Lab #4: Quantitative Spectroscopy of the Hydrogen Emission Spectrum

Background Information:

The emission spectrum of an element acts as a fingerprint for identifying the element. When an atom is exposed to certain forms of energy, the electrons can be excited or moved to higher energy levels. When the electrons return to lower energy levels, they lose the energy as a photon of light (electromagnetic radiation). These photons of light have energies that are specific to the difference between the two energy levels.

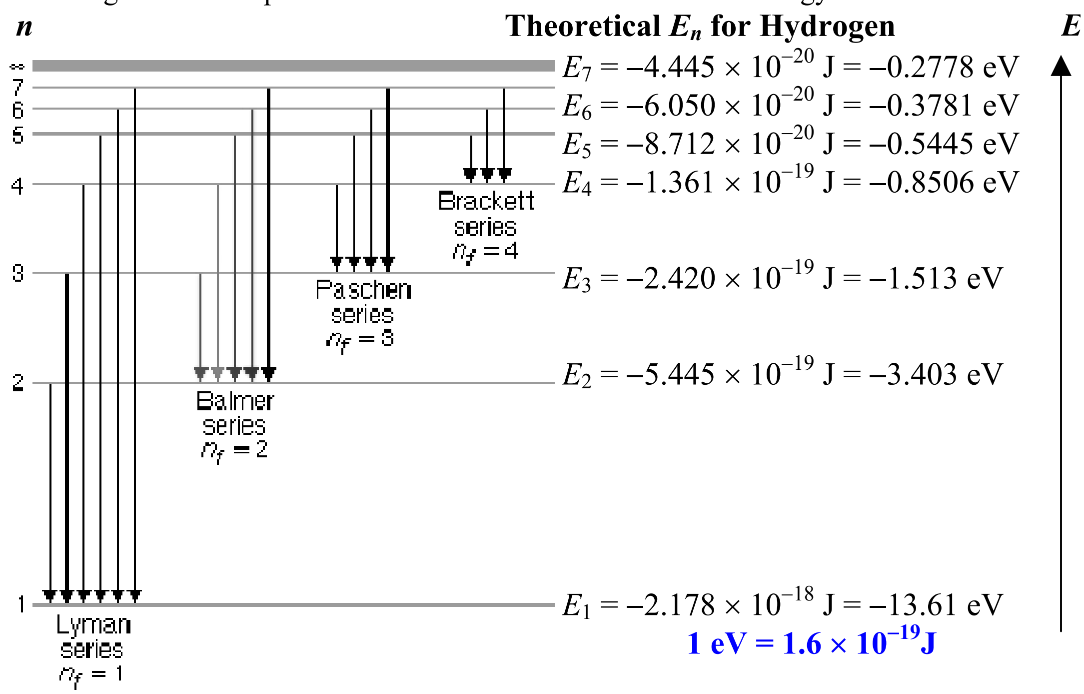

Figure 1

Figure 1 above displays a variety of different transitions that can occur between energy levels. Each transition has its own signature energy difference. The equation that relates the energy difference to the wavelength of light that is emitted is

$$\Delta E = h\nu$$

where ΔE is the difference between the energy levels, h is Planck's constant ($h = 6.63 \times 10^{-34}$ J·s), and ν is the symbol for the frequency of the light. Since the frequency and wavelength of the light can be related through the equation

$$c = \nu\lambda$$

where c = speed of light (3.0×10^{8} m/s), ν = frequency, and λ = wavelength of the light. These two equations can be combined to show:

$$\Delta E = \frac{hc}{\lambda}$$

The individual energy levels can be mathematically determined using the Rydberg equation:

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

In this experiment, a spectroscope (Figures 2 and 3) is used to measure the wavelengths of the emission spectra of various elements. Using these measurements and the equation described above, the value for the Rydberg constant, R_{H}, will be calculated. This value will then be compared to the literature value of R_{H}.

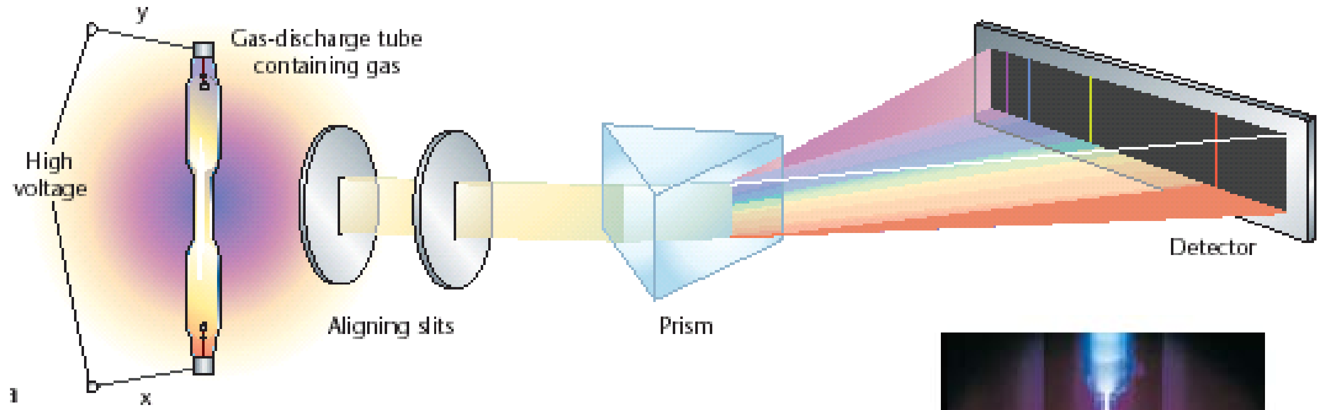

Figure 2: The inner working of a spectroscope and a gas discharge tub.

