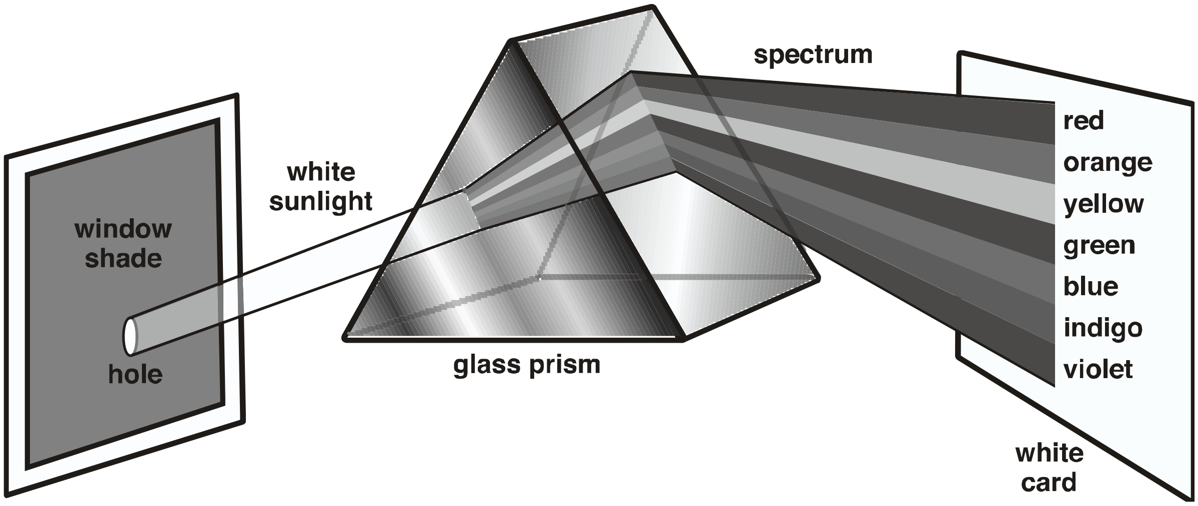

Figure 3. *Different colors of the spectrum as white light is separated by a prism. In this experiment, the colors are separated by a grating.*

Experimental Procedure

Part A. Emission Spectra of Gas Discharge Lamps

Safety Precautions

- ***The STPS-1* Power Supply is a *HIGH VOLTAGE supply***. Be very careful when working with the Power Supply. <u>The voltage between the 2 sockets is 5,000 V</u>. DO NOT TOUCH THE SOCKETS WITH THE POWER ON. Remove the AC plug from the wall socket when replacing spectrum tubes.
- Wear safety googles and labcoat at all times

Equipment

- spectrometer and software
- hydrogen, helium, and several other gas discharge tubes
- power supplies for discharge tubes
- hand-held spectrometer

1. Turn the power supply switch of the <u>hydrogen</u> discharge tube to the ON position.
2. If instructed, open the PASCO Spectroscopy Software and follow the directions provided to record the spectrum of the hydrogen lamp. Your instructor may have prepared the setup for the classroom.
3. Record the wavelengths and intensities (scale readings) of the peaks observed on the hydrogen gas spectrum.
4. Repeat steps 1-3 for the helium discharge tube.
5. Record the wavelengths of emission for two additional discharge tubes using the hand-held spectrometer following the directions below.

6. The spectroscope you will be using is illustrated in Figure 4. Hold the spectroscope so the small end with the square hole is toward you. The wider, curved end has a narrow slit (that lets light into the spectroscope) and a wide window with a numbered scale.
7. While holding the spectroscope a few inches in front of your eye, look through the eyepiece of your spectroscope (the square hole in the small end of the spectroscope that holds the diffraction grating) and point the slit end at the gas tube. The numbered scale should be to the left of the slit as you look through the eyepiece.
8. You should find that a continuous spectrum is located on the left side of the bright "white" slit. Be sure the slit is pointed directly at the light source for the best and brightest spectrum. Each number on the scale indicates the wavelength of light in nanometers when multiplied by 100 (that is, a reading of 5 on the scale is equivalent to 500 nm).
9. Record your observations in the report sheet (describe the observed spectrum).
10. Turn off the power supply for the discharge tube.

