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STARK BROADENING OF THE HYDROGEN H_γ SPECTRAL LINE

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Abstract. Stark broadening of the hydrogen H_γ spectral line is experimentaly investigated. Obtained experimental half-widths are compared with different theories. Plasma electron density was measured by CO_2 laser interferometer and by four parameters of He I 447.1 nm spectral line with forbidden component.

1. INTRODUCTION

During the last decades various theories considering Stark broadening of hydrogen lines have been developed and experimentally tested (Keple and Griem 1968, Vidal1 et al. 1973, Griem 1964, Griem 1974, Kelleher and Wiese 1973, Cooper et al. 1974, Wiese et al. 1975, Lee 1979, Fleurier et al. 1980, Demura and Sholin 1975, Griem 1983, Griem 1988, Stehlé and Hutcheon 1999, Gigosos et al. 2003, Poquérusse and Alexiou 2005). As a result, these lines appear to be an important tool in spectroscopic plasma diagnostics, especially for determining plasma electron densities. The H_β line has emerged as the optimal line at medium and high electron densities (on the order of 10^{16} to 10^{17} cm^{-3}). Higher-order members are rarely used for plasma diagnostics, although in some cases, they can be very useful, for example if lower members of the series are self-absorbed.

In plasmas of moderately low electron density, the higher members of the Balmer series could be very useful for plasma electron density deter-mination since they are not self-absorbed and are considerably more Stark-broadened. The H_γ line is around 30 % broader than the H_β line. This means that the contribution of the Stark effect to overall broadening is significantly more pronounced in the case of H_γ than in the case of H_β. Consequently, instrumental and Doppler broadening contribute less to the H_γ overall width, which decreases error in the Stark halfwidth (FWHM) determination.

The present study summarizes the experimental results of several experiments, including a study of plasma electron density determination using measured H_γ line profiles, modeled in conjunction with references Kepple and Griem (1968), Vidal et al. (1973) and more recent theories Stehlé and Hutcheon (1999), Gigosos et al.

(2003), Poquérusse and Alexiou (2005) that consider Stark broadening of H_γ. Our experimental setup enables us to systematically verify the inferred values obtained from Stark broadening against those obtained using one of the most reliable methods in plasma electron density diagnostics: a spectroscopically independent laser interferometric method (IFM). In this experiment, we also used the He I 447.1 nm line as an additional check for the plasma density measurement.

2. EXPERIMENT

A low-pressure plasma source, a repetitive 2-Hz pulsed arc was used, operating in a H_2:He gas mixture (with a volume ratio of 80% : 20%) under a pressure of 1.7 torr. The discharge circuit consists of a 2.5 μF capacitor C, which is connected to a power supply of 4 kV. The pulsed arc is fired at 4 kV by a grounded-grid thyratrone (see Fig. 1). The resistor R is used to critically damp the discharge current. The peak value of the discharge current (700 A) was maintained for about 10 μs and showed a high shot-to-shot reproducibility (within ±2%).

The light from the arc is focused onto the entrance slit of a 1-m monochromator by concave mirror M_2. The monochromator is equipped with a 1200 grooves/mm grating and a stepping motor controlled by a PC through a GPIB. This provided a spectral resolution of 0.005 nm, while the H_γ profiles were measured in 0.01 nm steps. The spectroscopic measurements were made with 15 μm-wide slits. A photomultiplier was placed at the exit slit of the monochromator and was used for spectral intensity measurements. The instrumental FWHM was 0.016 ± 0.002 nm, measured from the FWHM of several He I lines emitted from a low-pressure Geissler tube. The spectrum from the Geissler tube was introduced into the monochromator by means of semi-transparent mirror M_3. Mirror M_4 and semi-transparent mirror M_5 were used when the laser interferometry was performed.

An example of the recorded H_γ line is illustrated in Fig. 2, along with the theoretical FCS (Full Computer Simulation) profile Gigosos et al. 2003, which reproduces the experimental FWHM well, $\Delta\lambda_{1/2}$.

