DETERMINATION OF THE TEMPERATURE DISTRIBUTION IN THE CATHODE SHEATH REGION OF HYDROGEN GLOW DISCHARGE USING Q-BRANCHES OF FULCHER-α BAND

Milica Vasiljević[1], Gordana Majstorović[2] and Đorđe Spasojević [1]

[1]*University of Belgrade, Faculty of Physics, 11001 Belgrade, P.O. Box 44, Serbia*

[2]*University of Defence, Military Academy, 11105 Belgrade, Pavla Jurišića Šturma 33, Serbia*

Optical emission spectroscopy (OES) technique is used to measure the electric field strength, and the rotational and gas temperatures along the axis of an abnormal glow discharge parallel to the plane copper cathode surface (side-on) operating in hydrogen at low pressure.

➢The most of GDS analytical applications is based on the original Grimm design [1] with both direct current (DC) and radio frequency (RF) excitation [2] .

➢The knowledge of discharge parameters, like the electric field strenght F distribution and translational gas temperature T_{tr} of molecules in the cathode fall (CF) region, is of particular importance for characterization of Grimm GD sources.

➢ The optical emission spectroscopy (OES) technique is used to measure the electric field and gas temperature in the cathode fall region of the Grimm type glow discharge operating in an hydrogen - argon mixture at low pressure.

➢ The electric field strength distribution in the CS region of discharge is determined by fitting the experimental profiles of the π-polarized hydrogen Balmer alpha line Hα, by the model function (1), precisely explained in [5, 9].

➢The model function is adjusted to achieve the best matching between the model and the recorded line profile. In order to fit the spectral lines the following function is used:

$$I(\Delta\lambda;F)=b+\Im*\{G(\Delta\lambda;H_1,c_1,w_1)+G(\Delta\lambda;H_2,c_2,w_2)+G(\Delta\lambda;H_3,c_3,w_3,w_3)+ \\ +S_F*[G(\Delta\lambda;zH_1,c_1,w_1)+G(\Delta\lambda;zH_2,c_2,w_2)+G(\Delta\lambda;zH_3,c_3,w_{Z3},w_3)]\}\,, \quad (1)$$

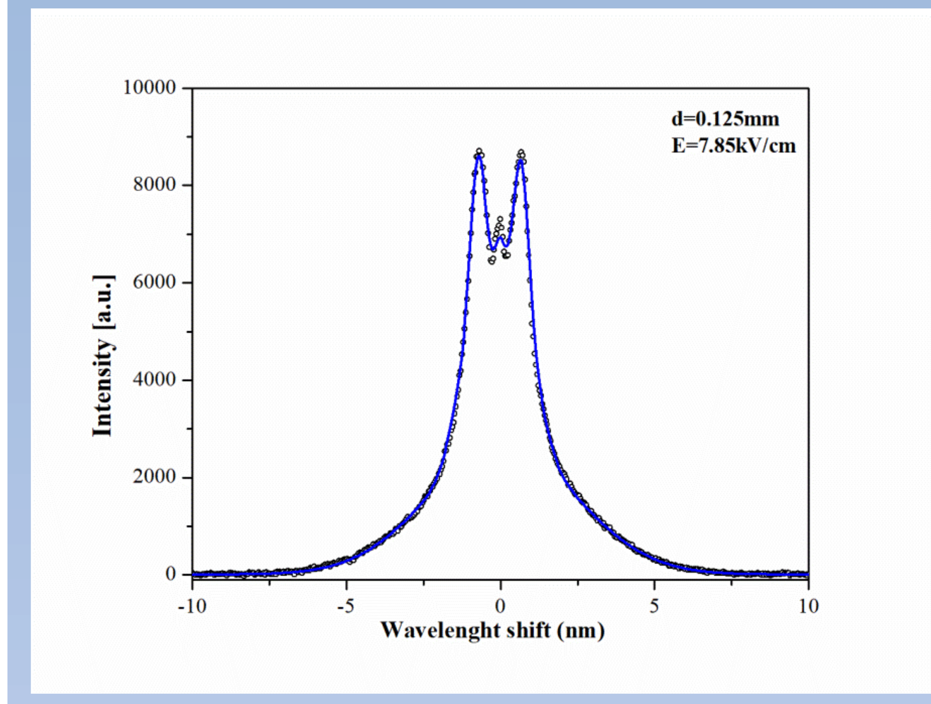


Figure 1. π-polarized side-on experimental profile (points) of the Hα line recorded at the first position in the CS region. The solid (blue) line represents the model function that best fits the experimental data. The corresponding value of the electric field strength F is shown in the legend together with distance d from the cathode of the recording position. Experimental conditions: cooper cathode, at p = 4.5mbar; I = 11 mA; U = 889 V.

