Experiment 29B

FV-10/15/03(CALCULATOR VERSION)

EMISSION SPECTRUM OF HYDROGEN

MATERIALS: Hydrogen vapor lamp and power supply, diffraction grating (transmission type), meter sticks (2).

PURPOSE: The purposes of this experiment are: (1) to observe the emission spectrum of atomic hydrogen and (2) to determine the wavelengths and energies of some of the electronic transitions of the Balmer series for hydrogen.

LEARNING OBJECTIVES: By the end of this experiment, the student should be able to demonstrate these proficiencies:

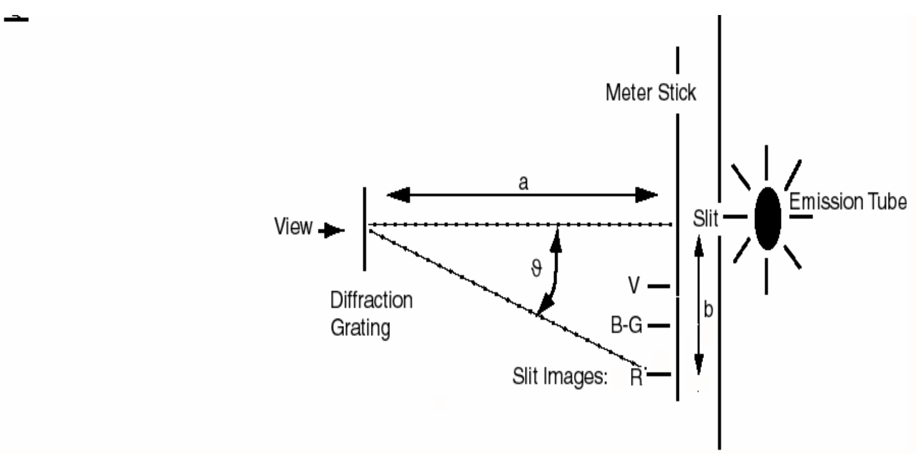
1. Explain how a diffraction grating operates.
2. Determine the wavelength of light from its angle of diffraction.
3. Calculate the energy of light from its measured wavelength.
4. Calculate the wavelengths of light expected for specific electronic transitions of hydrogen.
5. Compare the expected wavelengths to the observed wavelengths.
6. Use the Data/Matrix Editor of the Voyage 200 calculator for the execution of repetitive calculations.

DISCUSSION:

When an electron in an atom undergoes a transition from a higher energy level to a lower energy level, the atom emits light at a discrete frequency and wavelength determined by the energy difference between the levels. The emission frequency,ν, and wavelength, λ, are related to the transition energy, E, by the Planck equation

$$E = h\nu = \frac{hc}{\lambda}$$

where h is Planck's constant, $h = 6.6261 \times 10^{-34}$ J·s, and c is the speed of light, $c = 2.9979 \times 10^{8}$ m/s. Because the separation between the energy levels depends on the type of atom, the emission spectrum is characteristic of the element. Hydrogen atoms, if excited by an electrical discharge, emit a series of lines in the visible region called the Balmer series. This series corresponds to transitions from several different excited states to the n=2 level. Three lines of the Balmer series can be observed with the unaided eye. The schematic diagram shows how the wavelengths of the red, blue-green, and violet emission lines of the Balmer series are determined.



V = violet line
B-G = blue-green line
R = red line

A diffraction grating is a transparent film ruled with a number of closely spaced grooves. It is used to separate the light from the emission lamp according to its wavelengths. If light from an incandescent lamp is directed onto the grating, a continuous spectrum of colors is formed. The grating produces an image of the light for each color emitted; because all colors are emitted, these images blur together and appear as a continuous band (like a rainbow). When a hydrogen lamp is viewed through the grating, only three images of the light will appear, each in a different color. These correspond to the individual emission lines of the Balmer series, each with a different wavelength. Because they are separated in space, the images appear distinct. The wavelengths of these emission lines are determined by the diffraction equation

$$\lambda = d\sin\theta$$

where d is the separation between the grooves on the grating, and the angle θ is determined by the geometry of the schematic as shown above. Measurements of the distances shown will provide the angle θ, because tan θ = b/a. Note that the geometric relations hold on both the left and right side, as one views the lamp through the grating. Thus the pattern of a continuous band or set of discrete images appears on each side.

As indicated above, the emission spectra of hydrogen atoms and "hydrogen-like" (one electron) ions consist of a set of individual "lines" of specific wavelengths. The numerical values of the wavelengths of these lines fit a particular mathematical pattern called a series. Rydberg determined that the equation

$$\frac{c}{\lambda} = \nu = \left(\frac{R_H}{h}\right)\left(\frac{1}{m^2} - \frac{1}{n^2}\right)$$

could reproduce the pattern observed by Balmer for hydrogen, where R_H is the Rydberg constant, $R_H = 2.179\text{x}10^{-18}$ J, and m and n are positive integers for the states in the emission process. In the Balmer series the final state is m = 2 and n > m. While he did not understand what the numbers meant, this high regularity and agreement with experiment convinced him that he was on the right track. The wavelengths that you observe in this experiment should satisfy the Balmer-Rydberg relation within experimental error. Knowing the relationship, you can calculate wavelengths for a variety of integer pairs and compare those with your experimental data. A close match between observed and calculated values will allow you to assign the quantum numbers for each transition. Such repetitive calculations are performed easily by computer, using a spreadsheet program such as Excel, or with the Data/Matrix Editor in your calculator.

