EXPERIMENT 19
THE BALMER SERIES OF HYDROGEN

I. THEORY

When energized by high voltage or other means, atomic hydrogen emits a number of spectral lines, some in the ultraviolet region of the electromagnetic spectrum, some in the visible region, and some in the infrared region.

One series of these lines lies almost entirely in the visible region. In 1885, Balmer discovered that the wavelengths of the lines of this series, now called the Balmer series, fall into a mathematical pattern. The modern form of his equation is

$$\frac{1}{\lambda} = R\left(\frac{1}{4} - \frac{1}{n^2}\right)$$

in which R is called the Rydberg constant and has a value of 1.097×10^{-2} nm^{-1}. The quantity n takes the values of 3, 4, 5, etc., for the first, second, third, etc., lines of the series, which are called the alpha, beta, gamma, etc., lines.

The purpose of this experiment is to measure the wavelengths of the first four Balmer lines, and see how well they fit this equation. In the process, we will obtain an experimental value for the Rydberg constant.

We will use a Bunsen spectroscope to measure the wavelengths of the Balmer lines. These lines will be seen superimposed on a linear scale of arbitrary units. In order to convert the resulting scale readings into wavelengths, we must calibrate the scale. We do this by recording the scale readings of lines of "known" wavelength, namely the visible spectrum of helium.

II. LABORATORY PROCEDURE

CAUTION #1: The spectrum tube power supply produces high voltage.
CAUTION #2: The spectrum tube becomes hot when in use.

1. Place the spectroscope in a convenient position for use, with the eyepiece near the edge of the table.

2. Place the helium discharge tube in the spectrum tube power supply. **The power supply should not be plugged in.**

3. If necessary, adjust the height of your spectroscope or the spectrum tube power supply so that the slit on the collimator tube is at the same height as the center of the discharge tube.

4. Plug in the spectrum tube power supply, turn it on, and position it so that the spectrum tube is just beyond the slit. Look through the telescope at the helium lines. Move the source slowly back and forth and side to side until the lines are of maximum intensity.

5. Use a tripod base, a vertical rod, a right angle clamp, and a three-prong clamp to support the incandescent lamp and socket. Turn the lamp on and position it just beyond the short arm of the spectroscope. Adjust the eyepiece, by moving it in or out, so that the spectral lines are in sharp focus. Adjust the scale holder, located in the end of short arm of the spectroscope, so that the scale is horizontal and in sharp focus. If you have one of the large spectroscopes, do not loosen the setscrew on the telescope, as the telescope is easily disassembled but hard to reassemble. If the spectrum and scale are not both in sharp focus you will get a large amount of parallax error similar to holding a meter stick 30 cm above a lab stool and attempting to measure its diameter. When both the spectrum and scale are in sharp focus, they will move together as you rotate the knob that moves the telescope arm from side to side.

6. With the help of the helium spectrum diagram in Section IV, identify the spectral lines. Identify each line by its color, brightness and relative position. It may be helpful to widen the slit and/or turn the light bulb off while looking for the fainter lines. In order to see the entire spectrum, you must rotate the knob that moves the telescope from side to side.

7. Record the scale readings for the following lines: 402.6, 438.8, 447.1, 471.3, 492.2, 501.6, 587.6, 667.8, and 706.5 nm. The slit should be as narrow as possible, for precise readings. The three lines of shortest wavelength, near the ultraviolet region, may not be seen by all students. You may need to widen the slit and/or turn off your light bulb to find some of the faint violet lines.

8. Before proceeding, use a computer or graphing calculator to check that you will get a smooth curve when you plot wavelength versus scale reading for the nine helium lines used above. If any points are off from a smooth curve, you may have incorrectly identified one or more of the spectral lines. Do the following:
   - Make sure that the scale reading and spectrum move together when you adjust the knob which moves the eyepiece from side to side. If they do not move together, you must refocus and repeat all of the measurements for helium.
   - If you are in focus, recheck the scale readings for any points that are off from a smooth curve.
   - Refer to the helium spectrum diagram and make sure you are recording readings for the correct lines.

9. Turn off the spectrum tube power supply and unplug it. Use a paper towel to remove the hot spectrum tube. Replace it with the hydrogen tube. Plug in the power supply and turn it on.

10. Record the scale positions of the first four Balmer lines. They are red, blue-green, violet and violet, respectively. If a weak yellow line is seen, you do not need to record its position.

III. CALCULATIONS

1. Plot a graph of wavelength versus scale reading for the known wavelengths of the helium lines. Wavelength should be on the vertical axis and you do not need the point (0, 0) on your graph. Draw a **smooth curve** through the plotted points.

2. Use your curve and the scale readings for the four Balmer series lines to determine experimental values for the wavelengths of the Balmer series.

3. Using the **experimental values** of wavelength, make a table containing the following quantities: n, $1/n^2$, wavelength, and reciprocal wavelength. All quantities must be expressed in decimal form.

4. Plot a graph of reciprocal wavelength versus $1/n^2$. Draw the straight line that best fits the plotted points. Does the data appear to be linear? Calculate the slope of the line to three significant figures.

5. What physical value is represented by the negative of the slope calculated in the previous step? (Hint: Look at the equation given in Section I.) Find the percent error in this quantity.

HELIUM SPECTRUM

(wavelengths in nm)

388.9	violet	(faint)
402.6	violet	(faint)
412.1	violet	(very faint)
438.8	blue/violet	(faint)
447.1	blue	
471.3	blue	
492.2	blue/green	
501.6	green	
504.8	green	(faint)
587.6	yellow	
667.8	red	
706.5	red	(faint)