DAY LABORATORY EXERCISE #4:
SPECTROSCOPY

Goals:

- To see light dispersed into its constituent colors
- To study how temperature, light intensity, and light color are related
- To see spectral lines from different elements in emission and absorption
- To use spectroscopy to discover the components of an unknown gas mixture
- To use spectroscopy to discover the elemental composition of the Sun's atmosphere

Equipment: spectroscopes, discharge tubes of various elements, colored filters, light meters, light bulb, variable power source, colored pencils.

Methods:

- Observe brightness of light bulb through different colored filters for different levels of power to the light bulb.
- Observe spectra of flourescent lights using spectroscopes, to align spectroscopes
- Observe and record emission spectra from element discharge tubes, using spectroscopes
- Observe absorption spectra from the Sun and lab materials, using spectroscopes

Introduction - Most of what we know about the physical nature of stars comes to us from the practice of spectroscopy. In theory, one could learn almost all there is to know about a star (or a nebula or galaxy) from studying its spectrum. Its temperature, pressure, composition and velocity can all be determined. Unfortunately, once the light from a faint star has been spread out into a spectrum, it has become so faint that it is difficult to see, unless a large telescope is used. For this exercise, we will examine various types of light sources in the lab to see how the spectrum can change under different conditions of temperature, composition, and physical state of the material. The types of spectra emitted by materials under various conditions were first described by Gustaff Kirchoff in 1859. He stated his conclusions in the form of three "laws" which still are a useful way to describe the various kinds of spectra. We will examine these laws and their implications in the lab. Prisms and diffraction gratings cause light to spread out into a spectrum of colors (red to violet). For this lab, you will use a spectroscope with a diffraction grating as the dispersing element.

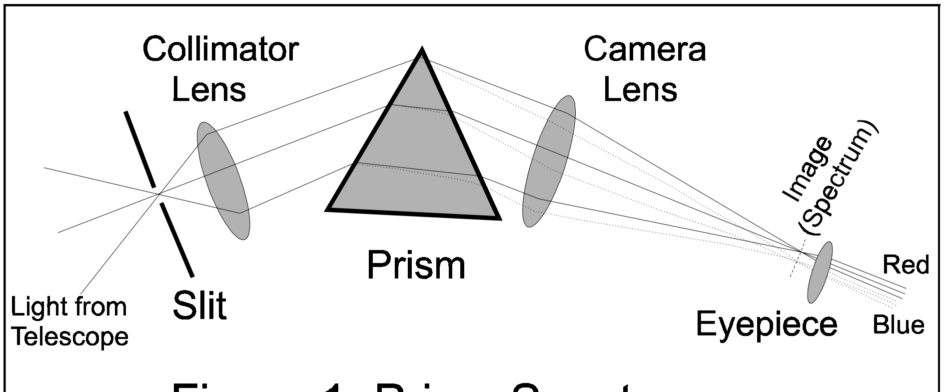


Figure 1: Prism Spectroscope

The **Prism Spectroscope** has five main components (see Figure 1):

Slit: Limits the amount of light which enters the spectroscope. The slit effectively acts as the light source, as it is the image of the slit which is viewed at the eyepiece.

Collimator Lens: Organizes the divergent light from the slit into parallel rays.

Prism: Disperses the incident light into constituent parts by **refraction** or bending within the glass. The prism may be replaced by a grating which uses the principle of **diffraction** to disperse light.

Camera Lens: Focuses dispersed light into a image called the **spectrum**.

Eyepiece: Collimates the image of the spectrum for viewing by the eye.

The **Grating Spectroscope** has many of the same basic features as the prism spectroscope but disperses the light into different colors using the principle of **diffraction** instead of refraction. Diffraction is the spreading or bending of light around an obstacle, such as a slit. Instead of a prism as the dispersing element, this instrument uses a **grating** which has thousands of closely spaced, equidistant, and parallel etched lines on a transparent medium. These thousands of etched lines act as numerous slits, allowing light of a particular color to strongly constructively interfere along a particular direction and light of other colors to be dispersed into other directions. Thus, incident white light is diffracted by the grating and separated into its constituent wavelengths by angle. Figure 2 shows a transmission grating with the diffracted spectrum displayed on either side of the central position.