Figure 3: Spectroscope

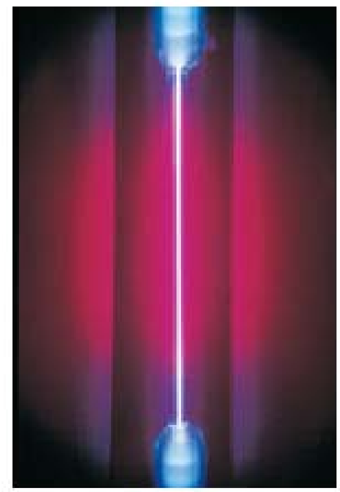

Figure 4: A Mercury Discharge Tube

<u>Objectives:</u> (write your own)

<u>Pre-Lab Questions:</u>

1. Briefly describe how electrons are distributed in the space around the nucleus of an atom.
2. What is the frequency of light that has a wavelength of 540 nm?
3. What is the energy of a photon of the light described in question **2**?

<u>Materials:</u>

Spectroscope | Mercury gas discharge tube | Hydrogen gas discharge tube

<u>Procedure:</u>

Obtain a spectroscope and set it up so that the discharge tube can be seen through the slit in the spectroscope.

Part A: Calibrate the Spectroscope

1. Observe the emission spectrum given off by the mercury gas discharge tube.
2. Record the wavelengths for each of the four lines in the data table.
3. Determine the average absolute error for your spectroscope.

Part B: Observe and Measure the Emission Spectrum of Hydrogen

1. Observe the emission spectrum of hydrogen
2. Record the wavelengths for the four lines in the data table. Some of the lines may be very difficult to see.
3. Adjust the readings taking into account the error that was measured during the calibration.
4. Compare the experimental values with the known wavelengths of the hydrogen spectrum

Observations:

Part A: Calibrate the Spectroscope*

Colour	Known Wavelength (nm)	Experimental Wavelength (nm)	Difference (nm)
Violet	404.7		
Blue	435.8		
Green	546.1		
Yellow	579.0		
		Average Difference	

Part B: Observe and Measure the Emission Spectrum of Hydrogen*

Colour	Measured Wavelength (nm)	Calibration (nm)	Adjusted Wavelength (nm)	Known Wavelength (nm)	Percent Error
Red				656.43	
Turquoise				486.26	
Violet				434.16	
Purple				410.28	

* Use the data below if accurate measurement of the wavelength is not possible.
Experimental Wavelengths for Mercury: *383 nm, 417 nm, 523 nm, 562 nm*
Experimental Wavelengths for Hydrogen: *613 nm, 459 nm, 392 nm, 374 nm*

Analysis:

1. Show the calculations used to find the ΔE associated with each of the lines in the hydrogen emission spectrum. Summarize your results in the first two columns of the second table found in the next step.

2. Use Figure 1 to determine the values for the quantum numbers, n_i and n_f, for the transitions that produce each coloured line in the spectrum. Show all your calculations. Summarize your results in the tables below.

Lyman Series		Balmer Series		Paschen Series		Brackett Series	
$n_i \rightarrow n_f$	Theoretical ΔE (J)	$n_i \rightarrow n_f$	Theoretical ΔE (J)	$n_i \rightarrow n_f$	Theoretical ΔE (J)	$n_i \rightarrow n_f$	Theoretical ΔE (J)
$7 \rightarrow 1$		$7 \rightarrow 2$		$7 \rightarrow 3$		$7 \rightarrow 4$	
$6 \rightarrow 1$		$6 \rightarrow 2$		$6 \rightarrow 3$		$6 \rightarrow 4$	
$5 \rightarrow 1$		$5 \rightarrow 2$		$5 \rightarrow 3$		$5 \rightarrow 4$	
$4 \rightarrow 1$		$4 \rightarrow 2$		$4 \rightarrow 3$			
$3 \rightarrow 1$		$3 \rightarrow 2$					
$2 \rightarrow 1$							

Colour	Experimental Adjusted Wavelength (nm)	Photon Energy ΔE (J)	n_i	n_f
Red				
Turquoise				
Violet				
Purple				

3. Using the Rydberg equation, determine the value of R_H from each of the sets of data above. Show all your calculations. Summarize your results in the table below.

Colour	Experimental Adjusted Wavelength (nm)	Experimental Value of R_H (J)
Red		
Turquoise		
Violet		
Purple		

4. Calculate the average experimental value of R_H.

Evaluation:

1. Find the theoretical value for R_H from your textbook or the AP Information Booklet. Compare the experimental value of R_H with the accepted value and determine the percentage error. Comment on the accuracy of the spectroscope used.

Conclusion:

1. The purpose of this lab was to quantitatively observe and measure the spectra of various elements. Comment on how effectively this purpose was achieved.
2. Astronomers often use spectroscopes to determine the chemical makeup of a star millions of light years away. Explain how this may be accomplished.
3. Explain how the use of this technique can be used to determine whether or not the star is moving away from the earth or toward the earth.