The Dynamic Stark-Effect in a Turbulent Hydrogen Plasma

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(Z. Naturforsch. **29 a**, 42–44 [1974]; received October 22, 1973)

The profiles of the first three Balmer lines of hydrogen are measured in a turbulent heating experiment. From the position of Stark satellites the field strength of low frequency oscillations ($\omega \sim \omega_{pi}$) is calculated. The energy density in these electrostatic oscillations can amount to 1% of the thermal energy. The presence of high frequency oscillations ($\omega \sim \omega_{pe}$) is concluded from satellites near $\pm\omega_{pe}$ from the unperturbed line position.

In turbulent heating experiments an electric field exceeding the run-away field, is applied to a plasma. This results in the excitation of e-e and e-i two-stream instabilities and ion-acoustic instabilities leading to a high level of longitudinal electrostatic oscillations. The wave energy saturates by the interaction between waves and particles. The transfer of energy from the waves to particles lead to electron and ion heating. In this paper the effect of low frequency ion oscillations ($\omega \sim \omega_{pi}$) and high frequency electron oscillation ($\omega \sim \omega_{pe}$) on the line shape of hydrogen spectral lines is shown experimentally. The observation of the profiles of the Balmer series can yield important information on the microscopic electric fields during the turbulent stage [1].

Calculations for the Ly_α line have been reported by Cohn et alias [2]. Similar calculation for the H_α and H_β profile under influence of static and dynamic fields are under way.

The turbulent plasma is produced by the discharge of a capacitor ($2\,\mu$F, 15 – 40 kV) across a hollow cathode discharge in a strong magnetic field ($B = 0.4 - 2$ T, discharge length 0.8 m). The profiles of the Balmer lines H_α, H_β, and H_γ are scanned with a one meter MacPherson monochromator in steps of 1/3 Å. The spectra are time averages over 0.5 μsec from three successive shots while the turbulent stage lasts for about 3 μsec. Side-on observations are carried out with a polarizer between plasma and monochromator. Specimens of the H_β and H_α lines are given in Figs. 1 and 2.

It is known from probe [3] and radiation [4] measurements that electrostatic oscillations at frequencies below $\omega \sim 2\,\omega_{pi}$ are present during turbulent heating. Besides that, strong electron oscillations at $\omega \sim \omega_{pe}$ were found [5]. The influence of low frequency fields on individual Stark components is in-

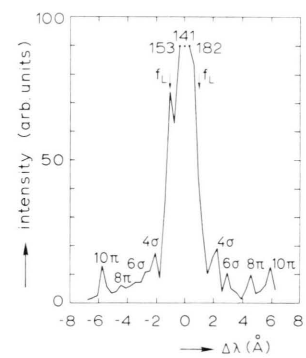

Fig. 1. Measured profile of the H_β line for $t = 1 - 1.5\,\mu$sec. f_L indicates the satellites caused by Langmuir oscillations. The parameter δ_S is greater than 100 for the Stark components $4\,\sigma$, $6\,\sigma$, $8\,\pi$ and $10\,\pi$.

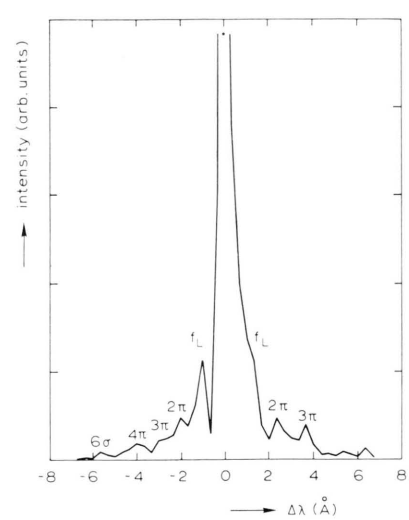

Fig. 2. H_α profile. $t = 1.5 - 2\,\mu$sec, density $n = 10^{20}\,\mathrm{m}^{-3}$. The electric field applied to the plasma is $E_0 = 28\,\mathrm{kV\,m}^{-1}$. The electric field $\tilde{E} = E_S$, deduced from the separation of the Stark components is $3.6\,\mathrm{MV\,m}^{-1}$.

