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THE INFLUENCE OF THE FINE STRUCTURE TO THE HYDROGEN BALMER LINE SHAPES IN THE CONDITIONS TYPICAL FOR THE ANALYTICAL GLOW DISCHARGE CATHODE FALL REGION

I. R. VIDENOVIĆ and M. M. PLATIŠA
Faculty of Physics, University of Belgrade, P.O.Box 368, 11001 Belgrade, Yugoslavia

Abstract. The influence of the fine structure to the shapes of the hydrogen Balmer H_β and H_γ lines in the external electric field strengths in the range 0 - 20 kV/cm, and excited hydrogen atoms temperature ranging from 0.1 to 300 eV is studied. No significant deviations of the line shapes calculated with and without fine structure influence has been encountered. The reasonable accuracy of the simple symmetrical Stark manifold for the cathode fall region diagnostic purposes is approved.

1. INTRODUCTION

Knowledge of the external electric field axial distribution is essential for the diagnostics of the cathode fall region (CFR) of a glow discharge. The nonintrusive spectroscopic method for the determination of the electric field distribution in the CFR of various types of glow discharges have been employed in several recent experimental studies (Barbeau and Jolly, 1991; Ganguly and Garscadden, 1991; Donkó *et al.*, 1994; Videnović *et al.*, 1996). This method is based on the polarization-dependent Stark splitting coupled with Doppler broadening of hydrogen Balmer lines. The influence of the fine structure to the Stark profiles of the hydrogen H_β line is first investigated by Lüders (1951), providing Stark patterns of polarized H_β profiles for the electric fields of 2, 4 and 6 kV/cm. For the same electric field strengths, our previous studies (Videnović *et al.*, 1996, Videnović and Platiša, 1998) showed that, when the temperature of the emitters - excited hydrogen atoms exceed 5 eV, the effects of the fine structure splitting to the line shapes of both hydrogen Balmer H_β and H_γ lines may be neglected. In this paper, we extend our previous calculations to the electric field range of 0 - 20 kV/cm and excited H atoms temperature range of 0.1 - 300 eV, with intention to cover all conditions typical for the analytical glow discharge CFR (see Videnović *et al.*, 1996).

2. THEORY

2.1. SYMMETRICAL STARK SPLITTING

Both semiclassical and quantum mechanical theory of the linear Stark effect, applied to the hydrogen and hydrogen-like emitter, yield the same result (Condon and Shortley, 1977): each energy level is splitted into equidistant sub-levels. Therefore, the hydrogen spectral lines consist of numerous components which are polarized either linearly, parallel to the vector of external field $\vec{F}$ (π-components), or circularly, in the plane perpendicular to $\vec{F}$ (σ-components). The relative wavelength positions of these components are proportional to the electric field strength and form the characteristic symmetrical Stark pattern. In numerical modeling of Stark profiles of hydrogen lines we assumed that plasma broadening effects in the CFR of a glow discharge may be neglected. Thus, to each Stark component we have assigned a Gauss function only which takes into account the instrumental and Doppler broadening. The overall profile is calculated as the superposition of all components. A detailed explanation of the theoretical basis of these calculations one can find in Videnović *et al.* (1996).

2.2. FINE STRUCTURE COMPONENTS AND INTENSITIES

For the calculation of hydrogen atom eigenvectors and eigenvalues, the perturbed Hamiltonian in the external electric field $\vec{F}$ is taken, with eigenvalues E_ν obtained by solving the Schrödinger equation. The intensities of the components including fine structure splitting of the transition $n \rightarrow n'$ are given by the relationship (Gigosos and González, 1998)

$$I_{nn'} = 2\mathrm{Re}\,\mathrm{tr}\,(\vec{d}_{n'n} \cdot U_n^{+} \vec{d}_{nn'} U_{n'}) \,, \tag{1}$$

where $\vec{d}_{nn'}$ is the nn' box of the atom dipole momentum operator that connects the group of states n with the n' one and U_n is the evolution operator of the group of states with main quantum number n for a given configuration of the static electric field. Using the projector P_ν on the subspace of states with eigenvalue E_ν, one obtains:

$$I_{nn'} = 2\mathrm{Re} \sum_{\nu} \sum_{\nu'} \exp\left[-\frac{i}{\hbar} (E_\nu - E_{\nu'}^{'}) t \right] \mathrm{tr}\,(\vec{d}_{n'n} \cdot P_\nu \vec{d}_{nn'} P_{n'}) \,. \tag{2}$$

The inclusion of the Z components of the vector $\vec{d}_{nn'}$ yield intensities of the π transitions, while X and Y components yield intensities of the σ transitions.