➢ The temperature obtained from the Q branch of Fulcher-α band may be considered as the most reliable for the temperature estimation, see details in [1, 8, 9]. The Q branch lines of the electronic transition $d^3\Pi_u^-, \nu' \rightarrow a^3\Sigma_g^+, \nu''$ ($\nu'=\nu''=0, 1, 2$) are well resolved and have high enough intensities in the 595-645 nm wavelength region [2], see an example of recorded spectra in figure 3. So, Boltzmann plot technique is used for evaluation of rotational temperature $T_{rot}(n',\nu')$ of the excited state, see figure 4.

➢ Due to Λ-type doubling, $d^3\Pi_u$ state degenerates into the $d^3\Pi_u^-$ and $d^3\Pi_u^+$ states. The $d^3\Pi_u^-$ state can only have a Q-branch, whereas the $d^3\Pi_u^+$ state has both P and R branches, in the spontaneous rovibronic emissions to $a^3\Sigma_g^+$, see figure 2. Since the degenerated $d^3\Pi_u^+$ state interacts strongly with the $e^3\Sigma_u^+$ state, the P and R branches of the Fulcher-α band are perturbed and relative transition probabilities for these lines differ from the Hönl-London factors [8]. Therefore, we used the Q-branches from the $d^3\Pi_u^-$ state.

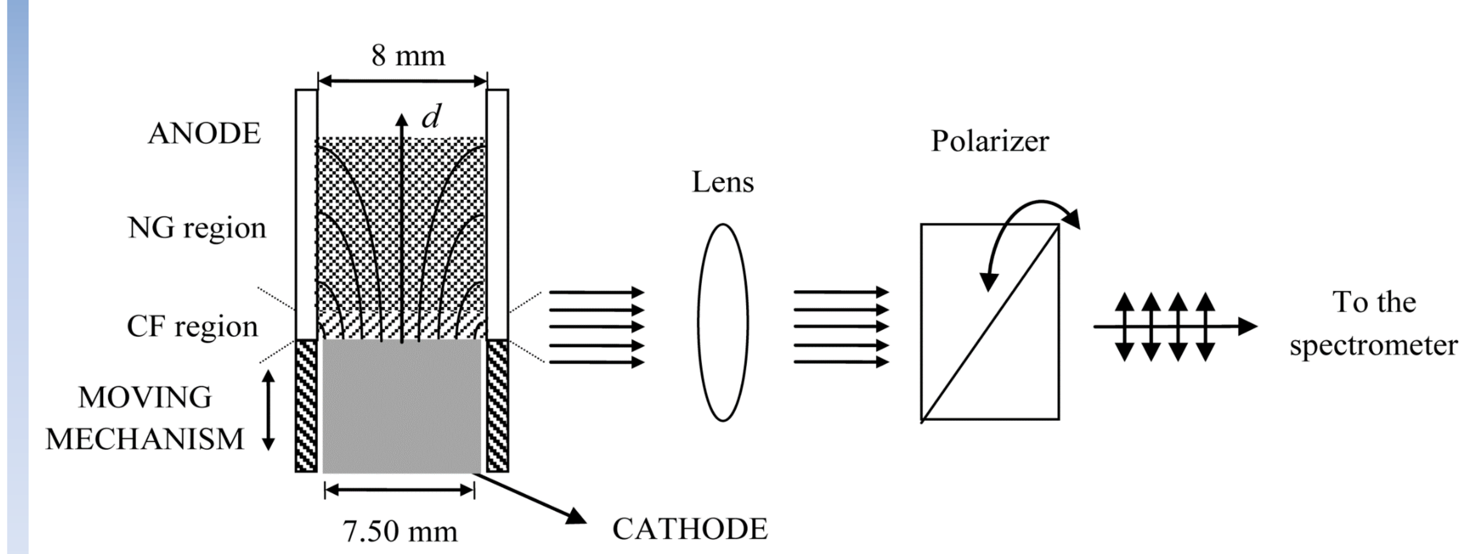
➢ Within the framework of model discussed in [1, 6, 8], the rotational temperature of ground vibrational state T_0 (n',ν') determined from the rotational population density distribution in an excited (n',ν') vibrational state can be considered as a valid estimation of the ground state rotational temperature, i.e. H_2 gas temperature.

