# Physics 197 Lab 11: Discrete and Continuous Spectra

## Equipment:

| Item | Part # | Qty per Team | # of Teams | Total Qty Needed | Storage Location | Qty Set Out | Qty Put Back |
|---|---|---|---|---|---|---|---|
| Red Tide Spectrometer | Vernier V-Spec | 1 | 8 | 8 | | | |
| Computer with Logger Pro | | 1 | 8 | 8 | | | |
| Optical Fiber Assembly | For Red Tide | 1 | 8 | 8 | | | |
| Ring Stand and Clamp | | 1 | 8 | 8 | | | |
| USB Cable – Red Tide to Computer | | 1 | 8 | 8 | | | |
| Discharge Lamp Assembly | | 1 | 8 | 8 | | | |
| Hydrogen Discharge Tube | | 1 | 8 | 8 | | | |
| Discharge Tubes He, Ne, Ar, Kr, $N_2$ | | share | 8 | 3 each | | | |
| Stefan-Boltzmann Tungsten Lamp | PASCO TD-8555 | 1 | 8 | 8 | | | |
| DC Power Supply for Lamp with Cords | | 1 | 8 | 8 | | | |

## Layouts:

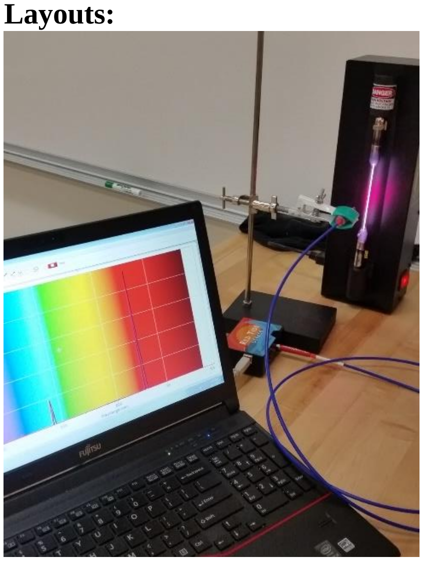


Figure 1, Spectrometer Setup for H discharge

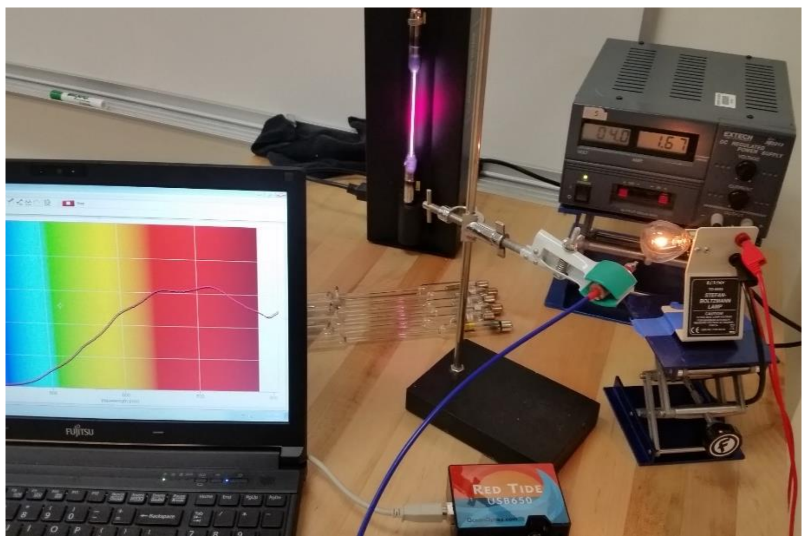



Figure 2, Setup for Blackbody Radiation from Tungsten Filament

## Summary:

In this lab, students will investigate emission spectra from various discharge lamps and from a tungsten filament. In Experiment A (figure 1) the emission spectrum from a hydrogen discharge lamp will be recorded. By using the wavelengths for the observed emission lines, along with the Balmer series wavelength formula, the Rydberg constant can be calculated. In Experiment B, the emission spectra of various gas discharge tubes (He, Ne, Ar, Kr, and $N_2$) will be observed and recorded. In Experiment C (figure 2) the blackbody emission spectrum from a tungsten filament operated at different temperatures will be observed.