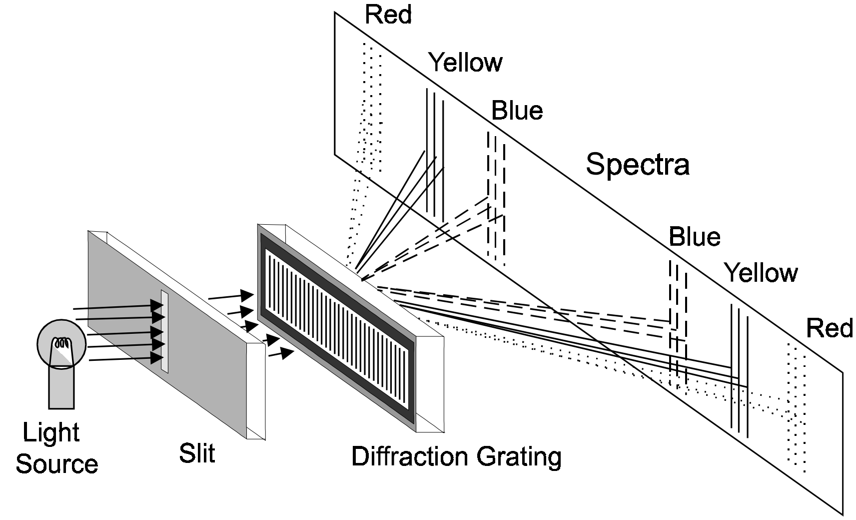


Figure 2: Grating Spectroscope

Figure 3: Project Star Personal Spectroscope

The grating spectroscope you will use in this exercise (Figure 3) has grating material in a window at the narrow end of the instrument. On the wider end, a small slit is placed to one side. To operate this instrument, one looks through the window to view the spectrum, while pointing the slit (the side forming a right angle with wide end, with the slit being at the intersection of edges) in the direction of the light source. The spectrum will appear on either side of the slit. There is an internal ruled scale within the spectroscope, which is calibrated in nanometers of wavelength.

This lab exercise is organized as

"Stations," each featuring one of the three Kirchoff Laws:

Station 1: Kirchoff's First Law: Kirchoff's first law states that any hot substance (i.e. solid, liquid, or gas) under high enough pressure gives off a **continuous spectrum**, that is, it emits photons of all wavelengths. The wavelength (or color) at which the spectrum appears brightest depends on the temperature of the object. At this station we will investigate Kirchoff's first law by using an incandescent bulb connected to a variac (a source of electrical energy whose power level may be varied). The material making up the filament in the bulb provides the continuous spectrum. The variac allows the temperature of the filament to be varied based on the amount of power supplied to the filament. Starting at a low power level, you will use a light meter to record the brightness in different colors of the spectrum seen through different colored filters.

Station 2: Kirchoff's Second Law: An **emission line** spectrum is produced by a hot rarified gas, according to Kirchoff's second law. The spectrum given off consists of bright lines at specific wavelengths. These lines are characteristic of the particular substance being used. An emission spectrum can be produced by a discharge tube which contains a small amount of gas and two electrodes. When a high voltage is applied across the electrodes, the gas is heated, and the electrons in the gas are excited into higher energy levels. In returning to lower energy levels, the gas atoms emit photons of specific energies (therefore specific wavelengths), which can be seen using the spectroscope. Since each element emits at characteristic wavelengths, spectroscopy is a powerful tool for chemical analysis. At this station, you will use your spectroscopes to study the light from several different discharge tubes.

Observe the spectrum of each tube and sketch the pattern observed, remembering that each contains a distinct gas and thus a distinct spectrum. Use the color pencils provided to

