Bimodal Fitting of Atomic Hydrogen Spectrum in Hydrogen-argon Mixed Gas Plasma

Bohan Luan¹,*, Yongpeng Zhao²-a and Weijiang Zhao³-b

¹College of Electronic Engineering, Heilongjiang University, Harbin 150080, China
²Harbin Institute of Technology, Harbin 150001, China

*Corresponding author e-mail: 2008038@hlju.edu.cn, a1196523899@qq.com, b939796748@qq.com

Abstract. In the research field of new energy sources, hydrogen energy has become the same green energy as solar energy and wind energy. Fractional hydrogen atom is a hypothesis of a new atomic state, which proposes that under the action of certain catalysts (such as Ar+) hydrogen atoms of ground state can transit to the energy level of fractional principal quantum number that lower than the ground state energy level, and releases a lot of energy at the same time. The results of this study are as follows, fitting the measurement results of the hydrogen Balmer α line, and by which obtaining the bimodal structure of the spectrum. The analysis of the fitting results shows that the bimodal structure well explains that the hydrogen atoms in the hydrogen-argon plasma can be divided into two components: high temperature and low temperature, and the more accurate fitting line of the hydrogen atom spectrum broadening can be obtained by this fitting method.

1. Introduction
With the energy crisis approaching, hydrogen energy as an important new energy source has been the research hotspot in the world for decades, and the research of high-energy hydrogen-containing plasma has opened up a new field of hydrogen energy research. In the past decade, the special spectral phenomena found in mixed gas plasma containing hydrogen have been reported in the world [1] (the extraordinary broadening of the Balmer line of hydrogen atom). At present, these phenomena have been realized in various discharge mechanisms, including high temperature incandescent filament heating, radio frequency excitation and glow discharge [2-4]. All these experiments indicate the existence of a high-energy state in the hydrogen-containing plasma. In 2002, R. Mills et al. of the United States completed the energy measurement experiment of this plasma, which proved that the heat enthalpy released by per unit mass hydrogen was one order of magnitude higher than that of oxyhydrogen combustion, which made it possible to become a new energy source in the future.

In 2000, R. Mills proposed hypothesis of the fractional principal quantum number energy level of hydrogen atoms: hydrogen atoms may have larger bound energy states, which are generated by resonance transfer of energy between hydrogen atoms and certain catalysts (such as Ar+). These energy states (fractional energy levels) are:

\[ E_n = \frac{13.6eV}{n^2} \quad n = \frac{1}{2}, \frac{1}{3}, \frac{1}{4}, ..., \frac{1}{p} \]
Up to now a series of experiments have proved that hydrogen atoms can transit to the fractional energy level after catalytic reaction. If this fractional hydrogen plasma does exist, its high energy will greatly solve the problem of human energy. For example, the energy released by a hydrogen atom from \( n=1 \) to \( n=1/2 \) is 40.8eV, far more than that released energy by a hydrogen atom combining with oxygen atom to form water molecule (about 1.25eV).

2. Experimental scheme and device
The phenomena of extraordinary broadening of the Balmer \( \alpha \) line of hydrogen atoms found in hydrogen-containing plasma have been observed and studied in various schemes of experimental devices. These discharge devices mainly include: tip electrode discharge device, hollow cathode discharge device, wave energy discharge device and so on. In our research a hollow cathode discharge device was used to study the spectra of hydrogen-argon discharge plasma. The main purpose of this study is to verify the super-broadening phenomenon of hydrogen atomic lines and to find out the law of such broadening by spectral analysis.

As shown in Fig.1, the experimental device consists of a hollow cathode discharge tube, a vacuum system, a gas supply system, a vacuum gauge, a discharge power supply and a monochromator for spectral measurement. During the experiment, the discharge tube was pumped into a low vacuum by a vacuum pump, and the gas pressure was less than 1 Pa. Then the mixture of hydrogen and argon gas was injected into the discharge tube from the gas storage tank with a flowmeter. The mixing ratio was set prior to the experiment. Under the condition of monitoring the pressure in the discharge tube with a vacuum gauge, the gas injection valve of the flowmeter and the pumping valve of the vacuum pump are adjusted so that the pressure in the discharge tube reaches a basically constant value, i.e. the gas pressure in the tube reaches a dynamic equilibrium, so as to maintain a certain period of time to ensure that the flowing gas will take away the original air impurities in the tube. The discharge power supply is then activated to stabilize the glow discharge of the hollow cathode. The light emitted by the discharge plasma is guided through the quartz glass window at the front end of the discharge tube. After focusing through the lens, the light is coupled to the end of the photoconductive fiber of the monochromator. Finally, the specific spectrum lines of hydrogen atoms are scanned by the monochromator.