3. RESULTS

For the quantitative characteristics of the H_β and H_γ line profiles, we used the full halfwidth $\Delta\lambda$ and the distance between strongest maximums $\Delta\lambda_{pp}$, see Videnović *et al.* (1996), Videnović and Gigosos (1998). For the H_γ (σ) profiles, for numerical reasons, $\Delta\lambda$ only is calculated. The electric field and temperature dependencies of the line profiles parameters are shown in Figs. 1 and 2.

By intercomparison of the surfaces at the left-hand and right-hand side of both figures, one may, at first sight, recognize them as identical. That approves once again that the fine structure splitting does not play an important role in the spectroscopic diagnostics of the CFR of a glow discharge, which employs Stark profiles of hydrogen lines. The usage of simple symmetrical Stark manifold of hydrogen lines enables quick estimation of the local electric field strength in the CFR and, by fitting the experimental profiles with theoretical ones, the temperature of the excited hydrogen atoms.

In addition, by analyzing the surfaces in Fig. 1, one may conclude that the halfwidth of all profiles depends linearly both, on the electric field strength and on the excited H-atoms temperature, for $T_H < 10$ eV. In absence of high-resolution spectral equipment, this feature can be used in determination of low electric fields, near the negative glow region, where Stark profiles has no distinguished maximums (see Videnović *et al.*, 1996).

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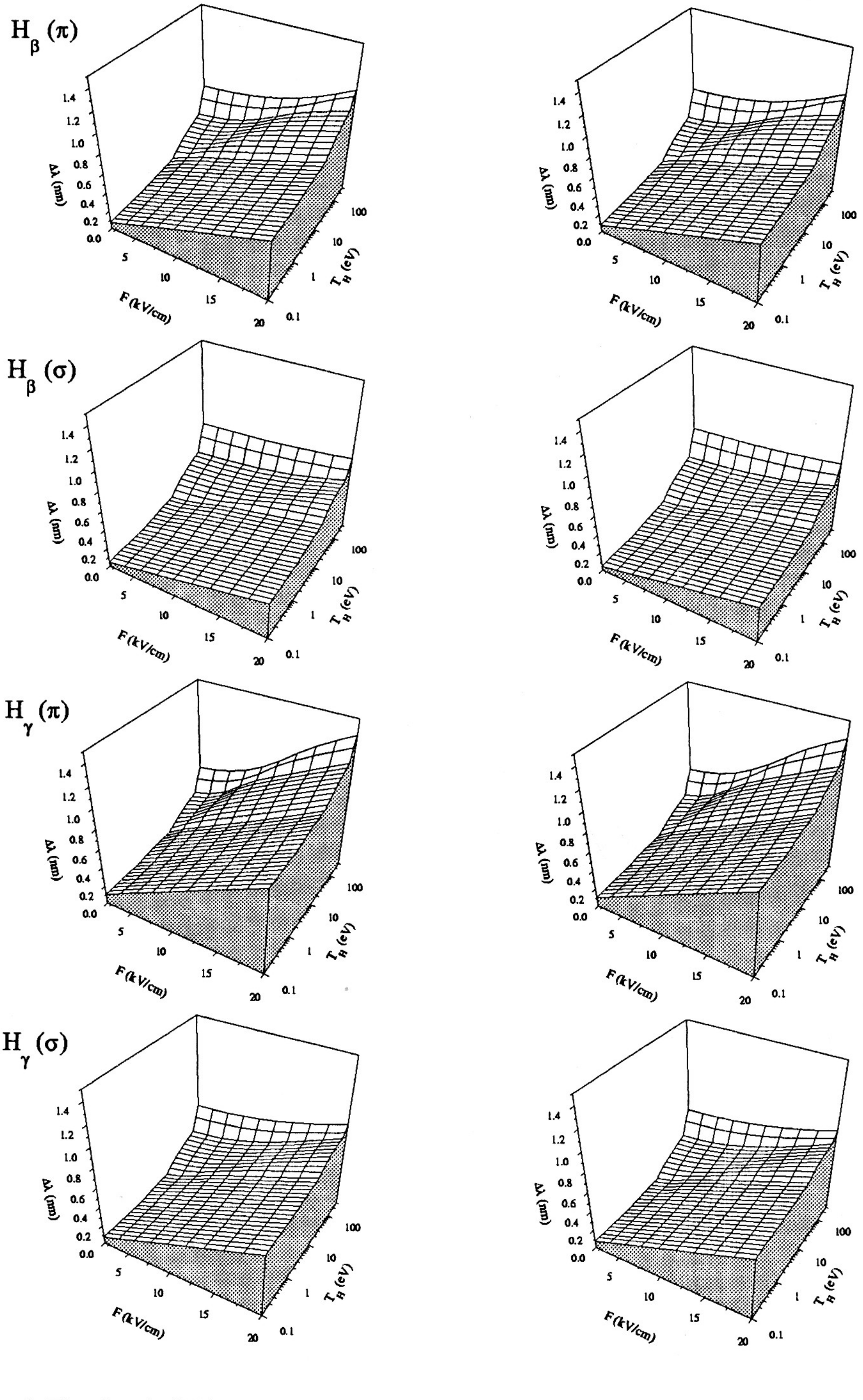