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vestigated by Yakovlev[6]. He calculated the line shape in a harmonic electric field $\boldsymbol{E}_S(t) = \boldsymbol{E}_S \sin(\Omega_S t + \varphi)$ for random phase φ in the quasi stationary limit $\delta_S = \Delta\Omega_S/\Omega_S \gg 1$. $\Delta\Omega_S$ is the shift due to a field $|\boldsymbol{E}_S|$ and Ω_S the angular frequency. His calculation results in a sharp maximum in the radiation intensity near the position of the Stark satellite for completely static fields of the same value. It is known[7] that high frequency fields $\boldsymbol{E}_D \sin \Omega_D t$ ($\delta_D = \Delta\Omega_D/\Omega_D \lesssim 1$) only give rise to satellites at $\pm n\,\Omega_D$ with n an integer.

Here the composite electric field may be described by

$$\boldsymbol{E} = \boldsymbol{E}_S \cos(\Omega_S t + \varphi) + \boldsymbol{E}_D \cos(\Omega_D t + \varphi_2)$$

during some tens of ion plasma periods. For the experimental density of about 10^{20} m^{-3} the fundamental frequencies are $\Omega_S \sim 10^{10}$ sec^{-1} and $\Omega_D \sim 5 \cdot 10^{11}$ sec^{-1}. Rough estimates for $\Delta\Omega_S$ and $\Delta\Omega_D$ can be obtained from anomalous conductivity data and from the emitted radiation near ω_{pe}[5]. From this follows $\delta_S > 50$ and $\delta_D < 1$ for our experimental conditions. The high frequency field gives satellites at the Langmuir frequency, f_L, and harmonics, symmetrically with respect to the unshifted line and the quasi-static Stark components.

The measured H_β profile (Fig. 1) and H_α profile (Fig. 2) show satellites at f_L during the entire turbulent state whereas separate Stark components

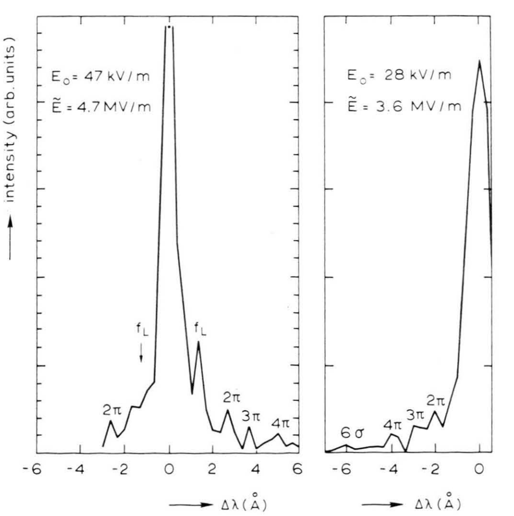

Fig. 3. The H_α profile for two values of the applied field E_0. Plasma conditions see Figure 2.

analysed as 4σ, 6σ, 8π, and 10π for H_β and 2π, 3π, 4π and 6σ for H_α appear after 0.5 μsec. The frequency shift of the distinct Stark components is larger than 10^{12} sec^{-1}. The intensities seem to be correlated with ion heating[8]. In Fig. 3 the H_α profile is shown for two different values of the electric field across the discharge. The turbulent fluctuations increase with increasing applied field, as is found from the separation of the Stark components. Measured values of the electrostatic field strength $\tilde{E} = E_S$ are given in Table 1.

Table 1. Measured values of the field strength $\tilde{E} = E_S$ of the low-frequency electrostatic oscillations.

line	Orientation of polarizer	Applied field E_0	Microfield $\tilde{E}$
H_α	$\perp$	47×10^3 V/m	4.5×10^6 V/m
H_α	$\parallel$	47	4.7
H_β	$\parallel$	47	4.5
H_α	$\perp$	28×10^3 V/m	3.6×10^6 V/m
H_α	$\parallel$	28	3.6
H_β	$\parallel$	28	3.5
H_γ	$\parallel$	25×10^3 V/m	3.2×10^6 V/m

Earlier observations of the H_β side bands have been reported at the V European Conference[9] but at that time the spectral resolution was insufficient to see the individual Stark component resolved. Gallagher and Levine[10] have reported Balmer line anomalies of the same character for a toroidal high-β plasma. The relation between shift and field strength for the components $k\pi$ and $k\sigma$ is $\Delta\Omega = 3/2\, a_0 k E_S$.

The intensities of the π and σ components are rather insensitive for the orientation of the polarizer between plasma and monochromator. This indicates that the low frequency electrostatic waves have no preferential direction of propagation for this particular experiment.

Acknowledgement

The authors are indebted to Prof. C. M. Braams for fruitful discussions.

The help of Mr. R. A. A. Ambags and Mr. B. de Groot during the measurements and the acquisition of the data is greatly appreciated.

This work was performed under the Euratom-FOM association agreement with financial support from ZWO and Euratom.

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