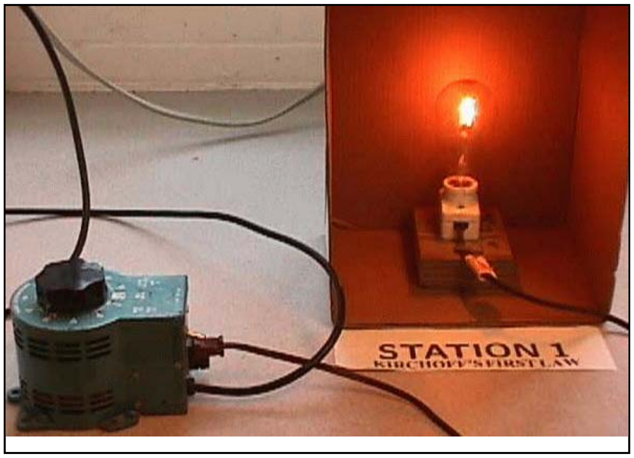


Figure 4: Station 1 showing variac and light bulb

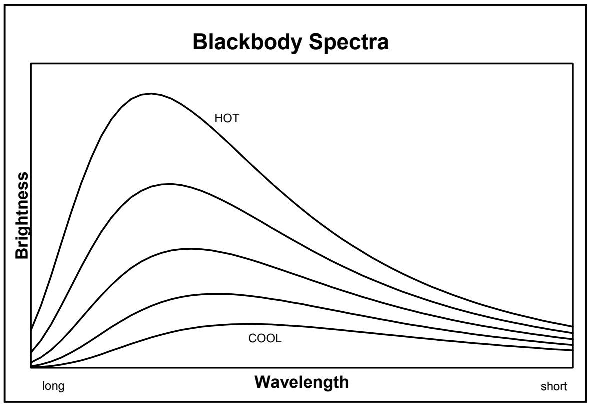


Figure 5: Blackbody spectra

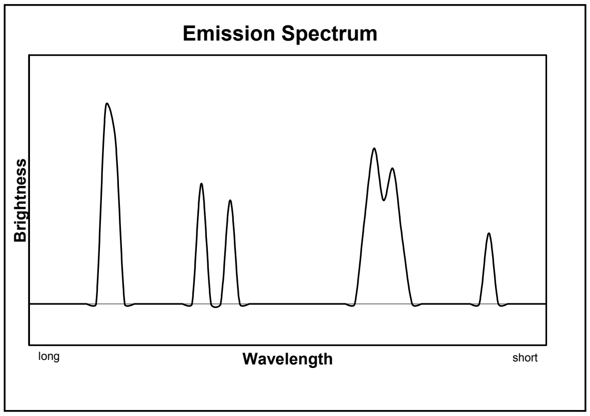


Figure 6: Emission Spectrum

draw the colors and accurate positions of the lines found. Repeat this for all of the different discharge tubes available. At the "Unknown #1" box in this station, use the fact that the pattern of lines uniquely identifies the characteristic gas elements in the spectrum tubes to aid you in identifying the unknown light source, which is a combination of more than one gas element.

Station 3: Kirchoff's Third Law: According to Kirchoff's Third Law, an **absorption spectrum** is observed when a cooler gas is situated in front of a hotter material. In this case, the cool gas **absorbs** light emitted by the hotter material, again at specific wavelengths characteristic of the cooler substance. The absorption and emission spectra are complimentary, in the sense that for a specific element, its emission line pattern will exactly match its absorption line pattern. The Sun has a nice absorption spectrum which can be seen with our spectroscopes.

According to Kirchoff's third law, when a hot, opaque object (or any other source of a continuous spectrum) lies behind a cool, low-density gas, dark absorption lines appear in the otherwise continuous spectrum. This occurs in nearly every star, since light from the interior must pass through the cooler, outer layers. In fact, it was in the spectrum of the sun that William Wollaston first observed dark absorption lines in 1802. Between 1814-1815, Joseph Fraunhofer carefully studied the solar spectrum to find approximately 600 dark lines. Since he was the first to recognize these absorption lines, these solar lines are called "Fraunhofer lines." Some of the "lines" are actually much broader in wavelength than others. These "bands" are formed by molecules, which in addition to transitions between different electron energy levels have transitions between different rotational and vibrational states. The combination of rotations, vibrations, and electron energy levels allows many molecules to absorb a much wider range of wavelengths and produces absorption bands.

At this station, we will investigate absorption lines formed in simple solutions and solid materials. After viewing these solutions and solids, use your spectroscope to study "Unknown #2" in order to ascertain its composition. To obtain the solar spectrum, point your spectroscope toward the window and view the blue sky. You will see that there are a number of vertical dark lines at various wavelengths (colors). Sketch the solar spectrum, indicating where the most obvious absorption lines occur and at which color.