**PreLab:**

The light you see when you plug in a hydrogen gas discharge tube is a shade of lavender, with some pinkish tint at a higher current. If you observe the light through a spectroscope, you can identify four distinct lines of color in the visible light range. The history of the study of these lines dates back to the late 19th century, where we meet a high school mathematics teacher from Basel, Switzerland, named Johann Balmer. Balmer created an equation describing the wavelengths of the visible hydrogen emission lines. However, he did not support his equation with a physical explanation. In a paper written in 1885, Balmer proposed that his equation could be used to predict the entire spectrum of hydrogen, including the ultra-violet and the infrared spectral lines. The Balmer equation is shown below.

$$\lambda = B\left(\frac{n^2}{(n^2-4)}\right)$$

where n is an integer greater than 2 (e.g., 3, 4, 5, or 6), and $B$ = 365.46 nm. When one solves the equation, the calculated wavelengths are very close to the four emission lines in the visible light range for a hydrogen gas discharge tube. Balmer apparently derived his equation by trial and error. Sadly, he would not live to see Niels Bohr and Johannes Rydberg prove the validity of his equation.

Johannes Rydberg was a mathematics teacher like Balmer (he also taught a bit of physics). In 1890, Rydberg's research of spectroscopy (inspired, it is said, by the work of Dmitri Mendeleev) led to his discovery that Balmer's equation was a specific case of a more general principle. Rydberg substituted the wavenumber, 1/wavelength, for wavelength and by applying appropriate constants he developed a variation of Balmer's equation. The Rydberg equation is shown below.

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

The energy levels are the integers in the equation, labeled $n_i$ and $n_f$ for initial and final levels, with $R_H$ representing the Rydberg constant. Relating it to the Balmer equation, $R_H = 4/B$. For the hydrogen atom Balmer series, $n_f$ is 2, as shown in the first equation. The term $1/\lambda$ is the wavenumber, as expressed by Rydberg in his version of the Balmer equation. Niels Bohr used this equation to show that each line in the hydrogen spectrum corresponded to the release of energy by an electron as it passed from a higher to a lower energy level. In experiment A you will measure the emissions from a hydrogen gas discharge tube and analyze the emission data to calculate the Rydberg constant.

Use the Balmer equation to calculate the four wavelengths in the visible light range for the hydrogen gas emission. Please record your information in the data table below. The calculated wavelengths should give you a strong clue as to the color of the four emission lines.

| $n_i$ | $n_f$ | $\lambda$ (nm) | color |
|---|---|---|---|
| | 2 | | |
| | 2 | | |
| | 2 | | |
| | 2 | | |

**Experiment A: Rydberg Constant from Hydrogen Spectrum**
(The following write-up, along with the pre-lab description, are copied from Vernier Spectroscopy Lab 6, "The Rydberg Constant")

**OBJECTIVES**

In this experiment, you will

- Measure and analyze the emission spectrum of a hydrogen gas discharge tube.
- Use the data from the hydrogen emission spectrum to calculate the Rydberg constant.

**PROCEDURE**

1. Connect a fiber optic cable to the threaded detector housing of the spectrometer.

2. To prepare the spectrometer for measuring light emissions, in Logger *Pro*, open the Experiment menu and select Change Units ► Spectrometer: 1 ► Intensity.

3. To set an appropriate sampling time for collecting emission data, in Logger *Pro*, open the Experiment menu and choose SetUp Sensors ►Spectrometer:1. In the small dialog that appears, change the Sample Time to 60 ms, change the Wavelength Smoothing to 0, and change the Samples to Average to 1.

