

L-5

THE BALMER SERIES

The hydrogen atom consists of a single electron bound to a proton. The behavior of the hydrogen atom, and the discrete nature of the light it emits are not explainable by classical electrodynamics. In 1913 N. Bohr proposed his "Quantum Theory" of the hydrogen atom. In this theory the energy of the bound electron takes only discrete values corresponding to orbits with discrete radii.

Radiation occurs only when the electron makes a transition from one energy level to a lower (more tightly bound) level. The electromagnetic radiation that is emitted in this "quantum jump" may be visible light, or it may have shorter (Ultra Violet) or longer (Infra Red) wavelengths, and be invisible. The energy of the various levels is given by:

$$E_n = -\frac{me^4}{8\epsilon_0^2 h^2} \cdot \frac{1}{n^2} \quad (1)$$

and corresponds to orbits with radii given by

$$r_n = \frac{\epsilon_0 h^2}{\pi m e^2} \cdot n^2 \quad (2)$$

where n is an integer called the "quantum number" of the orbit. A large quantum number n corresponds to an orbit with a large radius r_n , and a large energy E_n , a small quantum number corresponds to an orbit with a small radius r_n and a small energy E_n . The energy of the levels is negative, this means that the electron is bound to the nucleus.

A NOTE TO THE INSTRUCTOR

You should see that the spectrosopes are properly adjusted, and that the collimator is near ~ 2 cm from the source. Students often bump the apparatus, and bring it out of alignment; make sure they know to call you if this happens.

YOU NEED TO KNOW

The formula for the energy of the photon emitted in an electron transition between two discrete energy states in a hydrogen atom is

$$E_{ph} = E_{n_u} - E_{n_l} \quad (3)$$

THE HYDROGEN ATOM

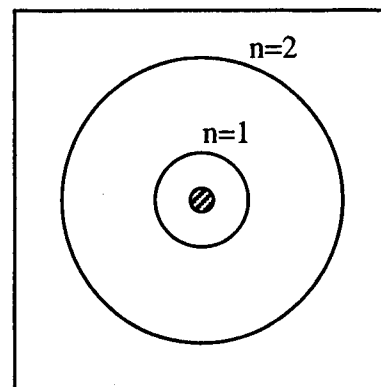


Fig. 1

Where n_l is the quantum number of the lower level which has a small radius and a large negative energy; and n_u is the quantum number of the less tightly bound upper level ($n_u > n_l$). The family of transitions which have a common lower quantum number is called a series; the series where $n_l = 1$ is called the Lyman series; the corresponding radiation is in the ultraviolet, outside the visible region.

The series that lies in the visible region corresponds to $n_l = 2$ and is called the Balmer series. It is this series of transitions that you will be observing in this experiment. Three of the transitions are in the visible region. A graphical representation of the energy levels and energy transitions is shown in fig. 2

$$\begin{aligned}\lambda_{5-2} &= 0.4340 \mu\text{m} \\ \lambda_{4-2} &= 0.4861 \mu\text{m} \\ \lambda_{3-2} &= 0.6562 \mu\text{m}\end{aligned}$$

Using the relationship between the energy of a photon and its frequency $E = hf$ and the relationship between wavelength and frequency $f = c/\lambda$ one obtains

$$\frac{1}{\lambda} = R \left[\frac{1}{n_l^2} - \frac{1}{n_u^2} \right] \quad (4)$$

In the above

$c = 3 \times 10^8$ m/s, is the velocity of light in vacuum.

$h = 6.63 \times 10^{-34}$ J · s is Planck's constant.

$R = 10.97 \cdot 10^6$ m⁻¹ is the Rydberg constant.

The wavelength formula was found experimentally by Rydberg in 1895, and it was first calculated by N. Bohr's quantum theory.

You must also know the grating equation:

$$\lambda = d \sin \theta / m \quad (5)$$

where m is an integer called the "order of the spectrum" and d is the spacing of the grating, i.e., the distance between adjacent lines of the grating. More than one order can be observed by going to large angles but in this experiment you should restrict your observations to the first order; that is, to the spectrum at relatively small angles where $m = 1$.

IN THIS EXPERIMENT

In this procedure you will use a diffraction grating to measure the wavelength λ of the three visible Balmer lines of hydrogen and compare your results with Bohr's theory.

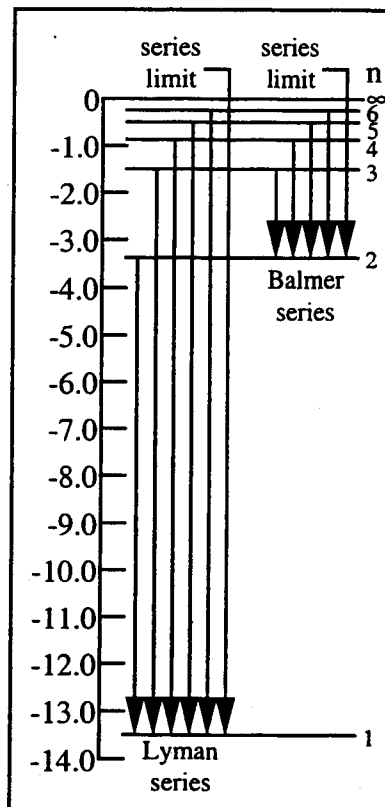


Fig. 2: The energy levels

The layout of the experiment is schematically as shown below.

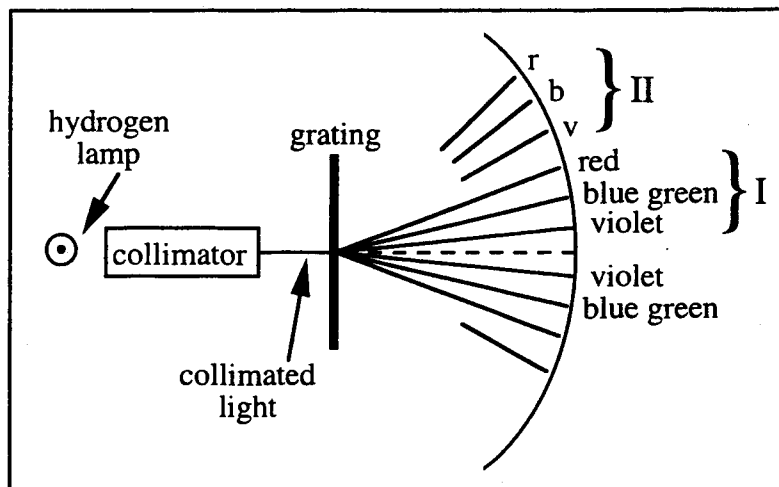


Fig. 3: Schematic setup

You will be finding the angular distance between lines of the same colour on opposite sides of the centerline, this is twice the angle given by (5). Don't forget to use decimal degrees; don't confuse the $\alpha_{1/2}$ with $\alpha_{L/R}$ readings.

THE EQUIPMENT

in this experiment consists of:

- ⇒ A spectroscope with a light source for alignment.
- ⇒ A diffraction grating with 600 lines per mm.
- ⇒ A black cloth for covering the instrument to avoid letting extraneous light into the telescope tube.
- ⇒ A hydrogen discharge tube with power supply.

The spectrometer is a device for measuring angles with great precision. The spectrometers in the laboratory can measure angles to one minute of arc ($\frac{1}{60}$ of one degree).

The spectrometer has a light collimator (C) to gather as much light as possible into the telescope; it consists of a slit and a focusing lens (D).

THE SPECTROMETER