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STARK PROFILES OF H_β LINE IN THE CATHODE FALL REGION OF AN ABNORMAL GLOW DISCHARGE

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Abstract. The theory of linear Stark effect has been employed to create numerical model of hydrogen Balmer H_β profiles in external electric field of cathode fall region. The influence of fine structure splitting to the shape of theoretical line profiles has been studied in details. An example of fitting the theoretical profiles to the experimental recordings of H_β line emitted from the cathode fall region of the Grimm-type abnormal glow discharge is presented.

1. INTRODUCTION

The presence of external electric field in the cathode fall region of glow discharges predominantly determines the shape of hydrogen Balmer lines. Recently, the polarization dependent Stark splitting of neutral hydrogen lines has been employed in several measurements of electric field strength in the cathode fall region of glow discharges (Barbeau and Jolly, 1991; Ganguly and Garscadden, 1991; Donkó et al., 1994). In this work, we have treated Stark profiles of H_β line, taking into account all components induced in transitions between sub-levels of neutral hydrogen atom in external electric field. The analysis of the influence of fine structure splitting to the shapes of H_β Stark profiles is also performed. Using least square method, the experimental data are fitted with theoretical profiles, providing results of local electric field intensity and temperature of excited hydrogen atoms.

2. THEORY

The splitting of energy levels of the hydrogen and hydrogen-like emitter in an external electric field is successfully described by both semiclassical and quantum mechanical theory of the linear Stark effect (see e.g. Condon and Shortley, 1977; Ryde, 1976). Both theories yield the same result: energy level with principal quantum number n is splitted into (2n – 1) equidistant sub-levels determined by quantum number k ($|k| < n$). Therefore, spectral line emitted as a transition between energy levels 1 and 2 of hydrogen atom consists of numerous components. These components are polarized either linearly, parallel to the vector of external field ***E*** ($\Delta m = 0$, or π-components), or circularly, in the plane perpendicular to ***E*** ($\Delta m = \pm 1$, or σ-components). The way of polarization is determined by the parity of the integer $[(n_1 + k_1) - (n_2 + k_2)]$, so one has

$$\Delta(n+k) = \textit{even} \text{ integers - } \pi\text{-components},$$
$$\Delta(n+k) = \textit{odd} \text{ integers - } \sigma\text{-components}.$$

The Stark manifolds of π and σ components of hydrogen Balmer H_β ($n_1 = 4 \rightarrow n_2 = 2$) line are presented schematically by vertical lines in Fig. 1.

Stark components are wavelength shifted from the line center by the value

$$(n_1 k_1 - n_2 k_2)\Delta\lambda_0, \tag{1}$$

where $\Delta\lambda_0$ is the smallest shift determined by the local field intensity. According to Ryde (1976), for H_β line one has:

$$\Delta\lambda_0[\text{nm}] = 1.52 \cdot 10^{-3} E\,[\text{kV/cm}] \tag{2}$$

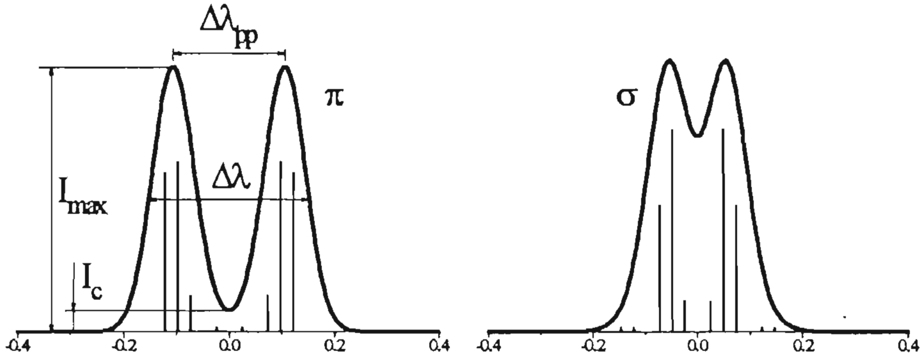

Fig. 1. Theoretical π and σ profiles of H_β line (thick solid lines) calculated for: 8 kV/cm electric field intensity, 5 eV temperature of excited hydrogen atoms and 0.014 nm instrumental half-width. Vertical lines represent theoretical Stark manifold, with relative intensities taken from Condon and Shortley (1977). Base lines: relative wavelengths in nm. The example of H_β (π) explain characteristic line profile parameters.

