$$\boxed{\text{Lab 9S}}$$

The Hydrogen Spectrum and the Rydberg Constant

(Physics 7, Experiment #9)

Equipment:

Hydrogen spectrum tube
Spectrum tube power supply
Spectrometer (stored in wooden box)
Diffraction grating (15,000 lines per inch)
Grating holder

Background:

When heated, a gas will radiate light at specific wavelengths. Furthermore each type of gas emits its own unique set of wavelengths of light. These wavelengths are not confined to the visible portion of the electromagnetic spectrum, but can range throughout the entire EM spectrum. This set of wavelengths is called the emission spectra of the gas, and since it is unique to each gas, the emission spectra provides a 'fingerprint' of the gas. Therefore the emission spectra becomes a very important way for scientists to identify a gas being studied. The field of 'emission spectroscopy' was first studied in the mid 1800's by Anders Angstrom and further developed by David Alter, Gustav Kirchhoff and Robert Bunsen. Over the years many scientists have made important contributions to this field.

Principles:

When viewing the visible light portion of the Hydrogen spectra, one can see 4 distinct lines of color: red, blue-green, blue and violet. (In general, the blue and violet lines are fainter and darker in color thus making them harder to see.) See spectra shown above. Hydrogen gas also emits a few lines in the ultraviolet region of the spectrum and a number of lines in the infra red region of the EM spectra. Scientists in the mid to late 1800's were searching for an explanation of this emission lines, but none was forthcoming until 1885 when J. J. Balmer found an empirical formula that correctly predicted the wavelengths of the 4 visible light lines. Balmer's formula was subsequently slightly modified by J. Rydberg and is:

$$\frac{1}{\lambda} = R_H\left(\frac{1}{2^2} - \frac{1}{n^2}\right) \quad n = 3, 4, 5, 6 \ldots \quad \text{Eq. (1)} \quad R_H \text{ is a constant known as the Rydberg constant.}$$

Further empirical formulae for other wavelengths of the spectral lines of Hydrogen were discovered by Lyman, Paschen, Brackett and Pfund. (In the denominator on the right hand side, replace the 2^2 with $1^2, 3^2, 4^2$ or 5^2 to get the Lyman, Paschen, Brackett and Pfund series respectively.)

In 1913, the Danish physicist Niels Bohr introduced his now famous 'Bohr model of the atom', and in the process provided a theoretical basis for all of the above mentioned formulae. Bohr's model involved quantizing the angular momentum of the electron in its orbit around the nucleus of an atom. This idea led to the quantization of the orbital radii, meaning the electron could only occupy certain allowed orbits. These orbits are numbered starting at 1, and this 'principal quantum number' is represented by 'n' in the above formulae. Using Bohr's model the Rydberg constant was determined to be:

$$R_H = \frac{me^4}{8\varepsilon_0^2 ch^3} \quad \text{Eq. (2)} \qquad \text{In this formula, m is the mass of the electron, e is the charge on the}$$

electron, ε_0 is the permittivity of free space, c is the speed of light, and h is Planck's constant.

In the decades following the introduction of the Bohr model of the atom, the quantum model of the atom was developed and it is this quantum model that is accepted today. The quantum model proceeds from solving the Schrodinger wave equation for an electron in orbit around a nucleus. Applying boundary conditions to the

electron's orbit leads to not just one, but three quantum numbers, n, l and m_l. (A fourth quantum number, m_s, was later introduced as well.)

In this experiment we will view the 4 hydrogen spectral lines in the visible portion of the EM spectrum. These are the first 4 lines of the Balmer series, and correspond to the 4 different electron transitions from initial orbits with $n = 3, 4, 5, 6$ (in turn) to a final orbit with $n = 2$. The telescope on the spectrometer will rotate to allow you to view the lines on either side of center. By carefully measuring the angle of the spectral line from center, an accurate calculation of the wavelength of the line can be made. Recall the formula for a diffraction grating that relates the angle and the wavelength: $d \sin \theta = m \lambda$ Eq. (3)

In this formula, d is the grating constant (distance between adjacent slits), θ is the angle of the line as measured from the central position, m is the order of the fringe, and λ is the wavelength of light that produced the fringe. (This is the same formula that applies to the double slit experiment.)

We will be measuring the angle θ for the 4 first order fringes, and if visible we will attempt to measure θ for the 4 second order fringes.

Procedures:

