Optional • Lab #14: Hydrogen Spectrum

The Hydrogen Spectrum

Reading assignment: Chang, Chemistry 10th edition, pp. 282-287.

Goals

We will become familiar with the operation of the grating spectroscope in order to determine the wavelengths of the Balmer series of the hydrogen spectrum. This will involve the construction of a calibration graph using the known spectral lines of helium.

Equipment and Supplies

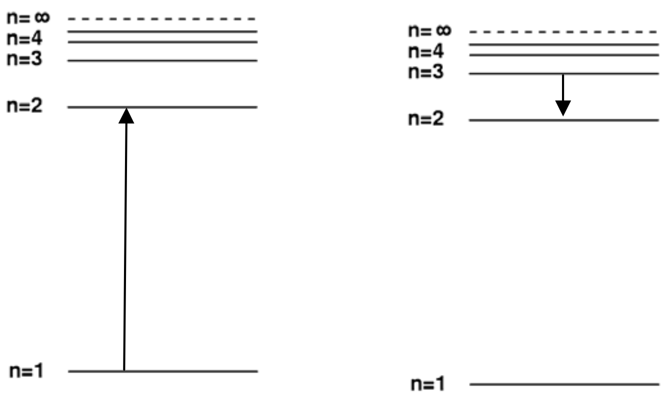
Spectroscope, hydrogen gas tube, helium gas tube, USB flash drive

Discussion

At the beginning of the 1900s, physicists were unable to adequately explain the spectrum of colors absorbed and emitted by atoms. It wasn't until the 1920s that a satisfactory theory for explaining the spectral properties of even the simplest element (hydrogen) was complete. One of the important observations is that when atoms are heated to a very high temperature, they begin to emit light. The emitted light occurs at specific wavelengths. For example, hydrogen atoms emit light at five distinct wavelengths in the visible region (400 nm – 700 nm). The line spectrum for hydrogen is shown below:

Visible line spectrum of hydrogen (wavelengths are in nanometers)

The hydrogen spectrum is an important piece of evidence that the electronic structure of the atom is quantized. The diagrams below show a representation of how we can explain the line spectrum of hydrogen. When a photon is absorbed by a hydrogen atom, the energy of the photon causes the electron to undergo a transition to a higher energy level ($n = 1 \rightarrow n = 2$, for example). When a hydrogen atom emits a photon, the electron undergoes a transition from a higher energy level to a lower one ($n = 3 \rightarrow n = 2$, for example). The arrow in each of the diagrams represents the transition of the electron. Since the energy levels of the atom are quantized, the spectrum will consist of wavelengths that reflect the differences in these energy levels. For example, the line at 656 nm corresponds to the transition $n = 3 \rightarrow n = 2$.



Absorption of photon   Emission of photon

In this experiment we will use a spectroscope to measure the wavelengths of light emitted by the two simplest atoms, hydrogen and helium. The spectroscope uses a grating to disperse light emitted by atoms into individual colors. This will allow us to determine the differences in energy levels of the hydrogen atom.

Procedure

SAFETY PRECAUTIONS
Safety glasses are not required for this experiment. The power supply for the hydrogen and helium tubes use 120 VAC. Care should be taken when using this equipment. The glass tubes are fragile and should be handled with care.

Students work in groups of two to three. Each student acquires one set of data for helium and hydrogen. The spectroscope should be calibrated at 0° by the students or by the instructor using the helium tube. Bring a 3-1/2 inch PC-formatted diskette or a USB flash drive.

Measuring the Lines of the Helium Spectrum

There are six emission lines from helium visible with the spectroscope.

1. Set the spectrocope to an angle of 0°.

2. Slowly rotate the telescope clockwise until the violet line is visible. Continue rotating the telescope until the violet line is centered in the cross-hairs of the telescope.

3. Record the angle of this line to 0.1° from the vernier.

4. Continue rotating the telescope to larger angles, measuring and recording each of the five remaining lines in the data sheet.