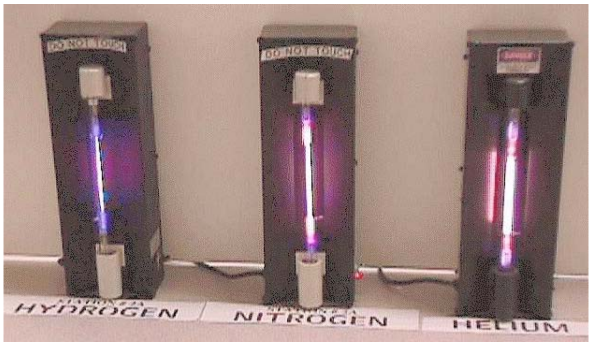


Figure 7: Three discharge tubes (hydrogen, nitrogen and helium) and their host high voltage power supplies

CAUTION: BE CAREFUL NEAR THE DISCHARGE TUBES. THEY ARE VERY FRAGILE, EXTREMELY HOT AND MAY GIVE AN ELECTRIC SHOCK IF MISHANDLED.

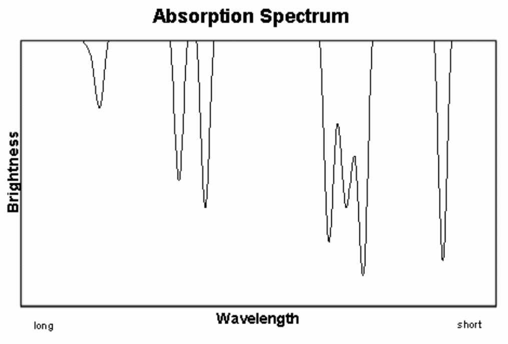


Figure 8: Absorption Spectrum

DAY LABORATORY EXERCISE #4:
SPECTROSCOPY

Name/ID\#____________________________ TA's Initials:________

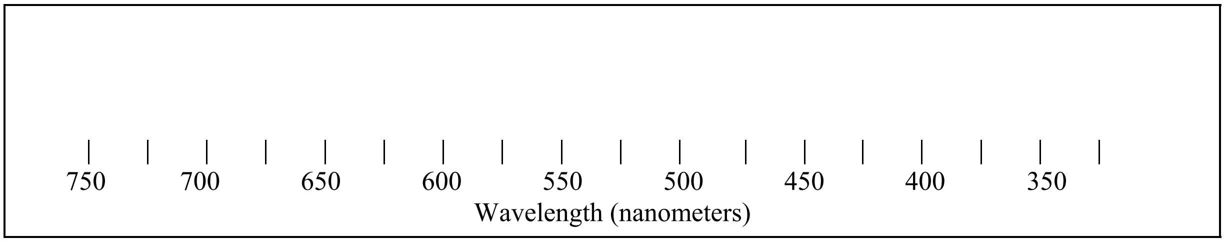
Class/Section: AS102/ ______ Date due:___________

Procedure -

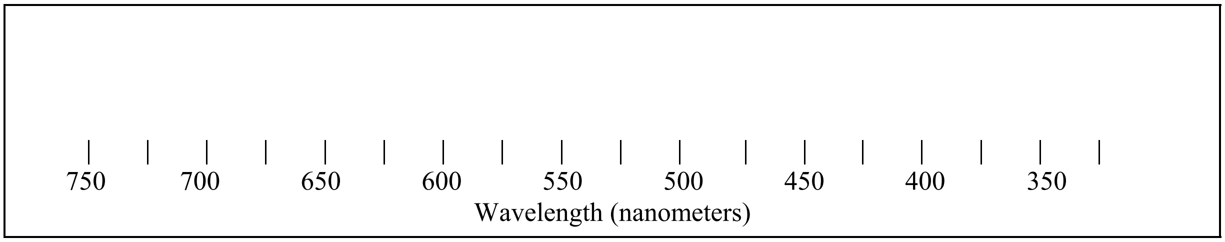
1. Your teaching assistant will explain the use of the spectroscopes and how to record data on the graphs provided. View the fluorescent lights with your spectroscopes to see the green lines.
2. At Station 1 (Kirchoff's First Law) - use the spectroscopes to view the illuminated light bulb. Then record what you see through the spectroscopes as you view the bulb through each of the colored filters. Next, set up a light meter to register the brightness of the light bulb. Placing the three filters one at a time in the light path to the light meter, record the light meter values for three different settings of the power source for the light bulb.
3. At Station 2 (Kirchoff's Second Law) - use the spectroscopes to view all of the different element discharge tubes. Record the views seen through the spectroscopes as accurately as to position and color as possible. These will become templates for identifying unknown mixtures of gases. View the unknown gas with your spectroscope, again accurately recording the positions and colors of the spectral features you see.
4. At Station 3 (Kirchoff's Third Law) - use the spectroscopes to investigate the absorption spectrum of some common solutions and solids. View the daytime sky with the spectroscopes to infer the solar spectrum.

