

# EXCITATION OF NON-EQUILIBRIUM ELECTRIC FIELDS IN CURRENT SHEET PLASMAS

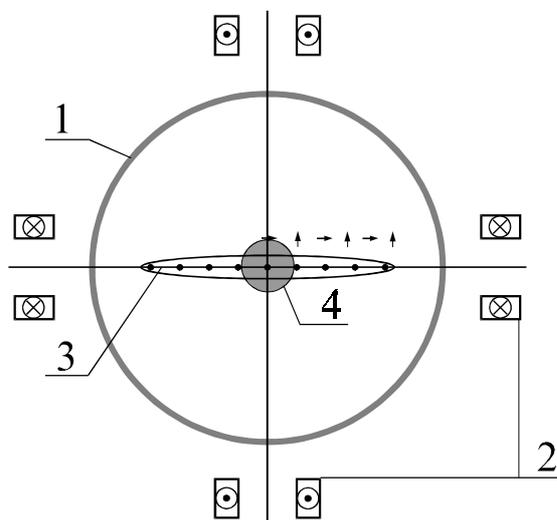
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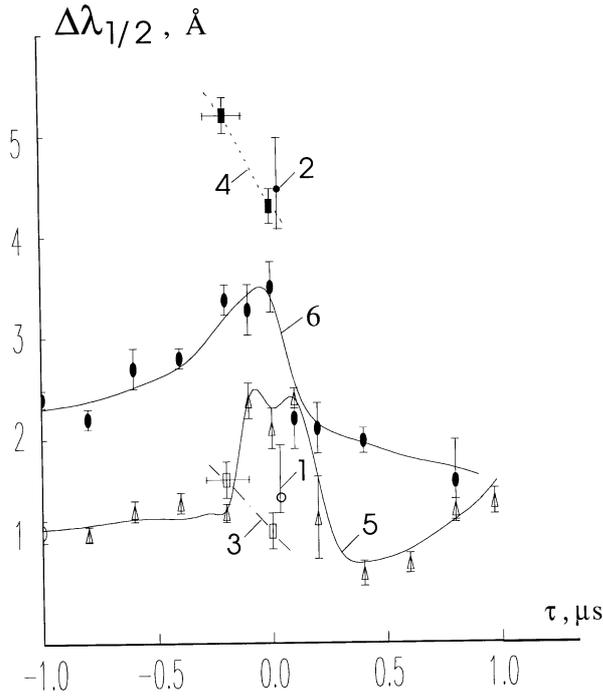
A problem, whether there is a relation between magnetic reconnection phenomena and an excitation of plasma microinstabilities, is one of the most complicated problems in physics of flare-type processes. A development of plasma turbulence and a sharp drop of the conductivity, as a consequence, could result either in an increase of the magnetic reconnection rate, or even in a transition to flare-type processes. But, on the other hand, plasma turbulence may be a secondary phenomenon which follows processes like thermal or tearing instabilities. In this report we present results of experimental and theoretical research of non-equilibrium electric fields in current sheet plasmas. We used two novel spectroscopic methods. Experiments were performed at the installation “Current Sheet” (General Physics Institute of Russian Academy of Sciences, Moscow), see Fig.1. A plane current sheet was produced by

exciting an electric current along the null line of two-dimensional quasistationary magnetic field [1,2].



**Fig. 1.** Experimental installation “Current Sheet”: 1 - vacuum chamber; 2 - current carrying conductors generating a quasistationary quadrupole magnetic field with null line; 3 - current sheet (arrows at its surface indicate positions and orientations of magnetic probes); 4- region, an emission from which is analyzed).

Spectral lines of Li-like impurity ions CIV, NV, OVI were studied in the first series of experiments [3]. The parameters of the plasma in the current sheet were as follows:  $N_e \approx 10^{16} \text{ cm}^{-3}$ ;  $T_e \approx 20 \div 100 \text{ eV}$ ;  $T_i \approx 40 \div 300 \text{ eV}$ . For each ion the profiles of two spectral lines were registered; one spectral line corresponded to 3s-3p transition and another to  $Hn_\alpha$  ( $n+1 \rightarrow n$ )-type transition, where  $n=5$  for CIV,  $n=6$  for NV and  $n=7$  for OVI. The broadening of the first line was primarily due to the Doppler effect, while the broadening of the second line was due to Doppler and Stark effects. Measurements of Doppler broadening



