13. ATOMIC CONSTANTS

OBJECT

-- The aim of this experiment is to examine the Balmer series of spectral lines emitted by hydrogen and from the measured values of the wavelengths to arrive at the value of the Rydberg constant and Planck's constant.

INTRODUCTION

In the Bohr or planetary model of the hydrogen atom, the electron is considered to move in a circular orbit about the nucleus. At any instant, the electron can be in one of a select number of orbits characterized by quantum numbers n = 1, 2, 3, 4, . . . In the innermost orbit where n = 1 the angular momentum of the electron would be equal to $\frac{h}{2\pi}$ where h is Planck's constant; in the next orbit, out, the angular momentum would be $2(\frac{h}{2\pi})$ and so on.......

Whenever the electron jumps from a higher energy outer orbit to an inner orbit of lower energy, a well defined amount of energy ΔE is emitted in the form of electromagnetic radiation; i.e. a photon is emitted having a frequency

$$f = \frac{\Delta E}{h}$$

and a wavelength:

$$\lambda = \frac{c}{f} = \frac{ch}{\Delta E} \qquad (1)$$

where c is the speed of light in vacuum.

The visible or Balmer series of spectral lines emitted by a hydrogen source corresponds to electrons in the atoms jumping from various outer orbits to the orbit of quantum number n = 2: the red line associated with electrons in a number of the atoms jumping from n = 3 to n = 2, the bluish-green line associated with the n = 4 to n = 2 transition . . . The relative number of atoms of the source in which electrons go from a particular initial energy state to the final (n = 2) state determines the relative intensity of the particular spectral line corresponding to this transition.

The energy of an electron in the n^{th} orbit is given by $E_n = \frac{E_1}{n^2}$ where E_1, the energy in the innermost orbit (equal numerically to that energy needed to ionize a hydrogen atom), has a value of -13.58 ev. (Note that 1 electron-volt = 1.60×10^{-19} joules.)

In 1885, Balmer obtained a simple relationship between the wavelengths of the visible lines emitted by hydrogen and the quantum numbers associated with the transitions giving rise to these lines, i.e.

$$\frac{1}{\lambda_n} = R_H \left(\frac{1}{2^2} - \frac{1}{n^2}\right) \qquad (2)$$

where n = 3, 4, 5, . . . and R_H is Rydberg's constant.

In this Study, the wavelengths of the first four Balmer lines will be measured using a spectrometer and diffraction grating. Rydberg's constant will then be determined graphically making use of the relationship indicated as equation (4) in experiment 8. Finally Planck's constant will be be determined from equation (3) in experiment 8 rewritten in the form:

$$h = \frac{(\Delta E)\lambda n}{c} = \frac{(E_n - E_2)}{c}\lambda_n \qquad n = 3, 4, 5, \ldots \qquad (3)$$

1. <u>Adjustment of Spectrometer</u> (Note: do this part very carefully)

   (a) Focus the telescope for parallel light by sighting on a distant object through a window.

   (b) Eliminate parallax between the image of the distant object and the cross hairs of the telescope by adjusting the eyepiece until there is no relative motion between the cross hairs and the image of the distant object when you move your eye from side to side slightly while viewing through the telescope.

(c) Align the spectrometer so that the collimator and the clamped telescope are in line. Insert the hydrogen spectrum tube into the holder on the power supply and then turn on the power supply.

WARNING:

After the power supply is turned on DO NOT touch the tube holder or replace the tube because of the high voltage which will cause a serious electrical shock.

2. Balmer Series Wavelengths

(a) Fix the diffraction grating on the prism table by means of the holder provided. Orient the table so that the plane of the grating is approximately perpendicular to the path of the light arriving at it from the collimator slit and note the angular reading on the scale.

(b) Move the telescope slowly to the right and locate the four lines of the Balmer series to be examined (in viewing order: two violet lines, a bluish green line, and a red line). Note the angular position of each.

Repeat this step to the left of the central image.

(c) Calculate the wavelength of each of the four lines using the grating relation:

$$m\,\lambda = d \sin\theta \qquad m = 0, 1, 2, \ldots$$

where d is the grating constant (separation between the lines) scratched on the grating material) determined in Experiment 7 and θ is the average angular separation between a spectral line and the central image.

3. Atomic Constants

(a) Plot a graph of $\frac{1}{\lambda}$ versus $\frac{1}{2^2} - \frac{1}{n^2}$ using the measured wavelength values. From the slope of the resulting line, compute R_H and then compare this result to the accepted value.

(b) Calculate the energy values for orbits of quantum numbers 2, 3, 4, 5, & (Note that they will all be negative).

Calculate $E_n - E_2$ for each of the spectral lines and, then, h using equation (3).

Compare the average experimental value of h to the accepted value.

Accepted Values:

(1) Rydberg Constant $R_H = 1.097 \times 10^7 \ m^{-1}$

(2) Planck's Constant $h = 6.626 \times 10^{-34}$ J-sec.