With the polarizer axis set parallel or perpendicular to the electric field, the appropriate (π or σ) overall profile is formed. The shape of these profiles depends also upon the resolution power of the spectral instrument used for observation. In order to create overall π and σ Stark profiles we assumed that plasma broadening in the cathode fall region may be neglected; calculations of Bogaerts et al. (1995) show that electron densities in the cathode dark space of analytical glow discharge do not exceed 10^7 cm^{-3}. Thus, to the each Stark component we have assigned Gauss function only. The full halfwidth $\Delta\lambda_G$ of each gaussian results from Doppler, $\Delta\lambda_D$, and instrumental, $\Delta\lambda_I$, halfwidths:

$$\Delta\lambda_G = \sqrt{\Delta\lambda_D^2 + \Delta\lambda_I^2} \tag{3}$$

In the case of hydrogen atom, Doppler halfwidth can be calculated from

$$\Delta\lambda_D = 7.16 \cdot 10^{-7}\, \lambda_0 \sqrt{T} \tag{4}$$

where λ_0 is the central wavelength of the line and T is the temperature of the excited H atoms. The overall profile is calculated as the superposition of all components:

$$I(\lambda, E, T) = \sum_{l=1}^{N} I_{0l} \exp\left\{-\left[\frac{\lambda - (n_1k_1 - n_2k_2)_l\,\Delta\lambda_0}{\Delta\lambda_G / 2\sqrt{\ln 2}}\right]^2\right\} \tag{5}$$

where I_{0l} are relative intensities (Condon and Shortley, 1977) and N is the total number of components which is equal to 10 for both H_β π and σ profiles. The examples of Stark polarized profiles, calculated for $E = 8$ kV/cm, $T = 5$ eV and $\Delta\lambda_I = 0.014$ nm (our typical experimental conditions), are presented by thick solid curves in Fig. 1. The characteristic parameters of a line profile are given in this figure also: full halfwidth $\Delta\lambda$, peak-to-peak separation $\Delta\lambda_{pp}$ and maximum-to-central intensity ratio I_{max}/I_c.

2.1. THE INFLUENCE OF FINE STRUCTURE SPLITTING

Theoretical Stark profiles obtained as described are symmetrical, see Fig 1. It is important also to consider the influence of the fine stricture splitting to the shape of π and σ profiles. The positions and intensities of the fine structure H_β Stark components, for electric fields of 2, 4 and 6 kV/cm, were calculated by Lüders (1951). We have compared π and σ H_β line profiles evaluated from Eq. (5) with those calculated using Lüders' component manifold for the same electric field intensities in the temperature range 0.1-100 eV. Temperature dependencies of the line characteristic parameters $\Delta\lambda$, $\Delta\lambda_{pp}$ and I_{max}/I_c, calculated with and without fine structure splitting are shown in Fig. 2. From the analysis of data in this figure one can conclude that halfwidth of the profile and separation between peaks do not differ very much for these two sets of results. Differences in $\Delta\lambda$ for π and σ profiles do not exceed 3% and 14% respectively. $\Delta\lambda_{pp}$ for π and σ do not differ more than 9% and 13% respectively. The only significant differences in I_{max}/I_c occur for the π profile at low temperatures, see Fig. 2. In our experimental conditions, however, temperatures of excited H atoms in the cathode fall region are of the order or higher than 5-6 eV (see Videnović et al., this Volume). From the dependencies of H_β line parameters one may generally conclude that differences between parameters of the π and σ profiles calculated with and without fine structure splitting completely disappear at temperatures higher then 12 eV. Therefore, in order to simplify the analysis of experimental data, we neglected the influence of fine structure splitting to the line profiles. Our experimental profiles are thus fitted with corresponding symmetric profiles (5) obtained by varying electric field intensity E and temperature T of excited H atoms.