PROCEDURE:

CAUTION**:** Be sure to wear goggles as protection from ultraviolet radiation given off by the emission tube.

Record all readings, to the proper number of significant figures and with appropriate units, in the Data Section.

1. Record the value for the number of lines per millimeter of the grating. This will either be printed on the grating frame, or supplied by your instructor.

2. Make sure that the meter stick is centered on the slit, with the light beam from the lamp at the 50.0 cm mark. Record the position of the slit along the meter stick. Also, check that the diffraction grating is parallel to the screen, and thus perpendicular to the light beam. The grating should be about 80 cm from the slit.

3. Turn off the overhead room lights; light from adjacent rooms should be sufficient. Look at the lamp and slit *through* the diffraction grating. You should be close enough that your goggles are nearly touching the grating. Without moving your head, look for at least two images, one red and one blue-green, on both sides of the slit. The violet line is also present but is much fainter. One side of the meter stick has a white slide to make the position of the lines easier to measure. Use this side for all readings.

4. Read the markings on the horizontal meter stick, and record the positions where the three colored images appear.

5. Using the second meter stick, *carefully* measure the distance (a) between the slit and the diffraction grating, and record it in the Data Section. Do not move the grating in the process.

Name ______________________________ Section ___________________________

Partner _____________________________ Date ______________________________

DATA SECTION
Experiment 29B

Diffraction Grating Ruling ____________ lines / mm

Number of separations/mm in diffraction grating ____________

Calculate width of one separation, **d**, in nm ____________

Position of slit along meter stick ___50.0 cm___

Positions of images along meter stick red ____________

blue-green ____________

violet ____________

Distance from slit to grating, **a** ____________

DATA TREATMENT

(1) Use the Data/Matrix Editor in your calculator to calculate the wavelength of the red, blue-green (b-g), and violet hydrogen emission lines from experimental data. Move the cursor to the **Data/Matrix...** icon (which looks like an open ledger book) and press **ENTER**. Select **3:New** and press **ENTER**. Select the following fields and then press **ENTER** twice.

Type	**Data**	
Folder	**Main**	(this is the folder where the data table is stored)
Variable	**E29exp**	(this is where you enter a name for your data table)

Label a block of cells to correspond to the headings below.

color	a(cm)	b(cm)	tanθ	θ(rad)	sinθ	d(nm)	λ(nm)
c1	**c2**	**c3**	**c4**	**c5**	**c6**	**c7**	**c8**

To enter headings, just move the cursor to the cell above the column label (e.g., **c1**), type in the heading, and press **ENTER**. (To create the Greek letter θ, use **2nd**, **CHAR**, select **1:Greek**, then **9: θ**. For λ, access the Greek characters, and select **A: λ**.

(2) From the data, enter the value for **a**, the distance between the slit and grating, into the appropriate cell for the red line. Enter the value for **b**, the distance between the red image and the slit, in the appropriate cell. Enter the value for **d**, the width of a diffraction grating separation in nanometers. Repeat for the blue-green and violet lines.

(3) Based on the geometry of the experimental setup, tan θ =b/a. You can instruct the calculator to compute this as follows. Place the cursor in the cell labeled **c4**. Look at the entry line at the bottom of the display. It should read **c4=**. Since the value for **b** is in column 3 (**c3**) and that for **a** is in column 2 (**c2**), then we can define all values in column 4 (**c4**) as **c4=c3/c2**. Complete the equation on the entry line and press **ENTER**. The values of tan θ will be calculated for all three lines. Move the cursor to a cell containing any of those computed values and look at the entry line. There will be a lock icon in front of the cell address, indicating that the value was determined by a formula, and cannot be changed. If you must alter a locked cell, go back to the cell with the column label (**c4** here) and **CLEAR** the column definition. Then you can either redefine the column equation, or move to a cell you wish to change and use the backspace key to delete it. In a similar way, create formulas to calculate entries for the values of θ and sin θ. (Note that $\theta = \tan^{-1}(\tan\theta)$.)

(4) Use the diffraction equation and the appropriate entries in the table to calculate the experimentally observed wavelengths of the emission lines of hydrogen. Define the equation for column 8 (**c8**) to perform the calculation. As a check, your red line value should be within a few percent of 650 nm. If it is not, correct your mistake before proceeding.