**Fig. 2.** Time evolution of the experimental FWHM of the following spectral lines:

- 1 - OVI 3811 Å (3s-3p), 2 - OVI 5291 Å (7dfghi-8dfghik),  
 3 - NV 4620 Å (3s-3p), 4 - NV 4945 Å (6dfgh-7dfghi),  
 5 - CIV 5812 Å (3s-3p), 6 - CIV 4658 Å (5dfg-6dfgh).

explain the large values of these FWHM is Stark effect in electric fields of plasma turbulence. We calculated profiles of the spectral lines  $Hn_\alpha$  of CIV, NV and OVI ions due to the combined effect of Doppler broadening and Stark broadening in electric field of low-frequency plasma turbulence. For the strength of the turbulent electric fields we used the following Rayleigh distribution function:

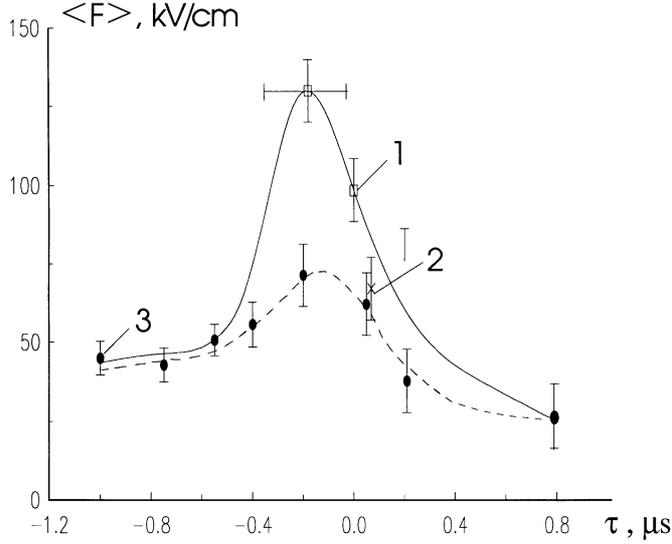
$$W(\eta) = 3 (6/\pi)^{1/2} \eta^2 \exp(-3\eta^2/2) \quad (1)$$

where  $\eta = F/\langle F \rangle$ , and  $\langle F \rangle$  is the root-mean square strength of the fields. Fig.3 presents the values  $\langle F \rangle$  obtained by the comparison of the theoretical and experimental profiles of the lines  $Hn_\alpha$  of ions CIV, NV and OVI. So, we revealed that non-equilibrium electric fields of the strength  $\langle F \rangle \approx 40 \div 120$  kV/cm were excited in a hot plasma of the central region of the current sheet. The increase in the strength of the fields up to the value 120 kV/cm was time-correlated with an explosive phase of the magnetic reconnection.

In the second series of experiments a cold collisional plasma was concentrated in a current sheet:  $N_e \approx (4 \div 9) \cdot 10^{16} \text{ cm}^{-3}$ ;  $T_e \approx T_i \approx 2 \div 3 \text{ eV}$  [4,5]. The profiles of two spectral lines were studied: HeI 6678 Å ( $2^1P - 3^1D$ ) and HeI 5876 Å ( $2^3P - 3^3D$ ). The FWHM of the line HeI 6678 Å was 3-4 Å, whereas the FWHM of the line HeI 5876 Å was 1.2-2 Å. The difference in

of 3s-3p spectral lines were used for the determination of ion temperature  $T_i$ . The Full Width at Half Maximum (FWHM) of all  $Hn_\alpha$  profiles were considerably larger than the FWHM of spectral lines 3s-3p. Fig.2 shows the FWHM of experimental profiles of 3s-3p and  $Hn_\alpha$  spectral lines of CIV, NV, OVI ions as a function of time.

The theoretical analysis of ‘‘Stark-Doppler’’ profiles of spectral lines  $Hn_\alpha$  of lithium-like ions CIV, NV, OVI was performed. This analysis has shown that the large experimental FWHM of  $Hn_\alpha$  spectral lines can not be explained by the action of individual electric ion microfield. The only physical mechanism that can



**Fig. 3.** Strengths (rms) of the anomalous electric field deduced from the experimental line profiles of different ions:  
 1 - NV 4945 Å (6dfgh-7dfghi),  
 2 - OVI 5291 Å (7dfghi-8dfghik),  
 3 - CIV 4658 Å (5dfg-6dfgh).

