Spectroscopy of Atoms and Color

Goals

- To develop skills in careful observation and recording of experimental data
- To understand the relationship between the color *emitted* by atoms and their electronic structure.
- To use color emitted by metal atoms in a flame to identify the metal in an unknown salt.
- To understand the relationships of light and color

Preparation. Read this lab and the material in your text (Section 3.6 in Hill and Kolb) on the electronic structure of atoms.

Background. For the object and its color to be seen, part of that light striking an object must travel to our eye and be recorded in our brain. The external appearance of an object depends, consequently, on (I) the nature of light itself and the (ii) the interaction of light with matter. These topics and the relationships of light to atomic structure are explored in this laboratory.

Emission spectrum of atoms. The radiant energy emitted by the sun (or other stars) contains multiple wavelengths of electromagnetic radiation. The portion of this radiation to which the human eye responds is designated as the *visible region* of the electromagnetic spectrum. Since an optical prism bends or refracts light to different degrees depending upon the wavelength, a rainbow of colors emerges when sunlight or another white light sources passes through a prism. Such a rainbow is called a continuous spectrum.

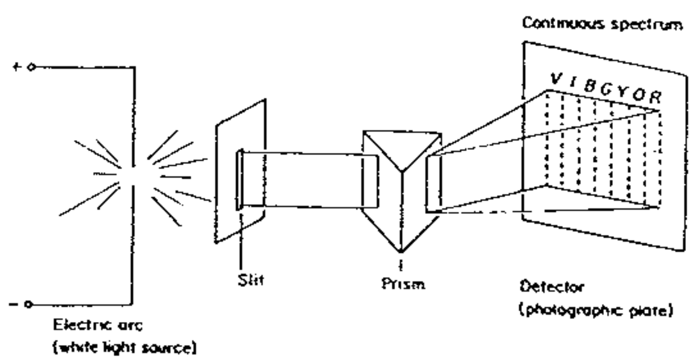

Figure 1: Generation of the spectrum of white light by passing it through a prism. The narrow slit between the light source and the prism sharpens the spectrum. A spectroscope, used to the component wavelengths of a light source, contains a slit, a device for separating or dispersing light into its component parts a prism or diffraction grating and detector or viewer. The spectroscopes used in this lab contain diffraction gratings as the dispersing element.

Just as the sun radiates its high thermal energy in the form of light, most substances will emit light if heated to a high enough temperature. For example, a fireplace poker glows red after sitting in a flame for several minutes. Similarly, neon gas in signs produces a bright red color when excited with an electrical voltage. Application of energy in the form of heat or electricity causes the constituent atoms (or molecules) of a substance to absorb that energy. Electrons within the atoms of the substance move from their normal positions (ground states) to positions of higher potential energy (excited states), farther away from the nuclei of the atoms. The excited atoms will then "relax" and will emit the excess energy. This emitted energy may be in the form of visible light.

In contrast to the sun, excited atoms do not emit light energy in a continuous spectrum but at only certain fixed wavelengths. If you have spilled common table salt, NaCl, into a flame, the yellow /orange light that you have seen is characteristic of sodium emission. If the light given off by the atoms of a particular element is viewed through a prism, or spectroscope, only the wavelengths of light characteristic of that atom will be observed. These resultant sharp bright-colored lines constitute the line spectrum of that element.

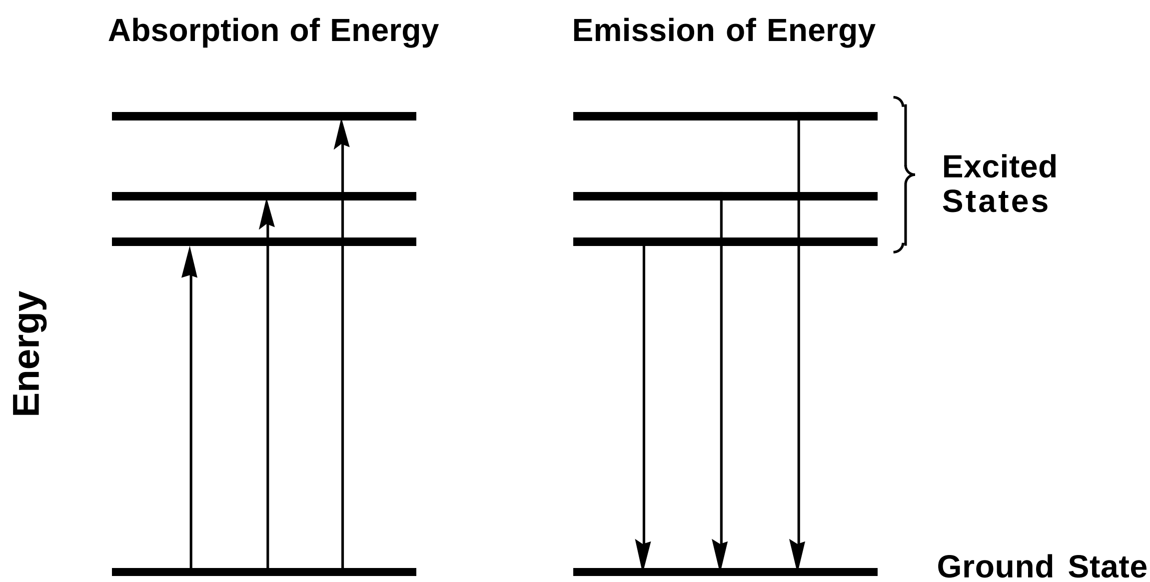

Figure 2. The energy level diagram of an atom showing the transitions between the ground and excited states of an atom when the electrons absorb energy (left) and then emit energy (right). Heat (a flame) or electrical energy can produce the excited atomic state. On returning to the ground state, the electrons will emit light corresponding to the energy differences between the three excited states and the ground state ($\Delta E = hc/\lambda = h\nu$). This process produces light of three different wavelengths or a three-line spectrum. Observation of such line spectra implied a regular, fixed electronic microstructure for the atom and led to our modern view of atomic structure.

