The Role of Hydrogen Molecular Lines in the Vicinity of H_β

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The profile of H_β emitted by a low pressure afterglow discharge (p_0 = 500 Pa, $n_e = 1 \cdot 10^{15}$ cm^{-3}) is measured with 1 μs temporal resolution on a 500-channel optical multichannel analyzer (1 channel = 0.09 Å). Several structures appearing superimposed on thermal line profile can be identified as hydrogen molecular lines. These results affect earlier observations under very similar conditions which have been interpreted in terms of plasma satellites.

Introduction

In 1976 Ramette and Drawin [1] presented measurements of H_β line profiles in a linear afterglow plasma. Besides a discrepancy in the line center between the measured profile and the theory of Kepple and Griem [2], Ramette and Drawin report the occurrence of plasma satellite-like structures on the line wings which are interpreted to arise from the AC-Stark-effect due to electron plasma waves. The energy source for these plasma waves may be found in the suprathermal electrons produced by superelastic collisions during the recombination phase.

Experimental

We have repeated the measurements of Ramette and Drawin in a device very similar to that described in Fig. 1 of Ref. [1]. The plasma is produced in a pyrex tube ($l = 470$ mm, $d = 24$ mm) with plane quartz windows at both ends. Langmuir probes can be inserted radially at 3 different positions. The discharge conditions were restricted in these preliminary investigations to the set: $I_0 = 600$ A, $p_0 = 500$ Pa. The discharge was short-circuited 200 μs after ignition. During this time the discharge current decreased only by 15%.

The electron temperature and density in the center of the plasma were derived from double probe characteristics. Arcing of the probe was not observed until the probe voltage exceeded 25 V. Several probe characteristics have been evaluated yielding an electron temperature of $T_e = 3.5$ eV and density of $n_e = 1 \cdot 10^{15}$ cm^{-3} at the instant of shortcircuiting. A typical characteristic is given in Figure 1.

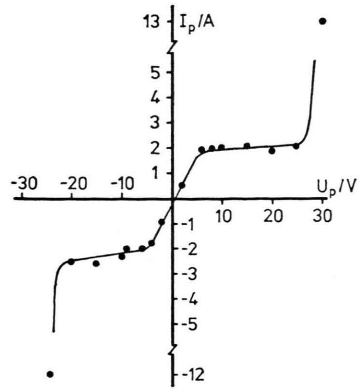

Fig. 1. Probe characteristic of a symmetrical double probe. The ion saturation current gives an electron density of $1 \cdot 10^{15}$ cm^{-3}, the slope in the origin an electron temperature of 3.5 eV.

The line profiles were recorded end-on along the tube axis. The center of the plasma column was imaged on the entrance slit of a $f = 1$ m grating monochromator. The exit slit was replaced by an optical multichannel analyzer (PAR model 1205 D). Using a grating of 1200 grooves per mm in second order a dispersion of 0.09 Å/channel was obtained. Crosstalk between adjacent channels reduced the effective spectral resolution to 2.5 channels. The whole line profile was recorded simultaneously on the 500-channel target. An exposure time of 1 μs was chosen as a compromise between line intensity and temporal resolution. The sensitivity amounted to 10 photons/count.

Results

A typical line profile of H_β recorded in the afterglow 6 μs after shortcircuiting is shown in Figure 2. The intensity is given as counts per channel on a linear scale, the statistical error of a single channel (± 3 counts) being indicated on the left. Several structures appear on the line profile which are compared with the positions of hydrogen molecular lines taken from the wavelength tables of Dieke [3]. The intensity of the superimposed structures lying in the range from 3 to 15 counts clearly exceeds the statistical error. The intensity of a particular structure varies from shot to shot by a factor of up to 2. Nevertheless the strongest molecular lines, for

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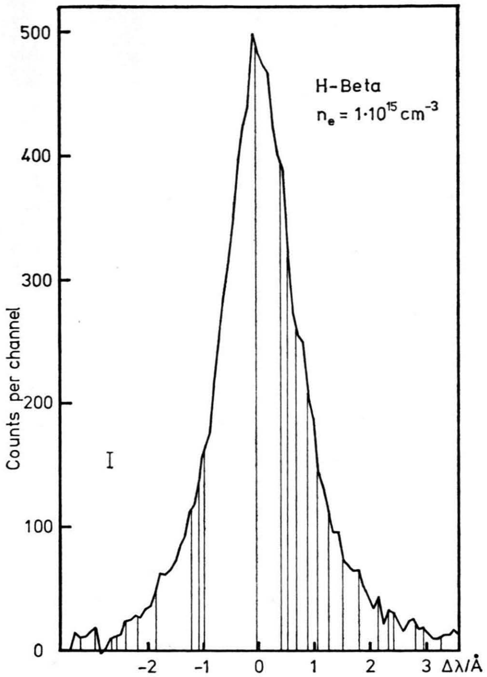

Fig. 2. Profile of H_β. The heavy line gives the measured profile. Vertical lines indicate the positions of hydrogen molecular lines. The statistical error is given on the left.

example the group at $\Delta\lambda = +0.5$ Å, can always be verified. 25 molecular lines could be identified, six of them are members of the electronic transitions $n=4 \rightarrow n=2$ and $n=3 \rightarrow n=2$, four lines belong to doubly excited upper states and for 15 known lines the corresponding transitions are not tabulated by Dieke.