$$\ln N^*_{n'\nu'N'} \equiv \ln\frac{N_{n'\nu'N'}}{g_{a.s.}(2N'+1)\tau_{n'\nu'N'}} = -\frac{hcE_{X0N}}{kT_0(n',\nu')} + const.$$

➢ In accordance with model [1], T_0 of the ground vibrational state $X^1\Sigma_g^+(\nu=0)$ is assumed to be equal to the gas temperature [5, 6]. In our case, the rotational temperature recalculated for the ground vibronic state $X^1\Sigma_g^+$ (ν = 0) is two times larger than the rotational temperature of excited states $d^3\Pi_u$,0 and $d^3\Pi_u^-$, 0 as is expected [1, 6, 8, 9], see figure 5. The rotational constants [4] for the upper $d^3\Pi_u^-$ and ground $X^1\Sigma_g^+$ (ν=0) states are (30.364 cm^{-1}) and (60.853 cm^{-1}), respectively.

➢ The dependence of the electric field strength and temperature T_0 versus distance from the cathode d are shown in figure 5.

Schematic diagram of the discharge source



Experimental

Working gas:	**Hydrogen**
Pressure	**1 – 10 mbar**
Current	**10 – 15 mA**
Cathode	**Cu**
Optical magnification	**1 : 1**
Monochromator	**Zeiss PGS-2 (2 m; 651 grooves/mm; 0.37nm/mm; FWHM 8.2 pm)**
Detector	**CCD ORMINS (Toshiba 1304 USB, 29.1mm; 3648 pixels)**