In this experiment, you will use spectroscopes to examine the line spectra of mercury, neon, and hydrogen, generated from excitation of these elements in a gas discharge tube.

You will also examine the colors generated by heating different metal salts in a flame and then identify an unknown based on its color. You may wish to use the spectroscopes to re-examine your unknown to confirm its identity.

Experimental

Emission of Atoms

Materials and Equipment

-dilute HCl
-water
-aqueous solutions of ionic salts: NaCl, KCl, LiCl, $SrCl_2$, $BaCl_2$, $CaCl_2$
-spectroscopes
-unknown salt for flame test
-test tubes
-holographic grating (C-Spectrum) for dispersing light into its component wavelengths

Procedure

1. *Continuous spectrum*. Your instructor will first show you the operation of a simple spectroscope. Make sure you understand how to read the scale. The tungsten light bulb in a flashlight will serve as the light source for this exercise.
   a. Observe the visible spectrum through the eyepiece of the spectroscope when a flashlight is held up to the slit. In your notebook, describe what you see. Record the readings on the spectroscope associated with the colors observed. Note that a table is a convenient form for compiling these data; the reading on the spectroscope scale can be converted to nanometers (10^{-9} meters) by multiplying by 100.

Table 1. Spectroscopic observations of tungsten light source.

Color	Reading on Spectroscope Scale	Wavelength Range in Nanometers, nm
Violet		
Blue		
Green		
Yellow		
Orange		
Red		

b. Effect of colored filters. View the light source again by holding one of the filters between it and the spectroscope (or the simple C-Spectrum¤ diffraction grating). Construct another table (Table 2) in which you record the color of the filter and the colors now missing when you look through the eyepiece.

2. *Line spectra*. Use the spectroscopes and the C-Spectrum diffraction grating, view the emission spectra of each of the substances provided: hydrogen, helium, mercury, and neon. Tabulate your results for each light source, giving the overall color of the lamp, the colors of the principal lines observed, and their wavelengths. You may also view these sources through the colored filters and note their effect on the spectra.

3. *Fluorescent lights*. Look at the fluorescent lights in the lab through the spectroscopes and record your observations of their emission spectra. How does this light source differ from the tungsten bulb (incandescent light)?

4. Optional (depending on the weather). Observation of sunlight. Lay a sheet of white paper in a patch of sunlight or look through a window at the outside light. Do not look directly at the sun because it can damage your eyes. Hold the slight end of the spectroscope toward the white paper and the eye-piece against your eye. Compare the observed emission spectrum of the sun with that of incandescent and fluorescent lights.

5. Color emitted by metal atoms in a flame and identification of the metal in an unknown salt.
   a. Obtain a test tube holder, five test tubes and a dip wire. Fill each test tube with a small amount of test solution and label it. Obtain a 50-ml beaker and add approximately 30 ml of dilute HCl into it. Light a Bunsen burner and adjust for the hottest flame possible. Clean the dip wire by immersing into the HCl solution and then holding the end of the wire in the flame to remove the residues imparting a color to the flame. If the impurities remain after the wire glows hot for 10 seconds, start again with another rinse. After you are satisfied that the wire is clean, dip the wire into one of the sample solutions and then into the flame. (The instructor will show you an alternate procedure for observing these materials.) Tabulate the colors for each salt you heat in the flame. You may also wish to observe the flames through C-Spectra or the spectroscope.
   b. Obtain an unknown from your instructor and note the number of your unknown, one of the salt solutions from part a. Conduct the same tests as above. Give your best estimate of the identity of your unknown and state the reasons for your assignment.

Discussion of Results.

1. Summarize your observations of color, wavelength, and light source in a single table or figure.

2. One of the most important relationships in understanding the relationship between light, energy, and the structure of atoms is given by equation (1):

$$\Delta E = hc/\lambda = h\nu$$

Here ΔE gives the difference between two energy levels (such as those in Figure 2). The letters h and c represents two constants: Planck s constant and the speed of light, respectively. The Greek letters λ and ν represent the wavelength and frequency of light, respectively. The important idea for Chemistry 103 students to understand from this relationship is the reciprocal relationship between energy and wavelength.

(a) To illustrate this understanding, compare two the wavelengths of two lines in the emission spectrum of one or more elements.
(b) Consider the colors observed from heating the metal salts in a flame. Compare the difference in energy transitions of two of the metals based upon the colors you observed from their chloride salts.

3. Use your data from the effects of filters to discuss the relationship between the nature of light hitting an object, its color, and the light reaching our eyes.