4. Turn on the hydrogen gas discharge tube. Aim the tip of the fiber optic cable at the tube.

5. Start data collection. An emission spectrum will be graphed. Set the distance between the discharge tube and the tip of the fiber optic cable so that the peak intensity on the graph stays below 1.0. When you achieve a satisfactory graph, stop data collection.

6. To analyze your emission spectrum graph click the Examine icon, , on the toolbar in Logger *Pro*. Identify as precisely as possible each of the four wavelengths of hydrogen's Balmer series. The third and fourth peaks are very small but they can be identified. Write down the four peaks of the graph in the data table below.

7. Store the run by choosing Store Latest Run from the Experiment menu in Logger *Pro*. You will need this for the last part of the data analysis.

**DATA TABLE**

Complete the table below. You will have recorded the wavelengths from examining the graph of the hydrogen discharge tube emissions.

| Wavelength (nm) | Wavenumber ($m^{-1}$) | Frequency (Hz) | Photon Energy (J) | $n_i$ (Balmer Series) |
|---|---|---|---|---|
| | | | | 3 |
| | | | | 4 |
| | | | | 5 |
| | | | | 6 |

**Calculation Guide**

- Wavelength: examine the graph and write down the peak in the specified regions.
- Wavenumber = $10^9$/(wavelength in nm)
- Frequency = ($3 \times 10^8$ m/s) / (wavelength in m) **Note**: 1 nm = $1 \times 10^{-9}$ m
- Photon Energy = (frequency) × $h$ **Note**: $h = 6.626 \times 10^{-34}$ $m^2 \cdot kg \cdot s^{-1}$

**DATA ANALYSIS**

1. Use the equation described in the introductory remarks to calculate the Rydberg constant for the four lines in the Balmer Series that you identified in the table above. What is the average value for the Rydberg constant, based on your data?

2. A second method of determining the Rydberg constant is to analyze a graph of the values of n in the Balmer Series *vs*. the wavenumber. Prepare a plot of Wavenumber (Y-values) as a function of $1/n_i^2$ (X-values). Calculate the best-fit line (linear regression) equation for the plot; the slope of this line is equal to $-R_H$.

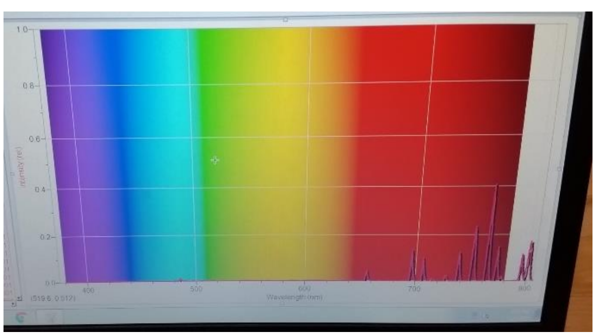
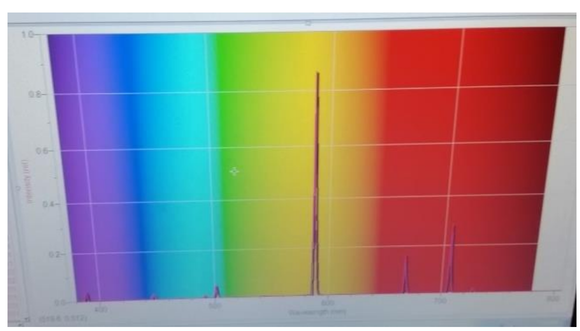
3. An accepted value of the Rydberg constant, $R_H$, is $1.097 \times 10^7$ $m^{-1}$. Compare your value of $R_H$ to the accepted value.