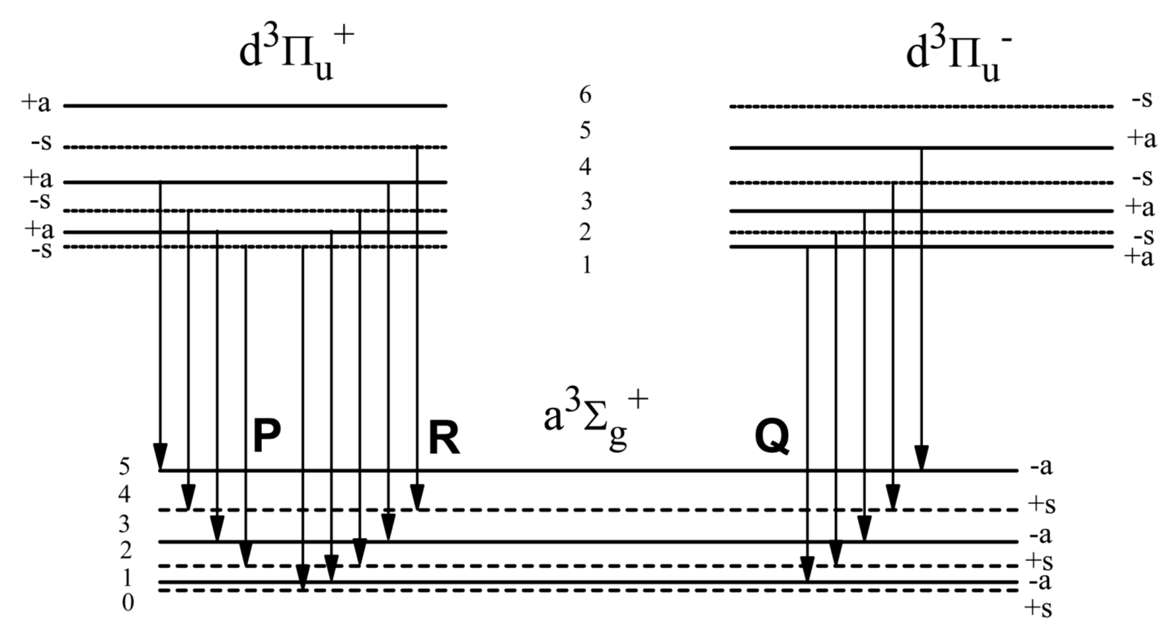


Figure 2. Term diagram for the Fucher-α band transitions for $\nu'=\nu''=0$

Table 1: Molecular constants for hydrogen ground state and Fulcher-α electronic states.

State	T_e (cm^{-1})	B_e (cm^{-1})	α_e (cm^{-1})
$d^3\Pi_u^-$	112753	30.364	0.5520
$a^3\Sigma_g^+$	95980	17.109	0.606
$X^1\Sigma_g^+$	0	60.853	1.0492

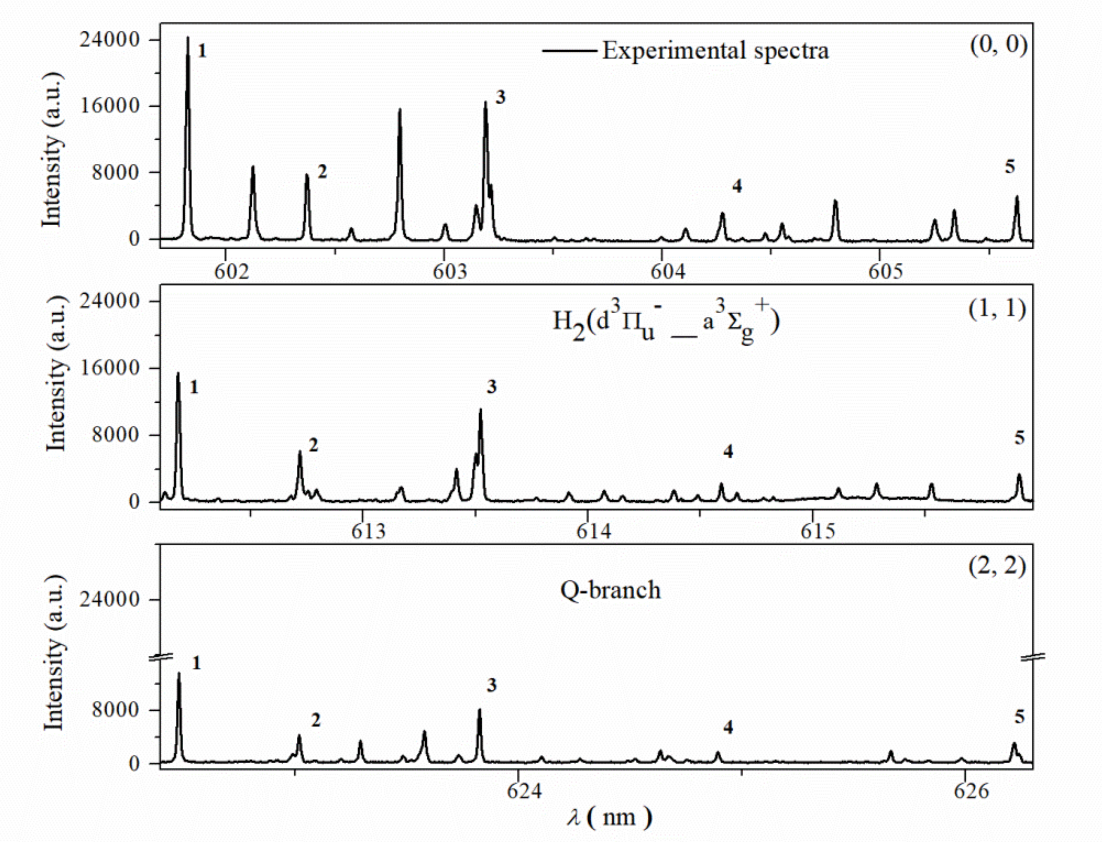


Figure 3. Emission spectra of rotational lines for $d^3\Pi_u \rightarrow a^3\Sigma_g^+$ system; Q-branch (with $\nu'=\nu''=$ 0, 1, 2) recorded in the second order of diffraction grating. copper cathode; Grimm GD in H_2 at the pressure p = 4.5 mbar, discharge current I = 11 mA, and discharge voltage U = 880V.