1. Spectroscope Orientation and Practice

- Use your spectroscope to view the flourescent lights on the ceiling. Record what you see in the spectroscope in the space provided below. Please be accurate as to the positions, colors, and relative brightness of the features you see.

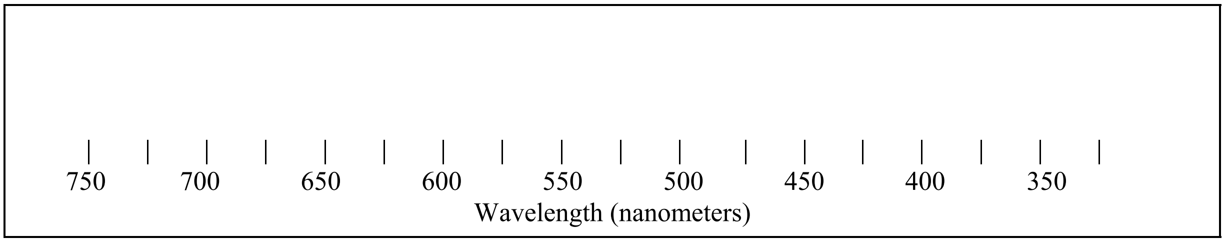


2. Station 1 (Kirchoff's First Law)

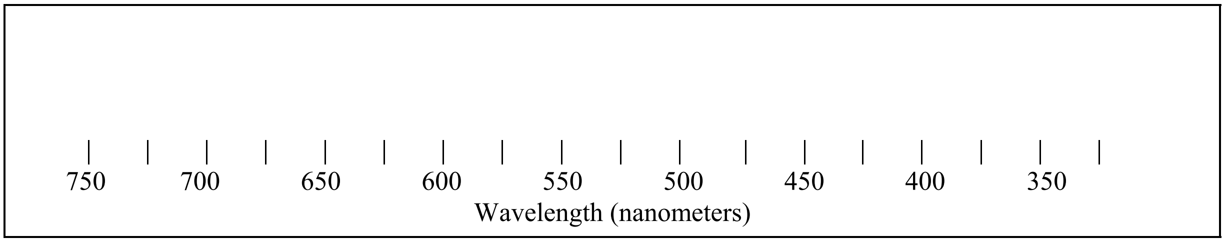


- View the illuminated light bulb through the "Red" colored filter with your spectroscope and sketch the spectrum you see (warning: do not place the filter cose to the light bulb or it will melt!):

- Repeat for the "Green" colored filter:



- Repeat for the "Blue" colored filter:



- Each filter allows a range of wavelengths of light to pass though, while blocking most other wavelengths of light. You can characterize each filter by the "average" wavelength of the light it passes. The average can be estimated as being located midway between the shortest and the longest wavelengths passed by each filter. What "average" wavelengths would you estimate characterize each of these three filters?

"Red" filter average wavelength = _____________________nanometers

"Green" filter average wavelength = _____________________nanometers

"Blue" filter average wavelength = _____________________nanometers

- Place the light meter on a holder near the illuminated light bulb. For each of five power settings, record the light meter reading for each of the three colored filters:

  - Power Setting 20%:
    Describe the brightness, color, and temperature of the light bulb.

    Light Meter Readings: Red Filter = ___________________

    Green Filter = __________________

    Blue Filter = ___________________

  - Power Setting 45%:
    Describe the brightness, color, and temperature of the light bulb.

    Light Meter Readings: Red Filter = ___________________

    Green Filter = __________________

    Blue Filter = ___________________

  - Power Setting 60%: Light Meter Readings:
    Red Filter = ___________________

    Green Filter = __________________

    Blue Filter = ___________________

  - Power Setting 80%: Light Meter Readings:
    Red Filter = ___________________

    Green Filter = __________________

    Blue Filter = ___________________

- Power Setting 100%:
  Describe the brightness and color of the light bulb. Predict (do not touch) the temperature of the light bulb.