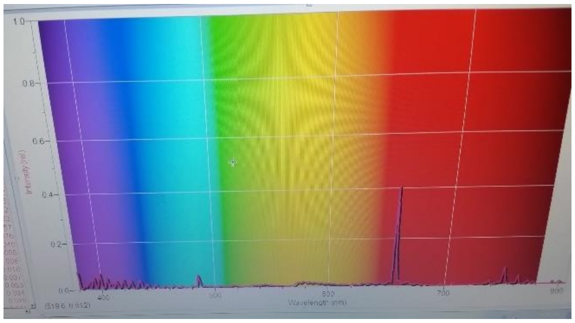
4. Use the $R_H$ that you calculated in Question #3 to predict the wavelength of the fifth line in the Balmer Series (n = 7). Examine your graph of the hydrogen discharge tube emissions. Does the fifth Balmer line appear as a peak in your graph?

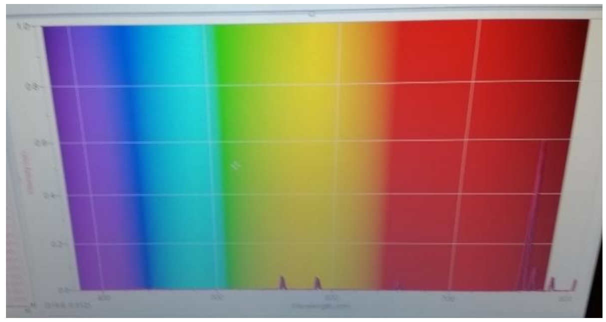
**Experiment B: Discharge Tube Spectroscopy.**

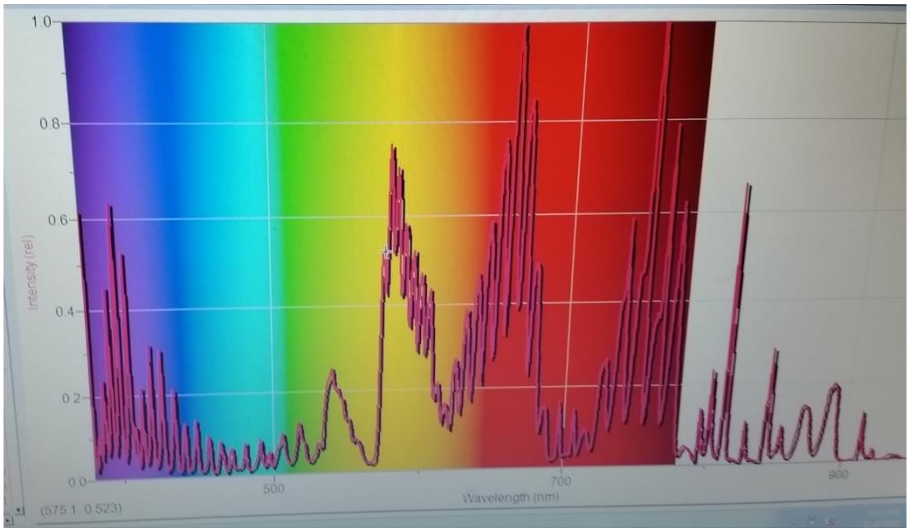
First, using the Disharge Lamp Assembly, Observe the spectra of Helium, Neon, Argon and Krypton. (Tubes can be swapped out carefully with the power OFF and the lamp COOLED by pressing the lamp down on the lower spring). Place the cursor on the peaks, and write down the measured wavelengths of the 8 brightest peaks for each lamp in your lab notebook. Next, observe the spectrum from the Nitrogen Discharge Lamp, make a sketch of it, and explain how it is qualitatively different from the other spectra you have observed. **IMPORTANT: Only run the Nitrogen Lamp long enough to record a spectrum, and then turn it back off. The lamp's lifetime is very limited.**

Sample spectra: (You may want to paste these in your laboratory notebook and indicate what gas discharge they corresponded to in your observations).