(5) Record the experimentally determined wavelengths you just calculated in the table below. Include units!

red		blue-green		violet	

(6) Create a new Data/Matrix table as done in step (1). Set "variable" to **E29calc** to distinguish this calculation table from the experimental table you just worked through. This will be used to calculate emission wavelengths with the Balmer-Rydberg equation. Label the columns to correspond to the table below. These terms refer to: the quantum number of the lower state, m; the quantum number of the upper state, n; the calculated wavelength, λ (in nm); the frequency, ν(in s^{-1}); and the transition energy, E (in J)**.** The calculator has no "ν" character, so just use "v" for frequency.

m	n	m^2	n^2	1/λ(1/nm)	λ(nm)	v(1/s)	E(J)
c1	**c2**	**c3**	**c4**	**c5**	**c6**	**c7**	**c8**

For the Balmer series of emission lines, the quantum number in the lower state is m = 2. Because they are emission lines, the quantum number n (in the upper state) must be greater than m. We will calculate wavelengths for specific values of n. By comparison with the observed spectrum, we will be able to associate each observed color with a specific transition; i.e., a specific pair of quantum states.

(7) For the first 8 cells in column **c1**, enter the value **2**, since all transitions in the Balmer series involve the m=2 state. For the first 8 cells in column **c2**, enter the values **10**, then **9**, then **8**, ... and finally the value **3** in row 8. The emission lines in the Balmer series all involve states with n>m; we simply cut off the possibilities at n=10 for convenience.

(8) Create formulas to calculate the entries in columns **c3** through **c8**, using the methods described above, and the basic relations provided in the lab. (Don't succumb to the temptation to do these by hand and then enter them! You will eventually compute over fifty different values in this table. The use of column formulas will make this a simple matter, MUCH easier and faster than you could possibly do it by hand. Work smarter, not harder!)

(9) As you complete each column definition formula, the entire column will be computed at once. As a check, three of your calculated wavelengths should approximate your three observed wavelengths. If this is not the case, correct your mistake before proceeding.

(10) For the emission lines that matched your observed spectrum, enter the quantum numbers, energies and wavelengths just calculated in the table below. Compare these to the observed values by calculating percent errors. When computing percent error, assume that the calculated value is the accepted or true value.

Line Color	m	n	E (J)	λ_{calc} (nm)	$\lambda_{observed}$ (nm)	% error
red						
blue-green						
violet						

(11) Optional: To check your results, enter them into the "Data Input and Feedback" section of MOLS at http://walnut.mathsci.usna.edu/~lomax/labs/login.html.

QUESTIONS
Experiment 29B

1. Which emission line in the Balmer series has the *longest* wavelength? ___________________________

   Which emission line in the Balmer series has the *highest* energy photons? _________________________

   What type of mathematical relationship exists between energy and wavelength? _________________________

2. As quantum mechanics developed, it eventually became clear that the form of the Balmer-Rydberg equation corresponded to a difference in the energies of the two stable states connected by the electronic transition, i.e.

$$\frac{c}{\lambda} = \nu = \left(\frac{R_H}{h}\right)\left(\frac{1}{m^2} - \frac{1}{n^2}\right) \quad \text{corresponds to} \quad \frac{\Delta E_{trans}}{h} = \nu = \left(\frac{1}{h}\right)\left(E_m - E_n\right)$$

where ΔE_{trans} is the energy of the photon emitted in the transition, and E_m and E_n are the energies of states involved in the transition, with principal quantum numbers m and n, respectively. Show how the equations above are related by deriving an equation for the energy of the lower state E_m. Calculate the actual value (in Joules) E_m, which has m=2 for a Balmer series transition.

3. Both He^+ and Li^{2+} are "hydrogen-like" ions, in that they only have one electron. These ions will also produce a line spectrum that obeys the Balmer-Rydberg equation, but with different R constants (we will call them R_{He} and R_{Li}). Knowing the wavelengths, and the appropriate integers for n and m, you can calculate these constants and gain some additional physical insight.

a) In the He^+ spectrum, a line appearing at 164.1 nm corresponds to the red emission you observed for H (i.e., the 164.1 nm line for He^+ has the <u>same</u> values of m and n as does the red line of H). Use that information to calculate the constant R_{He} for the helium ion. Show your work. Record that value in the table below.

b) Repeat the calculation for the Li^{2+} ion spectrum, where a line appearing at 72.9 nm corresponds to the red emission you observed for H (i.e., the 72.9 nm line for Li^{2+} has the same values of m and n as does the red line of H). Record the value of R_{Li} in the table below.

Constant	R_H (for Hydrogen Atom)	R_{He} (Helium Ion)	R_{Li} (Lithium Ion)
R value	2.179×10^{-18} J		
Integer	1		

4. You should find that the constants R_{He} and R_{Li} are integer multiples of the Rydberg constant R. Show the values of these integer multiples in the table above. The integers for all three are related to the atomic structure of the specific atoms (H, He, or Li). How do the integers relate to the <u>atomic structures</u> of the atoms H, He, and Li? (HINT: focus on the nucleus.)