3. Experiments and discussions
In the whole experiment, the monochromator was used to scan the target wavelength range to get the spectral measurement results. The experimental conditions are as follows: DC glow discharge, discharge voltage 250-350V, discharge current 0.1-1.0A, pressure 250-500Pa. Under this experimental condition, both theory and experiment show that the main mechanism of spectral line broadening is Doppler broadening, so Doppler broadening can be used to calculate the temperature of hydrogen atoms.
3.1. The abnormal broadening of the Balmer α line of hydrogen atom has been detected experimentally

Figure 2 shows the measurement results of hydrogen atom Balmer α line. The experimental conditions are as follows: the ratio of hydrogen to argon is 1:10, the pressure is 220 Pa, the discharge voltage is 365 V, and the discharge current is 0.2 A. The fitting results show that the broadening of the spectral line reaches 0.19 nm, and the temperature of hydrogen atom calculated by Doppler broadening reaches 14.6 eV. At the same time, the spectrum of argon ion has been measured. The result shows that the spectrum of argon ion has not been broadened, which indicates that the temperature of argon ion is still normal. This result clearly proves that the hydrogen atom in the hydrogen-argon plasma has been heated for some reason and reaches a high energy. This heating mechanism is obviously not yet known physical mechanism, because any known physical mechanism can not explain why only hydrogen atoms are heated, and can not explain from what source hydrogen atoms acquire so much energy. This result at least shows that fractional hydrogen theory may be an applicable theory for explaining the phenomena of high energy hydrogen atoms.

![Figure 2](image_url)

**Figure 2.** Measurement results of hydrogen atom Balmer line (solid line is the measured spectral line shape and dashed line is Gauss fitting results).

3.2. Gauss bimodal fitting of hydrogen atom Balmer α line

It is found that some spectral lines can be fitted by the superposition of hydrogen atomic lines of two temperature components. As shown in Figure 3, the experimental conditions are as follows: the ratio of hydrogen to argon is 1:10, the pressure is 220 Pa, the discharge voltage is 479 V, and the discharge current is 0.3 A.

As shown in the figure, the measured spectral lines can be seen as the superposition of two Gaussian lines. The broadening of these two lines is different, representing the hydrogen atom components of two kinds of energy, one is lower energy, and the other is higher energy. The calculation results show that the spectral line broadening of high-energy components reaches 0.54 nm, the temperature reaches 118.4 eV, and that of low-temperature components is 0.19 nm, and the temperature is only 14.6 eV. This phenomenon shows that the hydrogen atoms in the plasma have not reached the thermal equilibrium state, and the high-energy hydrogen atoms are continuously produced, and all the hydrogen atoms are heated by collision with other low-energy hydrogen atoms. It also indicates that some effect must occur in the hydrogen-argon plasma, so that some chosen by conditions hydrogen atoms can be heated first, and then the energy of other hydrogen atoms is increased by collision.
Figure 3. Bimodal fitting of hydrogen atom Balmer line (solid line is the measured spectral line shape and dashed lines are the fitting results of double peaks of Gauss line).

3.3. Bimodal Fitting can get more accurate fitting of spectral line with measured ones

As mentioned above, by fitting the two-peak Gauss line of the spectrum of hydrogen atoms, it is clear that some hydrogen atoms are in extremely high energy state, reaching an astonishing more than 100 electron volts. This ultra-high energy indicates that there is a certain effect on hydrogen atoms and releases a great deal of energy. Moreover, this fitting analysis can more accurately determine the different energy components of hydrogen atoms, which is helpful to better understand the process and mechanism of hydrogen atom reaction. In the future, more such spectral results should be obtained in experiments, and the law of generation and evolution of high-energy hydrogen atoms can be found through more analysis.

4. Conclusion

(1) The abnormal broadening of the Balmer α line of hydrogen atom (up to 0.19nm) was detected by using a single tube hollow cathode discharge tube, which indicates that there exist high energy hydrogen atoms in hydrogen-argon plasma.

(2) Gauss linear bimodal fitting of the spectrum of hydrogen atom is carried out. It shows that hydrogen atoms can be divided into two components: high energy and low energy. It shows that hydrogen atom in hydrogen-argon plasma is in non-equilibrium state. High energy hydrogen atoms are derived from the energy obtained by some hydrogen atom which meets the conditions of some heating mechanism. This phenomenon is even more likely indicates the existence of this mechanism.

(3) It is evident that more accurate fitting results can be obtained by the two peaks of the spectral lines. It also provides a better understanding of the kinetic processes of high-energy hydrogen atom generation and collision heating. Further experiments should be carried out in this regard.

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References

[1] M Kuraica, N. Konjevic, Line shapes of atomic hydrogen in a plane-cathode abnormal glow discharge, Phys. Rev. A. 46 (1992) 4429-4432
[2] Mills R, Nansteel M, Ray P, Argon-hydrogen-strontium discharge light source, IEEE TRANSACTIONS ON PLASMA SCIENCE. 30(2) (2002) 639-652
[3] Mills R, Ray P, Dhandapani B, Comparison of Excessive Balmer $\alpha$ Line Broadening of Inductively and Capacitively Coupled RF, Microwave, and Glow-Discharge Hydrogen Plasmas With Certain Catalysts, IEEE Trans. Plasma Sci. 31(3) (2003) 338-355
[4] Mills R, Chen X, Ray P, Plasma power source based on a catalytic reaction of atomic hydrogen measured by water bath calorimetry, Thermochimica Acta. 406 (2003) 35-53
[5] Mills R, Ray P, Dhandapani B, New power source from fractional quantum energy levels of atomic hydrogen that surpasses internal combustion, Journal of Molecular Structure. 643 (2002) 43-54.