Light Meter Readings: Red Filter = ___________________

Green Filter = __________________

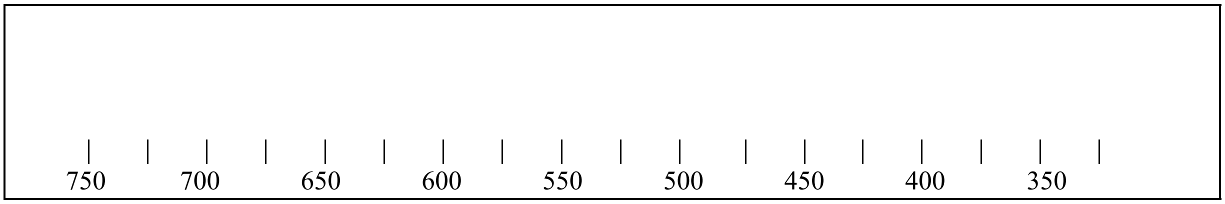
Blue Filter = ___________________

- In the box below, make a plot of the light meter readings versus the wavelength of the filters that you found on page 6. For each power level, plot the light meter readings through the red, green, and blue filters. Draw a line connecting the three filter points for each light bulb power level (you should develop a "family" or set of similar curves).

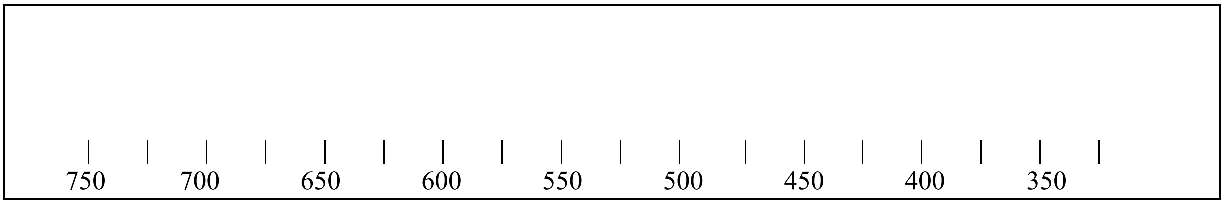
3. Station 2 (Kirchoff's Second Law):

- Examine the spectrum emerging from the "unknown" box to gain a sense of the complexity of emission lines in the unknown.
- Use your spectroscope to view five different element discharge. Accurately render the spectral features of each element using the colored pencils. Pay highest attention to the wavelengths, numbers, colors, and relative brightness of the spectral features.

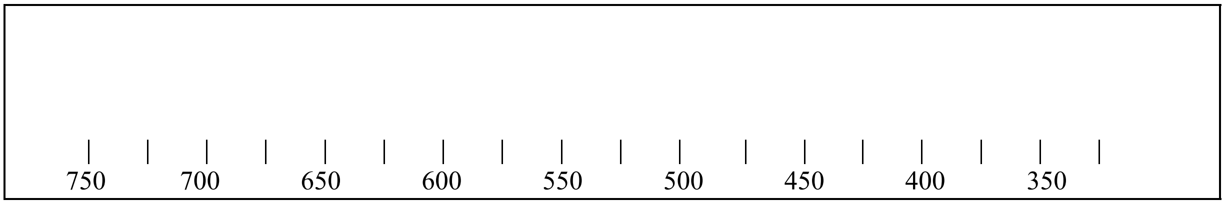
1. Element Hydrogen Overall color of discharge tube ____________________



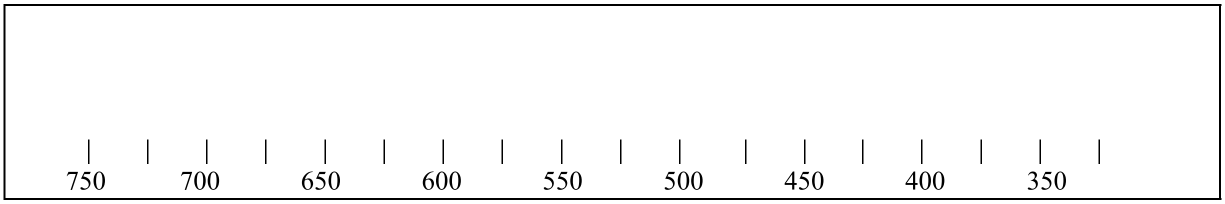
2. Element Helium Overall color of discharge tube ____________________



