Ryan Lenet

Chemistry 511
Experiment: The Hydrogen Emission Spectrum

Introduction

When we view white light through a diffraction grating, we can see all of the components of the visible spectra. (ROYGBIV) The diffraction (bending) of light by a diffraction grating will separate the electromagnetic radiation as a function of its wavelength. In contrast to a white light source, when we look at a source of electromagnetic radiation from an excited gaseous element we do not see a continuous spectrum; we only see specific bright lines of color. This phenomenon ultimately helped to unravel some of the mysteries of atomic structure.

In this experiment we will view the bright line spectrum for the simplest element, hydrogen. We will make some simple measurements and then apply the equation developed by the father and son "team" of Sir W.H. Bragg and Sir W.L. Bragg to calculate the wavelengths of light viewed.

Biographical note: In 1913 the Braggs determined that the scattering of X rays (short wavelength electromagnetic radiation) by crystals was a function of the wavelength of the incident X-ray and the distance between the layers of the crystal. By using only specific wavelengths of electromagnetic radiation, they were able to determine the structure of selected crystalline solids. For their work, the Braggs were awarded the Nobel Prize in Physics in 1915. Braggs Law is the equation:

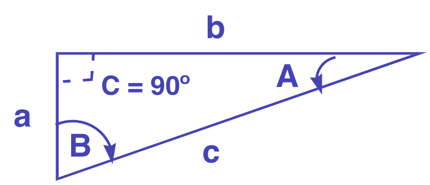
$$\mathbf{n\lambda = 2d\sin\theta}$$

The "business part" of the equation is λ = wavelength, d = distance between the layers of the crystal and θ = the angle of diffraction. [*n is actually a whole number which can be 1, 2, 3, … termed the order of diffraction. You will be observing 1st order diffraction, so, n will be equal to one (1) for us.*]

This equation, originally developed for the determination of crystal structure, has been applied in the quest to determine the structure of many other states of matter.

Background

It may be helpful to review some right triangle trigonometry. Given the right triangle:



Angle C is the right angle, side c is opposite of $\angle C$ and is called the *hypotenuse*.
The other two angles, A and B have opposite sides a and b respectively.

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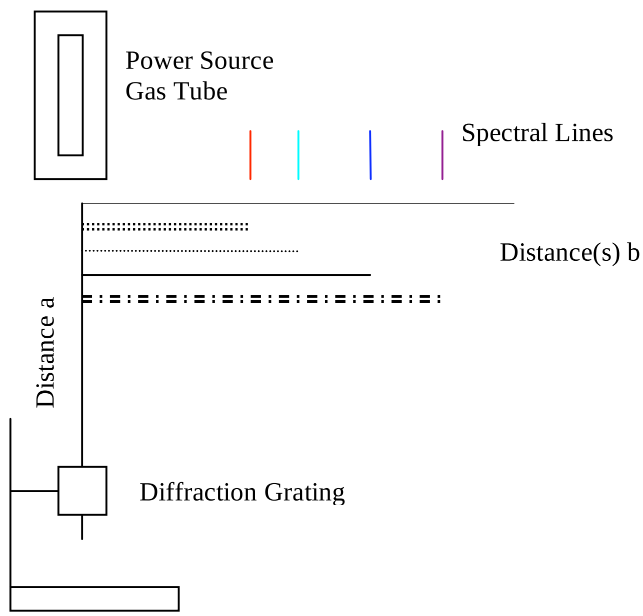
The following relationships apply:

- Pythagorean Theorem: $a^2 + b^2 = c^2$.
- Sines: $\sin A = a/c$, $\sin B = b/c$.
- Cosines: $\cos A = b/c$, $\cos B = a/c$.
- Tangents: $\tan A = a/b$, $\tan B = b/a$.

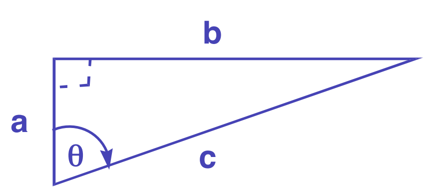
(adapted from http://aleph0.clarku.edu/~djoyce/java/trig/right.html accessed 1/07/06)

We can apply the ideas presented above to our experimental design.



In this experiment you will look through the diffraction grating to view the hydrogen spectrum produced by the high voltage source and the gas tube. You will measure distance a, the distance from the grating to the source and multiple distances long b, the distance from the source to each spectral line observed.

If we look at the measurements that are made, we see that we have a right triangle:



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We will adapt Braggs' Law to allow us to solve for each wavelength of light viewed using the equation:

$$\boldsymbol{\lambda = d \sin(\theta)}$$

Where λ = the wavelength of light, d = the spacing between the lines of the diffraction grating and θ = the angle of diffraction. Our next task is to determine how to arrive at $\sin(\theta)$ from the experimental data. The sine function of an angle is the length of the opposite side divided by the length of the hypotenuse. For angle θ we know the length of the opposite side (b) but we have not measured the length of the hypotenuse. We do have a measurement for the other side of our right triangle, side a. Applying the Pythagorean Theorem, $a^2 + b^2 = c^2$ we will be able to compute the length of the hypotenuse and then calculate the sine of the angle.

$$a^2 + b^2 = c^2$$
$$\sqrt{(a^2 + b^2)} = c$$

Our working equation to calculate each spectral line observed may be derived.

$$\lambda = \mathrm{d} \sin \theta$$
$$\sin \theta = \frac{b}{c}$$
$$\lambda = \mathrm{d}\left(\frac{\mathrm{b}}{\mathrm{c}}\right)$$
$$\lambda = \mathrm{d}\left(\frac{b}{\sqrt{a^2 + b^2}}\right)$$

Procedure:

1. The lab will be set up according to the diagram on page 2.
2. In a darkened room, one student will look through the diffraction grating to view the spectral lines of hydrogen.
3. A second student will move a pencil down distance b until the pencil and a spectral line of hydrogen are aligned. This distance will be recorded along with the color of the line observed.
4. This measurement will be repeated for each of line spectral lines observed.