5. Each remaining student in the group should repeat these measurements and record the data in the data sheet.

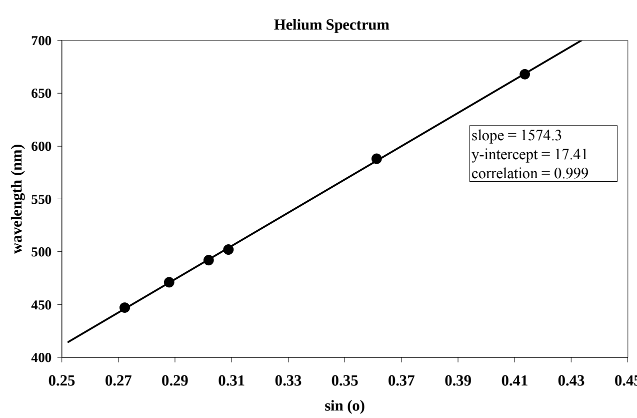
Measuring the Lines of the Hydrogen Spectrum

The visible wavelength of the hydrogen spectrum consists of four lines. However, only three of these lines are clearly visible using the spectroscope. Use the same method to measure the wavelengths of the lines of hydrogen that was used with the helium spectrum. Record the color you observe with each of the three lines.

Calculations

The Helium Spectrum

The wavelengths for the helium spectrum are given in the data sheet for each of the six lines that were measured. So the relationship between wavelength and angle can be shown through a graph. The plot of wavelength versus sin (θ) is linear. This linear relationship can be used to calibrate the spectroscope. Since wavelength varies linearly with sin (θ) we can used the calibration to determine the wavelength for any line if we know the angle (θ).



1. Construct a graph of wavelength versus sin (θ) using the data from the helium lines.

2. Determine the line of best fit for the graph and record the slope and y-intercept of this line.

3. The values of the slope and y-intercept will be used to determine the wavelengths of the hydrogen spectrum.

The Hydrogen Spectrum

1. Calculate the wavelengths of the three hydrogen lines using the following method:
The angle (θ) for each line of hydrogen was measured. Combining this data with the linear relationship between wavelength and sin (θ) we can determine the wavelengths of the lines of hydrogen. This is done by using the equation for the line of best fit from the helium data:

$y = m \cdot x + b$

where m is the slope and b is the y-intercept found from the line of best fit. Replacing wavelength for y and sin (θ) for x:

$\lambda = m \cdot \sin(\theta) + b$

Using this graphical method we can calculate the wavelength of all three lines of hydrogen to a high degree of accuracy.

2. The spectral lines of hydrogen can also be calculated accurately using a simple relationship.

$$\lambda = \frac{91.15 \text{ nm}}{\left(\frac{1}{2^2} - \frac{1}{n^2}\right)}$$

where n can be 3, 4, 5, …, ∞.

Calculate λ for n = 3 through n= 6.

3. Calculate λ for n = ∞. To calculate this consider what happens when n becomes very large. If n is very large then 1/n is very small. The value of $1/n^2$ is even smaller:

$$\lambda = \frac{91.15 \text{ nm}}{\left(\frac{1}{2^2} - \frac{1}{n^2}\right)}$$ when n becomes very large: $$\frac{1}{n^2} = \frac{1}{\infty^2} = 0$$

4. Draw an energy level diagram using the
5. Calculate the percent difference for the three hydrogen lines that were measured.

$$\% \text{ difference} = \frac{|\text{measured value - calculated value}|}{\text{calculated value}} \times 100$$

Observations and Notes

Date _____________

Name_______________________________________

Names of partner (s)_______________________________ ___________________________________

Helium Spectrum

Color	**λ (nm)**	**Angle (θ) student 1**	**Angle (θ) student 2**	**Angle (θ) student 3**	**Average angle(θ)**	**Sin (θ)**
Red	668	_______	_______	_______	_______	_______
Yellow	588	_______	_______	_______	_______	_______
Green (bright)	502	_______	_______	_______	_______	_______
Green (dull)	492	_______	_______	_______	_______	_______
Blue	471	_______	_______	_______	_______	_______
Violet	447	_______	_______	_______	_______	_______

Hydrogen Spectrum

Color	**Angle (θ) student 1**	**Angle (θ) student 2**	**Angle (θ) student 3**	**Average angle(θ)**	**Sin (θ)**
Red	_______	_______	_______	_______	_______
Green	_______	_______	_______	_______	_______
Violet	_______	_______	_______	_______	_______

Hydrogen Spectrum

n	color	λ (nm) measured*	λ (nm) calculated**	% difference
3	red	______________	______________	______________
4	green	______________	______________	______________
5	blue	______________	______________	______________
6	violet	not measured	______________	
∞			______________	

*From graph

** From $\lambda = \dfrac{91.15 \text{ nm}}{\left(\dfrac{1}{2^2} - \dfrac{1}{n^2}\right)}$

Wavelength, frequency, and energy for hydrogen

λ (nm)	υ (s^{-1})	Energy (J)
______________	______________	______________
______________	______________	______________
______________	______________	______________