Fig. 1. The electric field strength (*F*) and emitter temperature (T_H) dependencies of the polarized hydrogen Balmer H_β and H_γ profiles halfwidth (Δλ), calculated upon symmetrical Stark manifold (left-hand side graphs) and including fine structure influence (right-hand side graphs).

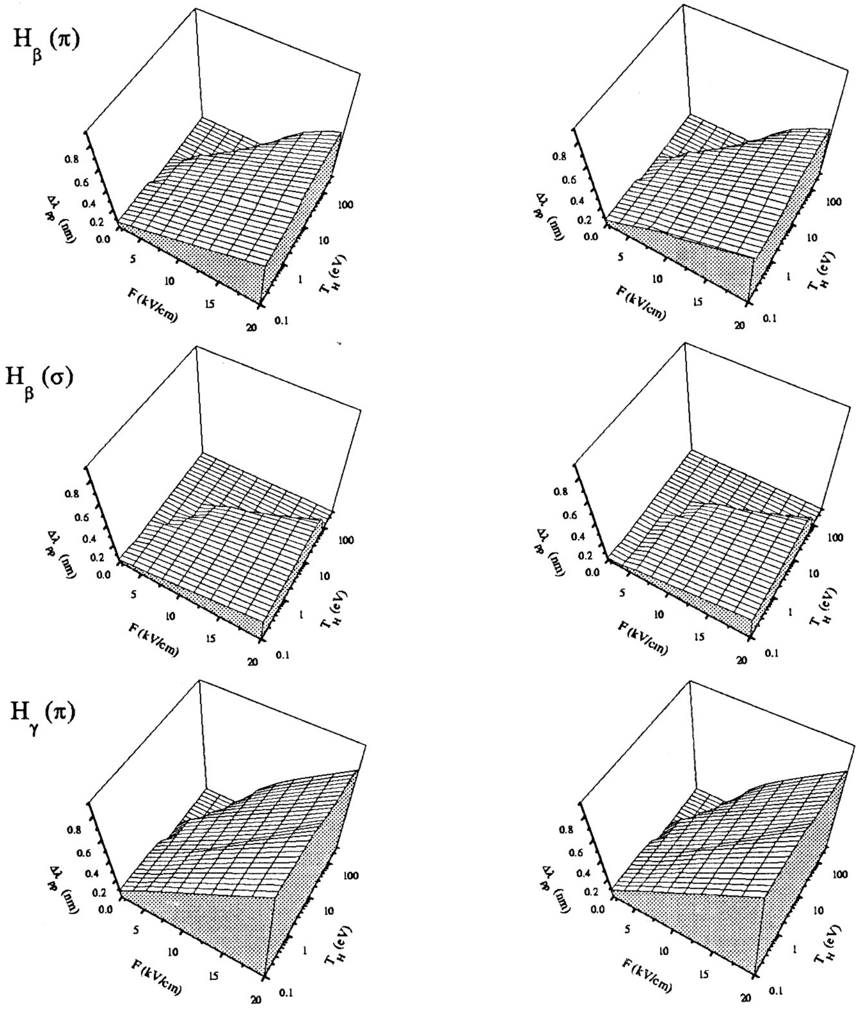

Fig. 2. Same as in Fig. 1, but for the distance between strongest maximums ($\Delta\lambda_{pp}$). For numerical reasons, this parameter is not calculated for the H_γ (σ) profile.

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