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Worked example:
a = 35.0 cm ; b = 17.0 cm ; d = 1000 nm

$$\lambda = \mathrm{d}\left(\frac{b}{\sqrt{a^2 + b^2}}\right)$$

$$\lambda = 1000\left(\frac{17}{\sqrt{35^2 + 17^2}}\right)$$

λ = 485.7 nm

Other useful formula and constants:

$$\mathrm{c} = \lambda \mathrm{f}$$

$$\mathrm{c} = 3.00\mathrm{x}10^{10}\,\frac{cm}{s}$$

$$E = h\mathrm{f}$$

$$\mathrm{E} = h\frac{c}{\lambda}$$

$$h = 6.626\mathrm{x}10^{-34}\,\frac{Js}{photon}$$

Resources:

http://www.eserc.stonybrook.edu/ProjectJava/Bragg/ accessed 12/29/05
http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html accessed 12/29/05
http://aleph0.clarku.edu/~djoyce/java/trig/right.html accessed 1/07/06
http://www.dartmouth.edu/~chemlab/info/resources/mashel/MASHEL.html
accessed 12/29/05

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The Hydrogen Spectrum Lab Report

[Recall that "d" represents the distance between lines in the diffraction grating. If you look at you grating your will read the following listing: "500 lines/mm", i.e., each millimeter (mm) contains 500 lines. So, the inverse of this, i.e., 1/500 should be the number of millimeters between a line and an adjacent line. Thus, (1/500) mm/line. The result should be: d = 0.002 mm between lines or 2000 nm between lines.]

Experimental Data and Calculations:

Distance a	90 cm	90 cm	90 cm	Calculation Formula
Distances b	20.1 cm	23.3 cm	32.0 cm	
Color Observed	Violet	Aqua/Blue	Red	
Wavelength	4.359 x 10^-5 cm	5.0125 x 10^-5 cm	6.7 x 10^-5 cm	Lambda= d(b/squareroot(a^2+b^2)
Energy	4.559 x 10^-19 J/photon	3.96 x 10^-19 J/photon	2.96 x 10^-19 J/photon	E= *h*f E=*h*(c/lambda)

Show representative wavelength and energy calculations. Then fill in the table with you results.

1. The energy values calculated represent the energy emitted by the electron when it transitions from higher energy level to a lower. The red line in the hydrogen spectrum is the result of a transition from the n=3 to the n=2 energy levels. What energy level transitions are represented by the other lines in the spectrum?

The energy level transitions represented by the other lines in the spectrum are H-beta, which is a transition from level 4 to the second level that yields a aqua/blue line and H-gamma which is a transition from level 5 to the second level that yields a violet line.

2. Using your results, explain how ΔE, the difference in energy between levels, varies as n, the energy level, increases.

When *n* gets larger, the lines start getting really close together. As *n* gets larger, 1/*n*^2 gets smaller, so there is less and less difference between consecutive lines. The series has a limit. As *n* gets larger and larger, the wavelength gets closer and closer to one particular value.

3. The spectrum you observed is the visible spectrum for hydrogen, also called the Balmer series. There are two other series for hydrogen: the Paschen and the Lyman series. The Pashcen series occurs at wavelengths *longer* than those observed in the Balmer series while the Lyman series occurs at wavelengths *shorter* than those observed in the Balmer series.

• In which part of the electromagnetic spectrum is each of these spectral series? Please explain your reasoning.

Recall that the lines in Balmer series can be represented as electron energy level changes (transitions) from n-levels > 2 (i.e., 3, 4, 5, 6, …) down to $n_f = 2$. So, for the Balmer series of lines, some of the electron energy level transitions are:
$n_i = 3$ ---> $n_f = 2$; $n_i = 4$ ---> $n_f = 2$; $n_i = 5$ ---> $n_f = 2$; etc. One of these "new"spectral series (Paschen or Lyman) involves transitions from higher n-levels to $n_f = 1$ and the other involves transitions from higher n-levels to $n_f = 3$.

Which electron transitions in the hydrogen atom produce each series?
Is this consistent with your answer to #2? Please explain your reasoning.

A pattern of spectral lines, either absorbed or emitted, are produed by the hydrogen atom. The various series of lines are named according to the lowest energy level involved in the transition that gives rise to the lines. The Lyman series involves jumps to or from the ground state (n=1). It lies in the ultraviolet with a series limit at 912A. The Balmer series(in which all the lines are in a visible region) correspond to n=2. The Pacshen series correspond to n=3. This series are the shortwave infrared lines.

The spectrum of radiation emitted by hydrogen is non-continuous. Therefore the lines seen in the image are the wavelengths corresponding to n=2 to n= infinity. This is consistent with my results in question 2.