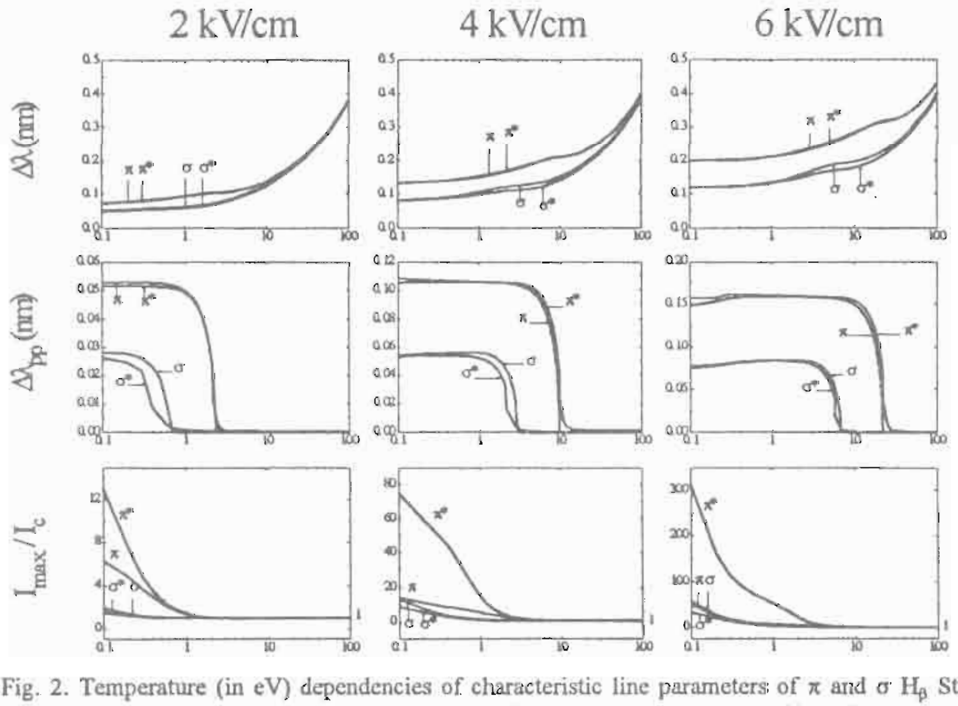

Fig. 2. Temperature (in eV) dependencies of characteristic line parameters of π and σ H_β Stark profiles. Line profile parameters calculated using fine structure splitting manifold (Lüders, 1951) are denoted with asterisks.

2.2. FITTING THE EXPERIMENTAL LINE PROFILES

Experimental setup for the spectroscopic measurements of the radiation emitted from the cathode fall region of the Grimm-type abnormal glow discharge is fully described elsewhere (Kuraica et al., 1992; Videnović et al., 1995). Typical results of Balmer H_β spectra recordings in the vicinity of the cathode of pure hydrogen and argon-hydrogen mixture ($Ar+3\%H_2$) discharge, their best-fits and results of local electric field intensity obtained in this way are shown in Fig. 3. The more complex discussion of the best-fit temperature results is the subject of another report of Videnović et al. in this Volume.

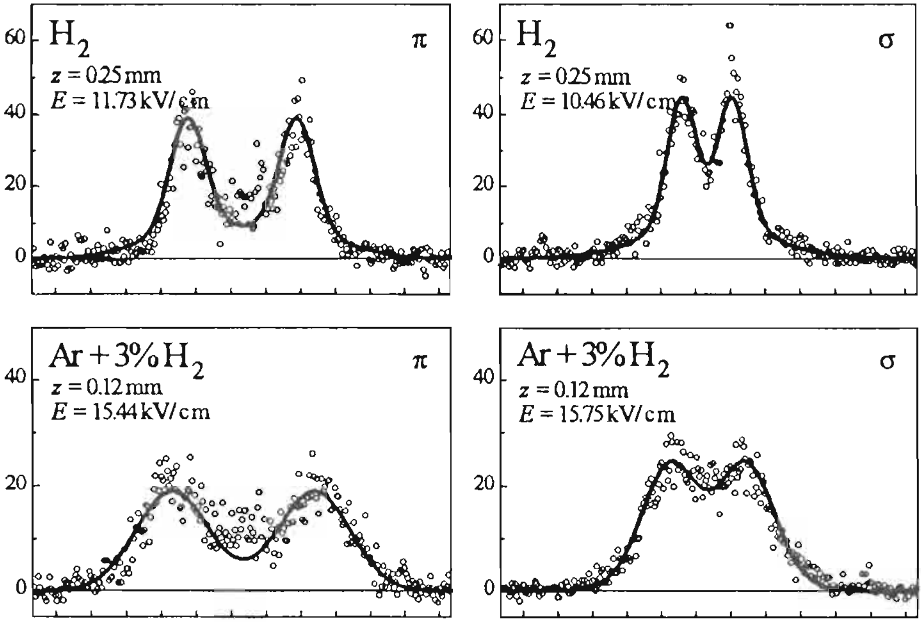

Fig. 3. Typical measured H_β Stark profiles in the vicinity of the cathode and their best fits. z is the distance from the cathode. The wavelength scale is given in 0.1 nm units.

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