**Experiment C: Blackbody Radiation and Planck Radiation Law**

According to Equation 39.25 in the text (Young and Friedman), Wien's Displacement Law gives the peak wavelength of blackbody radiation as a function of temperature as follows:

$$\lambda_m = hc/4.965kT.$$

Here, h = Planck's constant, c = speed of light and k = Boltzmann's constant. Plugging in the values gives

$\lambda_m = 2.9 \times 10^{-3}$ m*K/T (So the temperature in K should give the peak wavelength in m)

Unfortunately, we can't measure this peak wavelength directly for a tungsten filament using our spectrometer, because the wavelength is in the infrared. (Temperature 2000K, $\lambda$=1450 nm; Temperature 3000K, $\lambda$=967 nm)

In addition to the peak wavelength decreasing with an increase in temperature, the emitted intensity at all wavelengths increases, and the emitted intensity increases as the fourth power of the temperature, given by the Stefan-Boltzmann law as $I=\sigma T^4$, where $\sigma = 5.67 \times 10^{-8}$ $Wm^{-2}K^{-4}$ (Stefan-Boltzmann Constant).

In the following, qualitatively observe the shape of the blackbody spectra in the visible part of the spectrum, and note that as the temperature increases, there is more light emitted at all wavelengths, and this is particularly evident at the blue end of the spectrum. (Any apparent decrease in intensity to the red and infrared part of the spectrum is due to the decrease in sensitivity of the spectrometer detector at those wavelengths, rather than an actual decrease in spectral intensity from the lamp).

Observe spectra of the tungsten lamp (as in Figure 2) with an operating voltage of around 5 V (barely glowing), 7 V, 9V and 11 V. (Absolutely do not exceed 12V). Adjust the spectrum amplitude so it doesn't saturate the detector by moving the fiber optic further from or closer to the lamp. Record the current at each voltage.

The resistivity of the tungsten filament in the lamp is a strong function of temperature. The resistance of the whole circuit including the lamp is the sum of resistances from leads, contacts, and some of the internal lamp wiring (which does not change much) and the resistance of the filament which is highly dependent on temperature. By doing some careful fits to emission curves at different voltages, and by checking results using the Stefan-Boltzmann law (and by further assuming that all of the lamps are approximately the same), I found that the temperature T (in Kelvins) can be obtained from the measured resistance R (=V/I, in Ohms) using the following equation:

$$T = 118 + 894R - 34.8R^2 \qquad \text{Equation 1}$$

(This equation can be used between a temperature of about 2000K and 3000K, or for resistances between about 2.5Ω and 4Ω. At room temperature the total lamp resistance is only about 0.36Ω, and I estimate the filament resistance at 0.231Ω)

Calculate the temperature corresponding to each of your measured voltages and currents. Print out the blackbody spectrum taken at 11V and include it in your notebook, along with a discussion of how the spectra at lower voltages (and thus lower temperatures) looked different.

For a quantitative measurement, try using the full Planck radiation law, which gives the intensity at a particular wavelength as:

$$I(\lambda) = 2\pi hc^2/(\lambda^5(e^{hc/\lambda kT}-1))$$

where Planck's constant $h=6.626 \times 10^{-34}$ Js, Boltzmann's constant $k=1.381 \times 10^{-23}$ J/K and $c=3\times10^8$ m/s.

Set up the fiber optic so that the spectrum takes up the whole vertical scale when 11V is applied to the lamp. Measure the recorded Intensity level (vertical scale, arbitrary units) at a wavelength of 525 nm. (At this wavelength, the sensor response is not varying strongly with wavelength). Now, without changing the fiber geometry, turn down the voltage to 5V and measure the recorded intensity at 525 nm. Since the wavelength and the fundamental constants stay the same, and since at our temperatures $e^{hc/\lambda kT} >> 1$ the ratio of the two measured signals should be given by:

$$I_1/I_2 = (e^{hc/\lambda kT2})/(e^{hc/\lambda kT1})$$

Calculate T1 (Temperature at 11V) and T2 (Temperature at 5V) using Equation 1 above (Temperature as a function of Resistance), and see if the measured ratio of intensities at 525 nm agrees with what you would expect from Planck's radiation law. (Note that hc/λk = 27,417K at 525 nm wavelength).

If the upper temperature were in error by 25K, what percent difference would that make in your calculated intensity ratio?