The spectral line profiles were recorded at τ = 21, 23, 25, 27 and 29 μs after the peak of the discharge current. This technique was applied for the recordings of not only the H_γ line profiles, but also the different He I line profiles including the He I 447.1 nm line with a forbidden component. This line was recorded since its parameters are very sensitive to the electron density and since it has been well investigated (see Mijatović et al 1997 and the references therein). The agreement of electron density values obtained using He I 447.1 nm line and interferometric method is inside 2 %.

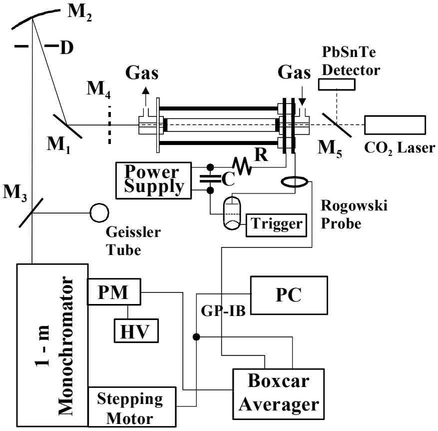

Figure 1: Experimental setup.

For the plasma electron density determination, in the range (1.9 – 5.9)·10^{15} cm^{-3} as an independent method, the laser interferometric technique was applied using a CO_2 laser interferometer at 10.6 μm. The electron temperature was determined from the line-to-continuum ratio of the hydrogen H_γ line (Griem 1964). Line profiles of several isolated He I lines were recorded to determine the gas temperature after the appropriate deconvolution procedure.

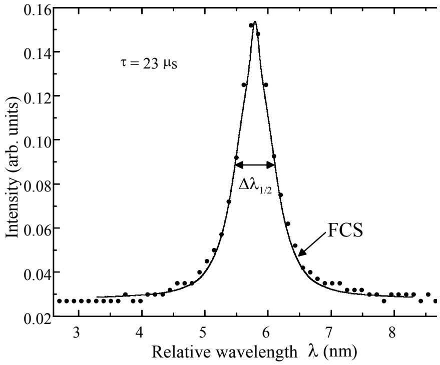

Figure 2: Recorded profile of Hγ.

3. RESULTS AND DISCUSSION

The electron densities determined from the Hγ FWHM are in conjunction with several theories ([a]Griem 1974,[b]Vidal et al. 1973, [c]Poquérusse and Alexiou 2005, [d]Stehlé and Hutcheon 1999, [e]Gigosos et al. 2003) as well as with the interferometric method [f](IFM), and these values are given in Table 1. The FWHM of the experimental H_γ line profiles for different plasma decay times are shown in the first column of Table 1.

The VCS theory predicts higher values, while FCS predicts lower values in comparison to the experiments and GRI and PST. This is valid for MMM as well with the exception of the result at highest electron density when MMM predicts higher value than experimental. At an electron density of 1·10^{15} cm^{-3}, this difference is considerable (roughly ±0.2·10^{15} cm^{-3}) while at higher densities, it is smaller. The other point that should be noted from Fig. 3 is that the MMM and FCS theories slightly converge at lower electron densities, while the others have a dependence on the FWHM that is similar to that of the experiments. As can be seen, the experimental results are in fairly good agreement with the theories GRI and PST at higher electron densities, while are somewhat higher than the MMM and FCS values

Table 1. N_e values obtained from different theories for measured H_γ FWHM and from IFM.

N_γ^{exp}	Ne (10^{15} cm^{-3})					
$\Delta\lambda_{1/2}$ (nm)	[a]GRI	[b]VCS	[c]PST	[d]MMM	[e]FCS	[f]IFM
8.49	6.5	7.8	6.0	6.1	5.5	5.9
6.36	4.4	5.4	4.0	4.0	3.6	4.5
4.97	3.1	3.9	2.9	2.8	2.5	3.4
4.12	2.4	3.0	2.2	2.1	1.9	2.5
2.93	1.5	1.9	1.4	1.3	1.2	1.9

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