1.	Place the hydrogen spectrum tube in the power supply. Place the diffraction grating in the grating holder at the center of the spectrometer. The unruled side of the grating should face the collimator, (the ruled side of the grating should face the spectrum tube). Adjust the grating holder so the plane of the grating is as close as possible to being perpendicular to the axis of the collimator as judged with the eye. The lines of the grating should be parallel to the slit of the collimator, and the center of the grating should be as near as possible to the center of the spectrometer table. Set up the spectrometer and spectrum tube, so that the collimator is directly in front of the hydrogen spectrum tube. These steps may have already been done for you. Turn on the spectrum tube power supply. Once the spectrometer is set up, be very careful when using and handling it, so as not to change the position or the adjustments.
2.	Look through the telescope and view the central image of the spectrum tube. This should appear the same color as the glowing tube does to the unaided eye. Adjust the collimator slit to be as narrow as possible and yet remain visible in the telescope. Make sure the telescope is adjusted so that when the eyepiece is focused on the crosshairs, the image of the slit is also in focus.
3.	Now move the telescope to the right until you find the first order spectral lines of Hydrogen. When the red line is close to the center of the crosshairs, turn the clamping screw located directly under the arm supporting the telescope. This clamps the telescope in position. Now use the tangent screw (located on the arm of the telescope) to make fine tuned adjustments until the spectral line falls directly on the intersection of the crosshairs.
4.	Record the angle of the telescope to the nearest minute of arc, making use of the vernier scale. Be sure to read and record the angle of the scale on the left and the scale on the right. Use the table below to record the measurements.
5.	Repeat steps 3 and 4 for the other first order lines (blue-green, blue and violet).
6.	Now move the telescope over to the left hand side of center and read and record the angles of all 4 of the first order spectral lines, using the table below. (Be sure to read and record the angles measured by the scale on the left and the scale on the right.)
7.	Swing the telescope out to larger angles and look for the second order spectral lines. If you can see these lines, (or at least some of them), then make the same set of measurements and record the data for all second order spectral lines you see.
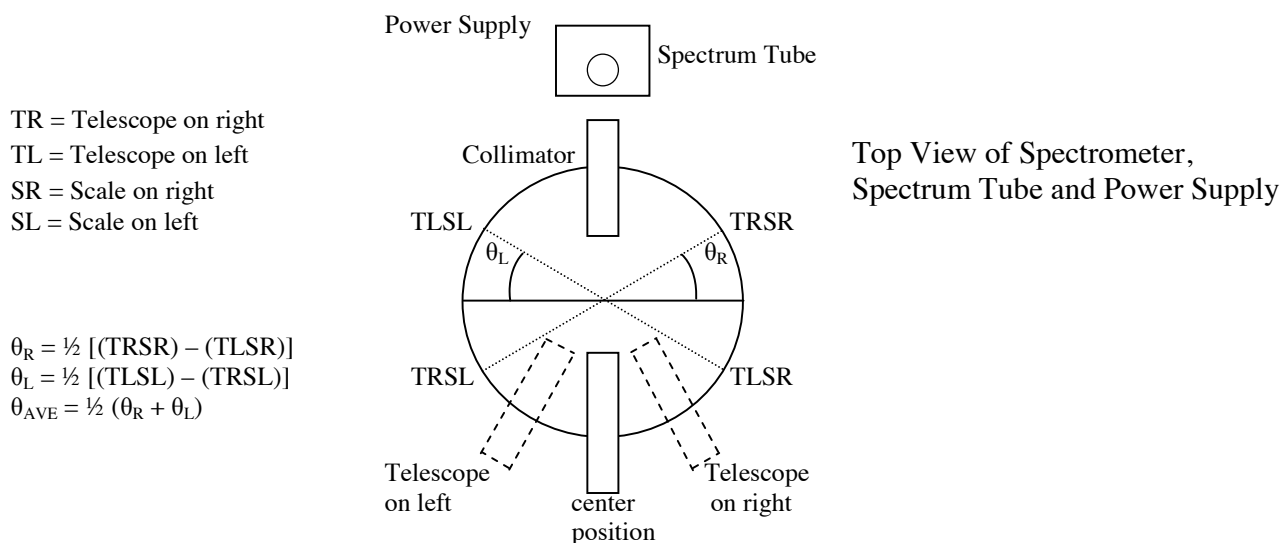
Calculations and Lab Report:
The calculations for this lab should be straightforward. *Be sure to watch your units in these calculations!*
1.	Start by determining the distance between adjacent lines in the diffraction grating. This value is known as the grating constant and is represented by the letter d. Find d in cm. (Hint: We are given the number of lines per inch for the grating, so it shouldn't be too difficult to determine the distance between adjacent lines.)
2.	Calculate θ_R, θ_L and θ_{AVE}, (using the formulae given below), and enter these values into the data table.

3.	Using the values of θ_{AVE} and Eq. (3) from above, find λ for each line and each order that you measured. Determine % errors between your experimental values of λ and the theoretical values of λ given in the table.
4.	Use Eq. (1) from the principle's section to find a value of R_H for each value of λ. (Use your experimental values of λ when calculating R_H.)
5.	Take the average of the values you found for R_H (this is the experimental value). Use Eq. (2) from above to find the theoretical value of R_H (when evaluating, use 6 significant digits for each constant, and then give R_H to 6 significant digits). Find a % error between the average value of R_H, and the theoretical value of R_H.
6.	Write a conclusion as usual. Indicate any sources of error in the experiment.

Hydrogen Spectrum Data Sheet

Power Supply

Spectrum Tube

TR = Telescope on right
TL = Telescope on left
SR = Scale on right
SL = Scale on left

Collimator

Top View of Spectrometer, Spectrum Tube and Power Supply

TLSL   TRSR

θ_L θ_R

θ_R = ½ [(TRSR) – (TLSR)]
θ_L = ½ [(TLSL) – (TRSL)]
θ_{AVE} = ½ (θ_R + θ_L)

TRSL   TLSR

Telescope on left   center position   Telescope on right

Data Table

Color	Order (m)	Telescope on Right		Telescope on Left		θ_R	θ_L	θ_{AVE}
		TRSR	TRSL	TLSR	TLSL			
Red	1							
Blue-Green	1							
Blue	1							
Violet	1							
Red	2							
Blue-Green	2							
Blue	2							
Violet	2							

Number of lines per inch on grating: n = _____
Grating constant (cm): d = _____

Summary Table

Color	λ (nm) (theoretical)	Order	θ_{AVE} (from data table)	λ (nm) (experimental)	% error in λ	R_H (m^{-1}) (experimental)
Red	656.3	1				
Blue-Green	486.1	1				
Blue	434.1	1				
Violet	410.2	1				
Red	656.3	2				
Blue-Green	486.1	2				
Blue	434.1	2				
Violet	410.2	2				

Average value of R_H = _____ (in standard units)

Theoretical value of R_H (Eq. 2) = _____ (in standard units)

% error in R_H = _____

Name of Student: _____

Date Performed: _____

Instructor's Initial: _____