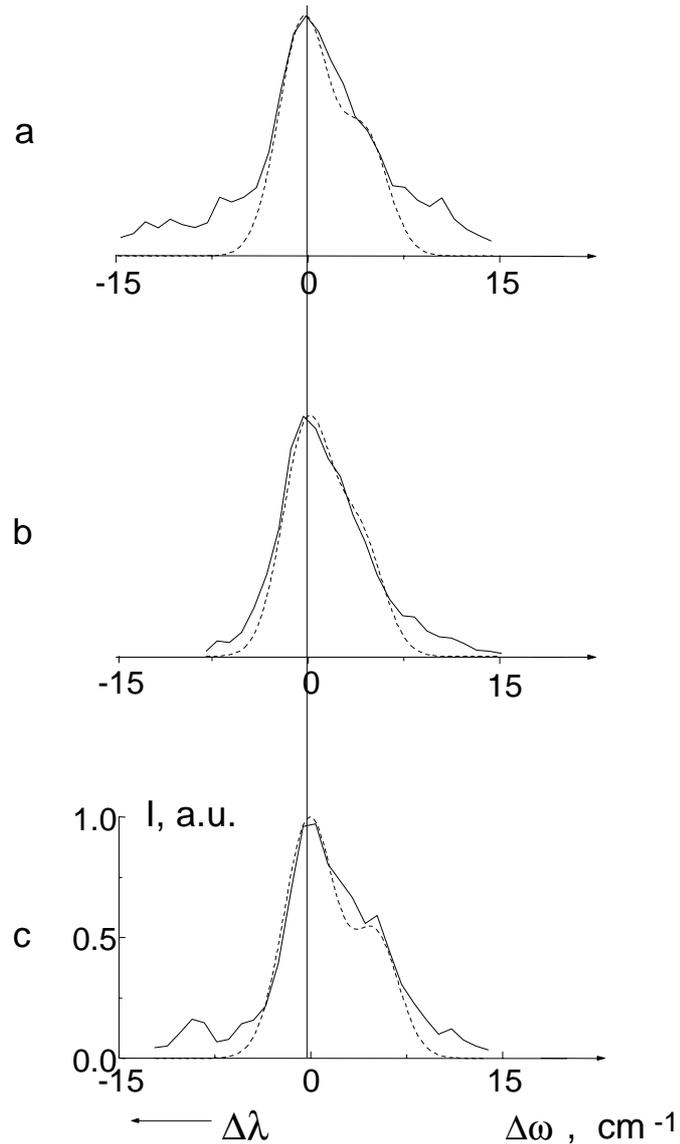
the Stark effect in the individual ion microfields, an asymmetry of this line would be obtained, namely, with the red wing more intensive than the blue one. However, the experimental profiles of HeI 6678 Å demonstrate the opposite type of the asymmetry, with more intensive blue wing.

To explain the observed profiles of spectral lines of helium, we assumed the existence of a low-frequency quasi-one-dimensional electric field in a current sheet plasma. Taking additionally into account the other broadening mechanisms, such as instrumental, Doppler, and Stark broadening in the individual plasma microfields, we obtained smooth profiles of the line HeI 6678 Å with the asymmetry similar to the asymmetry of the experimental profiles (see Fig. 4, dashed curves). The best fitting was achieved when the field strength was  $F \approx 100$ -120 kV/cm. Notice, that according to the experimental data [4,5], the anomalous quasi-one-dimensional electric fields were excited in the peripheral regions of a current sheet, i.e. in the regions with strong electron density gradients.

Thus, we have shown that the evolution of current sheets is usually accompanied by the excitation of non-equilibrium electric fields of the strength  $\geq 100$  kV/cm.

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the values of FWHM for two helium lines is due to the fact that the Stark constant for HeI 5876 Å is smaller than that for the line HeI 6678 Å. Besides we observed that HeI 6678 Å profiles were strongly asymmetrical: the blue wing was considerably more intensive than the red one (see Fig. 4, solid curves). At the same time, the profiles of the line HeI 5876 Å were approximately symmetrical with respect to the ordinate axis drawn through the maximum of the profiles. Assuming that the broadening of HeI 6678 Å is due to



**Fig. 4.** Experimental and theoretical profiles of the spectral line Hel 6678 Å. Solid curves - experimental profiles, dashed curves - theoretical profiles, in which Stark effect in the static electric field of the strength  $F$  is taken into account. The axis of observation is orthogonal to the direction  $F$ ,  $\Delta\omega_{1/2}^{\text{app}} = 4.3 \text{ cm}^{-1}$ . (a)  $t=0.5 \text{ mks}$ ,  $F=105 \text{ kV/cm}$ ; (b)  $t=3.5 \text{ mks}$ ,  $F=115 \text{ kV/cm}$ ; (c)  $t=4.9 \text{ mks}$ ,  $F=120 \text{ kV/cm}$ .

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