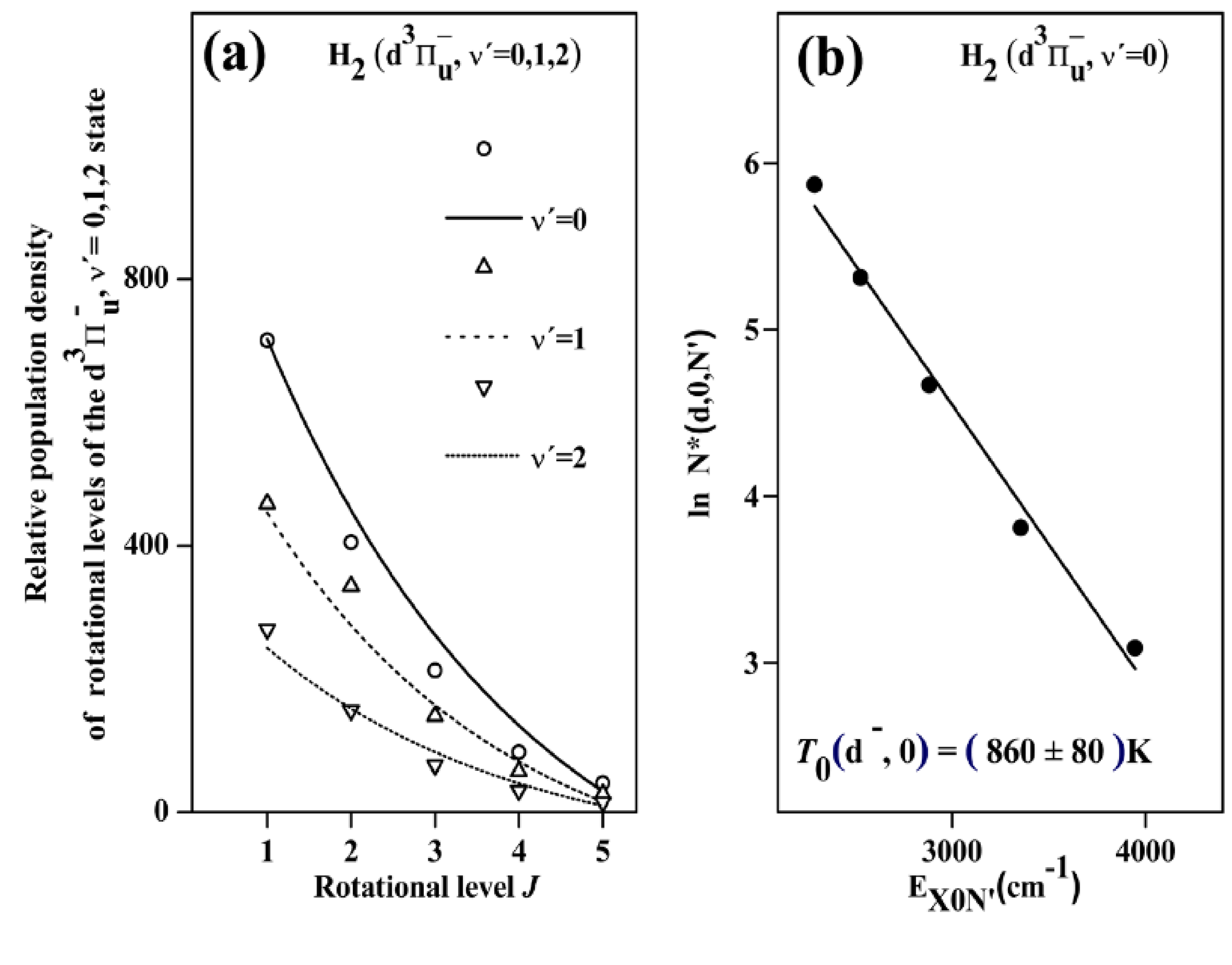


Figure 4. (a) Measured (points) and calculated (lines) values of the rotational population distribution of $H_2(d^3\Pi_u^-)$ levels. Lines represent the function $\exp(-B_vJ(J+1)hc/kT)$ for the corresponding rotational temperatures. (b) Semilogarithmic plot of rotational population densities of $d^3\Pi_u^-$ versus rotational energy of the molecular hydrogen ground states. Experimental conditions are the same as in Figure 3.