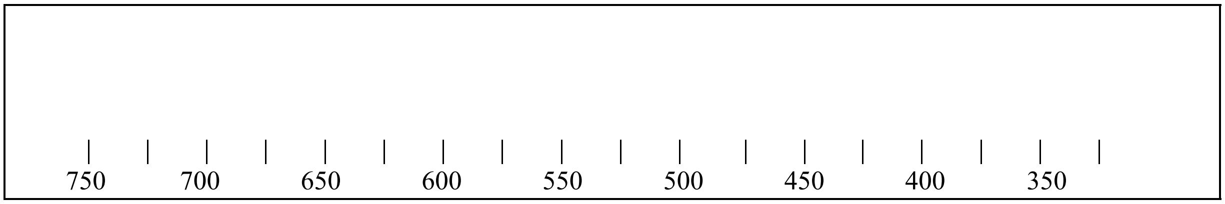
3. Element Neon Overall color of discharge tube ____________________



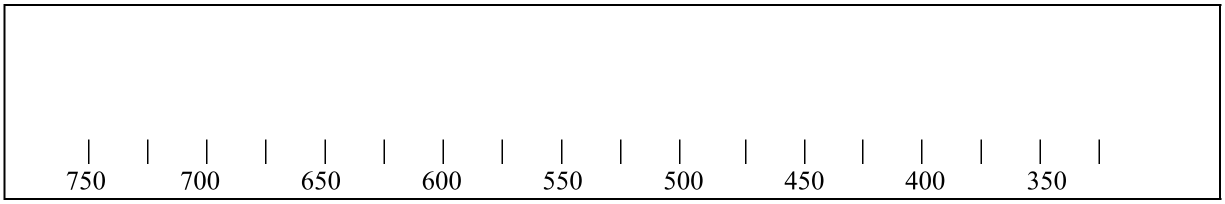
4. Element CO_2 Overall color of discharge tube ____________________



5. Element Mercury Overall color of discharge tube ____________________



- Next, use the spectroscope provided to view the gas in the box labeled “Unknown #1”. Record the spectrum:



What elements (up to two) do you think are present in this unknown gas sample? What do you base your conclusions on?

Element #1 _________________ Basis of Assignment = _________________________

Element #2 _________________ Basis of Assignment = _________________________

- Use your spectroscope to view another four discharge tubes. Do not draw the spectra, instead describe the features that distinguish each spectrum.

1. Element _______________ Overall color of discharge tube ____________________

Distinguishing Features:

2. Element _______________ Overall color of discharge tube ____________________

Distinguishing Features:

3. Element _______________ Overall color of discharge tube ____________________

Distinguishing Features:

4. Element _______________ Overall color of discharge tube ____________________

Distinguishing Features:

4. Station 3 (Kirchoff's Third Law)

- Take a peek at the spectrum for "Unknown #2".
- Use your spectroscope to view the spectra of the light bulb seen shining through liquid solutions and transparent solids.

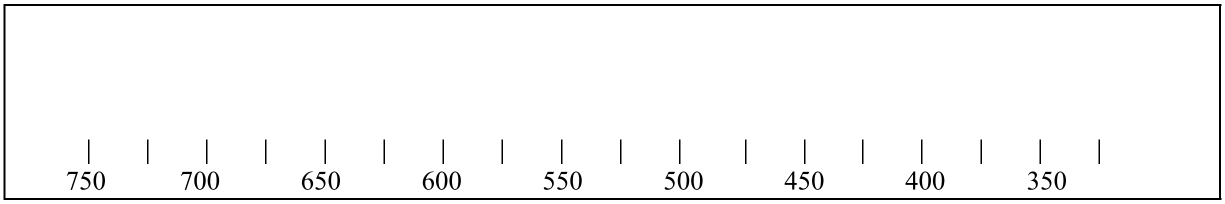
1. Liquid/Solid Type _______________ Overall color ____________________