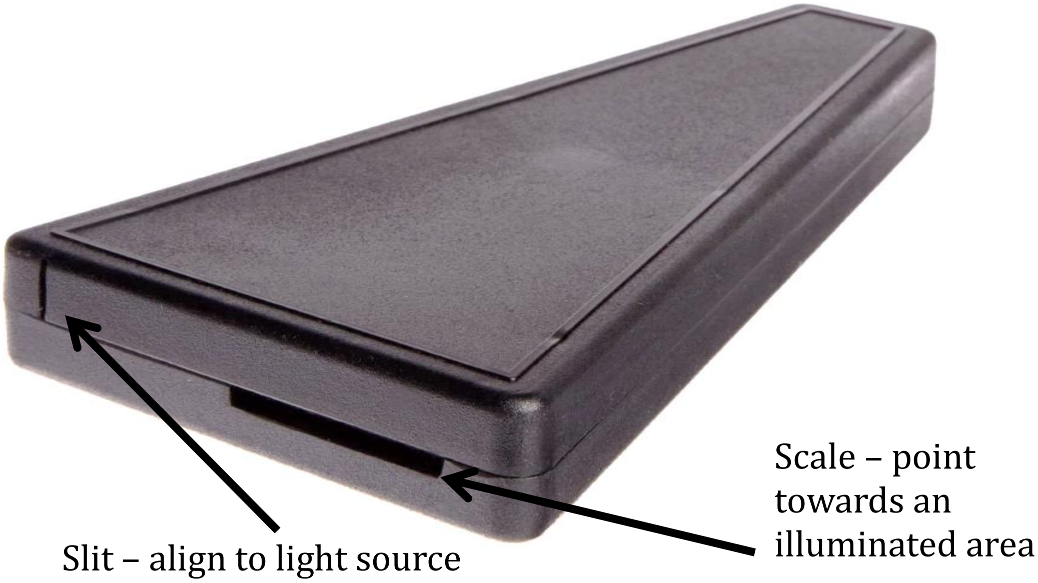

Figure 4. *Hand-held Spectroscope. The slit must be aligned to the light source. The scale bar will show the wavelengths for the lamp observed. The scale reading goes from 4 to 7. Multiply the value by 100 to convert to nanometers.*

Part B. Flame Spectra and Identification of an Unknown Salt

List of Chemicals

- deionized (DI) water
- 6M HCl
- solutions of: $SrCl_2$, $BaCl_2$, LiCl, $CaCl_2$, $CuCl_2$, KCl, NaCl

Equipment

- Bunsen burner
- cobalt glass
- innoculation loop
- small test tubes
- test tube rack

1. Pour a small amount of 6 M HCl into a clean test tube.
2. Obtain a set of 8 clean test tubes. Add a small amount of the following 0.5 M solutions to separate test tubes (enough to cover the wire loop): $SrCl_2$, $BaCl_2$, LiCl, $CaCl_2$, $CuCl_2$, KCl, NaCl, and the unknown salt. Record the unknown number.
3. Setup a hot flame on a Bunsen burner.
4. Clean the wire loop by immersing it in the HCl solution for a few seconds and heating in the hottest part of the flame. The wire should be "red hot" when it is heated. If the wire emits other colors repeat the cleaning process by immersing in the HCl solution followed by the flame. Continue the cleaning process until the wire does not change the color of the flame.

Technique 9

Figure 5. *Flame loop.*

5. Dip the wire loop into the first solution and hold the wire in the flame.
6. Describe the color of the flame and make observations of any other characteristics such as the intensity of the flame and approximately how long it lasts.
7. Repeat step 3: clean the wire by dipping in the HCl solution, then placing it on the flame.
8. Repeat steps 5 to 7 for the remaining solutions.