In addition the occurrence of hydrogen molecular lines at the predicted positions was verified experimentally by producing a stationary RF-discharge ($f=20$ MHz, $P=20$ W) in the same device. In both types of discharges impurity lines due to wall and electrode material could not be detected in the interesting wavelength interval around H_β. Also molecular spectra of typical impurities (H_2O, OH, SiH) lie far from H_β.

In order to determine the exact position of expected plasma satellites at $\pm\omega_p$ the plasma density has to be measured accurately. Our probe measurements are confirmed independently by the shape of the H_β line wings. A comparison with the unified theory of Vidal et al. [4] is given in Figure 3. The curve which shows best agreement in the slope of the line wing in the range $\Delta\lambda = 1 \dots 3.5$ Å has been

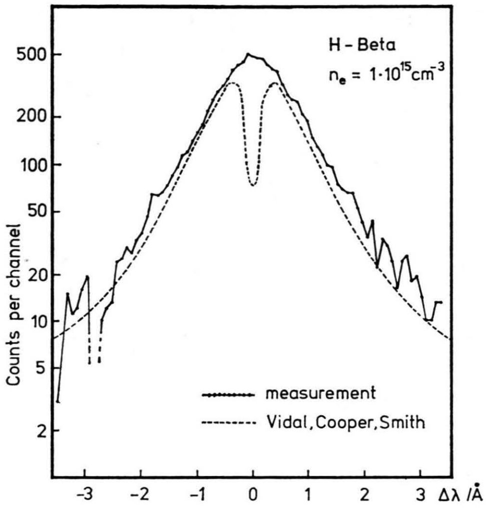

Fig. 3. Comparison of the measured H_β profile with the VCS-theory, calculated for an electron density of $1 \cdot 10^{15}$ cm^{-3}.

selected. The wings of the measured curve can be decomposed into the Stark broadened profile for an electron density of $1.0 \cdot 10^{15}$ cm^{-3} and superimposed structures. The uncertainty of the electron density can be estimated from a comparison with the unified theory for $n_e = 0.8 \cdot 10^{15}$ and $1.2 \cdot 10^{15}$ cm^{-3} to be less than 15%. Plasma satellites are therefore expected to occur at $\Delta\lambda = \pm 2.24$ Å, but weak structures at these positions may as well be identified with molecular lines.

The deep minimum in the line center predicted by the theory is not observed in our measurements for two reasons: End-on observations give an average over the axial density profile with low density layers contributing mainly to the line center and filling the hole. Doppler broadening is not included in the theoretical curve. It must be mentioned that although the comparison in the line center requires a more detailed analysis the determination of n_e from the line wings remains unchanged.

Discussion

Repeating the measurements of Ramette and Drawin under very similar conditions we find many structures coinciding with single or groups of molecular lines. This result contradicts the observations of the cited authors who report a smooth profile with sharp satellites at $\pm\omega_p$. Since these authors use a 10 channel polychromator covering only 1 Å of the spectral range their profiles are obtained shifting the polychromator by 1 channel from shot to shot and correcting for the varying total line intensity. The resulting line profile has to be considered as an average over at least 50 shots. Our line profile instead is obtained from a single shot. We suppose that the bad reproducibility of a particular molecular line leads to the apparent smoothing of the profiles Ramette and Drawin reported.

In a recent paper Drawin and Ramette [5] observed profiles of the He I 447.15 line and its forbidden component in the same experimental device. This line, which is often used to detect plasma satellites on helium lines, is obviously superimposed by helium molecular lines and the authors claim that some experiments showing plasma satellites may as well be explained by helium molecular lines. From this point of view we would expect molecular lines playing a more significant role in discharges of a molecular gas like hydrogen. A realistic calculation of the degree of dissociation involves the processes between all six constituents (H, H^+, H_2, H_2^+, H_3^+, e), recombination and diffusion, and was not obtained yet. A rough estimate results from a balance between dissociation by electron impact and wall recombination. This gives a lower limit to the molecular density of the order 1% to 10% of the atom density.

Conclusions

By improving the method of recording the H_β line profile in a hydrogen afterglow discharge we could detect many hydrogen molecular lines superimposed on H_β. For this type of discharge it will be very difficult to distinguish between observations of plasma satellites and molecular lines, since molecular lines will at least arise from boundary layers of the plasma. Generally observations of plasma satellites on hydrogen lines should therefore be scrutinized for accidental coincidences with molecular lines.

Acknowledgement

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