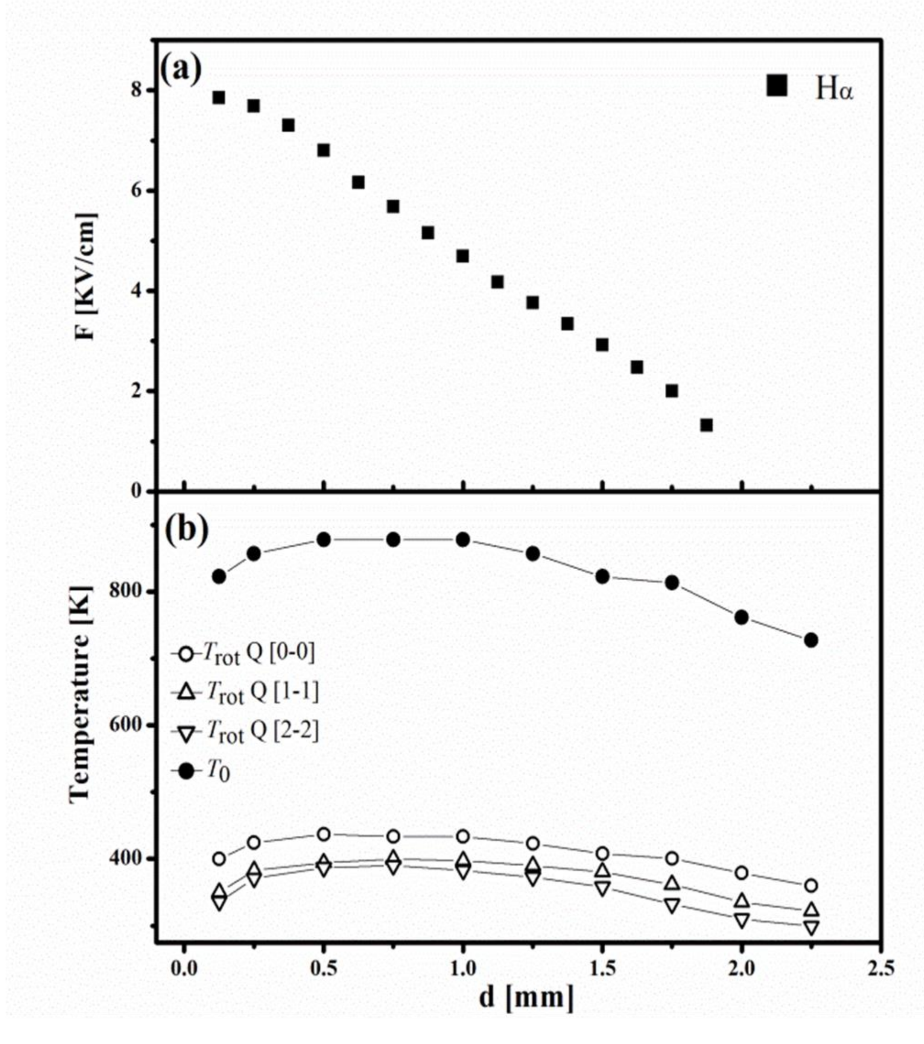


Figure 5. The dependence upon the distance from cathode d of: (a) Electric field strength F (b) Rotational (T_{rot}) and gas (T_0) temperature distribution of the excited state $H_2(d^3\Pi_u^-)$. Temperature T_0 of the $X^1\Sigma_g^+$ (ν=0) corresponds to gas temperature. Experimental conditions: cooper cathode Grim GD in H_2 at p = 4.5mbar, I = 11mA, and U = 880V.

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