Note: Try to distinguish between similar colors by comparing them carefully. Note that some colors will appear and disappear quickly. You must look for the color as soon as you put the test wire into the flame. Having more liquid on the wire will give better results for these colors. The sodium color will usually appear along with the characteristic colors of other flames, and should be disregarded.

9. You have just observed that the characteristic flame of potassium is not very intense. It may be impossible to see this flame if sodium is also present unless a special technique is used. Observe the flame color of Na^+ and K^+ again and observe the same two flames through a cobalt glass. Make a mixture of Na^+ and K^+ and observe the flame color with and without the cobalt glass. Record observations.

Experimental Data

Record the wavelengths and relative intensity (scale reading) for the different wavelengths of emission for both the hydrogen and helium lamp. Use the values obtained to calculate the energy of a photon for each wavelength.

Record the wavelengths of emission observed for each color of the two lamps evaluated.

Record your observations for the flame emission spectra of the different salts.

Clean up/Disposal

- Dispose of all solutions into the waste container inside of the fume hood.
- Clean the glassware with soap and tap water, and discard in the sink. Rinse it twice with distilled water, dry the outside of the glassware, and replace in its original location.

Pre-lab

1. What is the role of the high voltage power supply in the gas discharge tube to produce emission spectra?
2. What equation is used to calculate the energy of photons?
3. Explain the variance in the light color emitted by different cation solutions in flames.
4. Explain why a spectroscope makes it possible to see what color of light is emitted by the source of light.
5. If visible light is shining on a blue painted wall, what part(s) of the electromagnetic spectrum is (are) absorbed?
6. The red spectral line of lithium occurs at 671 nm. Calculate the energy of 0.50 moles of photons of this light.
7. Calculate the frequency of light with a wavelength of 250 nm.
8. How do you make observations of the flame colors of Na^+ and K^+ in this Experiment? What is the function of the cobalt glass?

Post-lab

Although color and wavelength are the experimental results that we record when looking through the spectroscope, energy is the important quantity in relating the spectrum to the energy levels of atoms. Calculate the energy of the red-orange hydrogen atom spectral line (See data table for the hydrogen spectra). Show the set-up for each step below.

a. Calculate the wavelength in m:
b. Calculate the frequency in Hz:
c. Calculate the energy in Joules of a photon of the emission.
d. Repeat the calculations (a through c) for the violet line.
e. Calculate the energy for the blue (486 nm) and indigo (434 nm) lines in Joules.

References

1. Adapted from Chemistry Experiments CHM 1045 & 1046 by J. Ems-Wilson and J. Benefield. Valencia College, 2000

Experiment 9:
Emission Spectra
Experimental Data and Calculations

Name: ____ **Date:** ____________________

Lab Partner: __________________________________ **Section:** __________________

Part A. Emission Spectra

1. Description of the emission spectrum of the hydrogen gas tube

Color of Hydrogen discharge tube emission: ___________________

Observations Through Spectroscope (describe the spectrum):

Color	Scale Reading	Wavelength, nm
red-orange		656
blue-green		486
indigo		434
violet		410

2. Description of the emission spectrum of the helium gas tube

Color of Helium discharge tube emission: ______________________

Observations Through Spectroscope:

Color	Scale Reading	Wavelength, nm
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		

3. Observations of two additional gas discharge tubes. You do not need to take the scale readings, just a brief description of the observed spectra.

Gas: ____________________ Color: ____________________

Spectral lines (color and amount):

____

____

____

Gas: ____________________ Color: ____________________

Spectral lines (color and amount): ____

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Part B. Flame Spectra and Identification of an Unknown Salt

1. Record the observations for the flame spectroscopy of solutions.

	SOLUTION	**FLAME COLOR**	**OTHER CHARACTERISTICS**
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.	Unknown ______		

2. Flame emission of potassium in the presence of sodium

SOLUTIONS	COLOR WITHOUT COBALT GLASS	COLOR VIEWED THROUGH COBALT GLASS
K^+ (KCl Solution)		
Na^+ (NaCl Solution)		
K^+ and Na^+ (KCl + NaCl Solution)		

3. Identity of the unknown