750 700 650 600 550 500 450 400 350

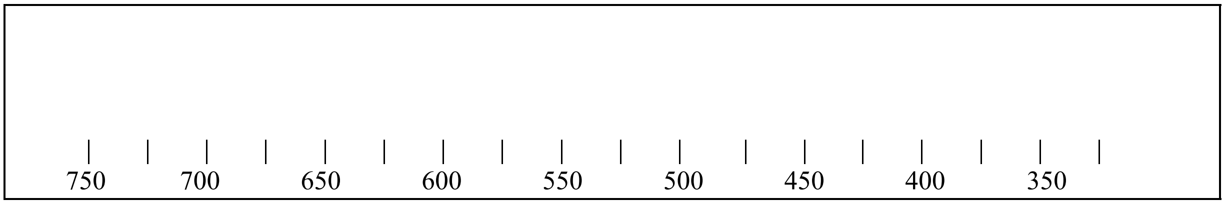
2. Liquid/Solid Type _______________ Overall color ____________________

750 700 650 600 550 500 450 400 350

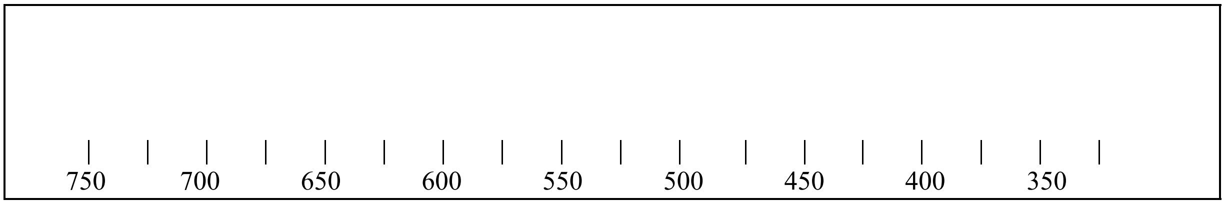
3. Liquid/Solid Type _______________ Overall color ____________________



4. Liquid/Solid Type _______________ Overall color ____________________



- Next, view the spectrum emerging from the “Unknown #2” box and sketch it below:

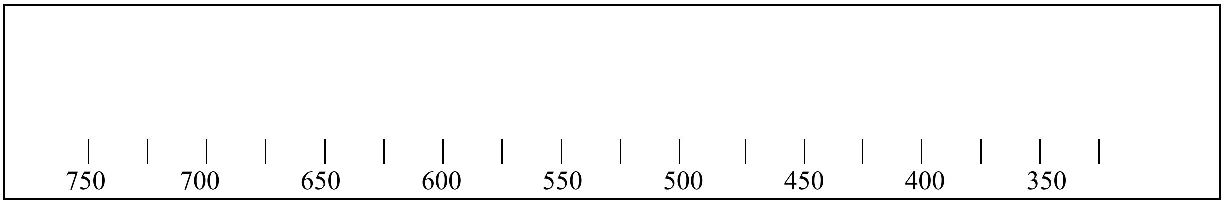


What are the constituents (up to two) of Unknown #2 and what is your reasoning?

Constituent #1 _________________ Basis for Assignment _______________________

Constituent #2 _________________ Basis for Assignment _______________________

- Use your spectroscope to view the daytime blue sky away from the direction of the Sun. Record what you see below, using a black pencil to mark absorption line locations.



- Next, using one of the wavelength tables or charts provided, match up the strongest spectral features seen in the solar spectrum with known elements.

Wavelength of Absorption Line = ______________ Element __________________

Wavelength of Absorption Line = ______________ Element __________________

Wavelength of Absorption Line = ______________ Element __________________

Wavelength of Absorption Line = ______________ Element __________________

Wavelength of Absorption Line = ______________ Element __________________

Wavelength of Absorption Line = ______________ Element __________________

Summary Questions:

1. Station #1 (Kirchoff's First Law)

   - What can you infer about the relationship between the temperature of the emitting material (as indicated by the power level to the light bulb) and the color of the light emitted?

   - What do you think is the most important characteristic which determines the colors of stars? ______________________

2. Station #2 (Kirchoff's Second Law)

   - What kind of spectrum would you expect to see from the atmosphere of a star by looking in the optical wavelength regime?

3. Station #3 (Kirchoff's Third Law)

   - Why does the hot Sun show absorption lines?

4. Applications
    - The Sun's corona shows emission lines. Why?

    - You are an astronomer studying the composition of the atmospheres of stars in a distant galaxy. What instruments would you want to use and how would you go about using them?