DETERMINATION OF THE TURBULENCE LEVEL IN A COLLISIONLESS MAGNETOSONIC SHOCK WAVE BY MEASURING THE STARK BROADENING OF THE BALMER Hβ LINE

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1. In our preceding experiments [1 - 4] we measured the front thickness $\delta = (6 - 1)c/\omega_{pe}$ of the collisionless magnetosonic shock wave propagating across a magnetic field, as well as the jump of the electron temperature $\Delta T_e \simeq$ 100 eV on the front. The effective collision frequency required to explain these results is $\nu_{eff} \gtrsim 2 \times 10^9\ sec^{-1}$. This exceeds the Coulomb frequency by two orders of magnitude and can occur only if turbulent electrostatic oscillations develop in the plasma. According to the theory [5, 6], several types of electrostatic plasma instabilities (two-stream, ion-acoustic, ion-ion) can occur in the transition zone of the shock wave. It turns out in this case that the turbulence level $\xi = E^2/8\pi NT$ can exceed the equilibrium level $\xi_T = (Nr_{Deb}^2)^{-1}$ by several orders of magnitude and can reach values $\xi \simeq 10^{-2} - 10^{-3}$ [7, 8]. At such a turbulence level and at the characteristic plasma parameters $N_e \sim 10^{14}\ cm^{-3}$ and $T_e \sim 10 - 20$ eV, the electric field intensity in the oscillations can exceed the interparticle field $E_0 = 2.6eN^{2/3}$ by one order of magnitude. It is therefore natural to use the Stark splitting of hydrogen spectral lines for the measurement of the turbulence level on the front of a magnetosonic shock wave.

2. In the investigated region of plasma parameters, the lifetime of the atom $\tau_\alpha = \gamma_\alpha^{-1}$ at the Stark sublevel turns out to be small compared with the period of the ion-acoustic and lower-frequency oscillations. Therefore the action of the electric fields of such oscillations on the atom should have a quasistatic character. The profile of a hydrogen line without a central Stark component (Hβ, Hδ, etc.) then turns out to be proportional over most of its length to the distribution function of the low-frequency electric field resulting from the addition of the statistically independent contributions from the ions located close to the emitter and from the collective electrostatic oscillations with frequencies $\omega \lesssim \omega_{pi}$:

$$W(E, \beta) = \iint W_H(E') W_R(E'') \delta(E - E' - E'') dE' dE'' \quad (1)$$

The distribution of the intensities of the electric fields from the individual ions, $W_H(E)$, is described by the Holtsmark function [10], and the distribution of the intensities of the fields of the oscillations with statistically independent phases, $W_R(E)$, is described by the Rayleigh function [11]. In Formula (1) the parameter $\beta = E_H/E_R$ represents the ratio of the scales of the fields in the Holtsmark and in the Rayleigh distributions. At $\beta < 1$, the maximum of the distribution function $W(E, \beta)$ shifts toward stronger fields $E_{max} \sim E_R > E_H$, and the dip in the region of small E is wider than in the function $W_H(E)$. Accordingly, the profiles of the lines Hβ and Hδ should experience a rather distinct splitting, from the value of which $(\Delta\lambda)_{exp}$ it is possible to determine the average intensity of the non-equilibrium electric fields of the low-frequency oscillations

$$\tilde{E}_{av} \approx \frac{8\pi\hbar c (\Delta\lambda)_{exp}}{3(n^2 - n'^2) e a_0 \lambda_0^2} \quad (2)$$

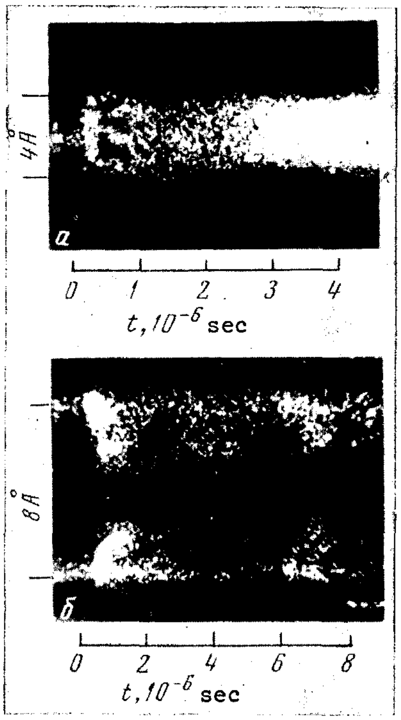

Fig. 1. Spectrochronograms of the Hβ line, obtained with an electron optical converter and an ISP-51 spectrograph crossed with a Fabry-Perot interferometer: a - shock wave excited by a magnetic field H parallel to the field H_1 in the unperturbed plasma (one order of interference); b - the same with H and H_1 antiparallel (two orders of interference).

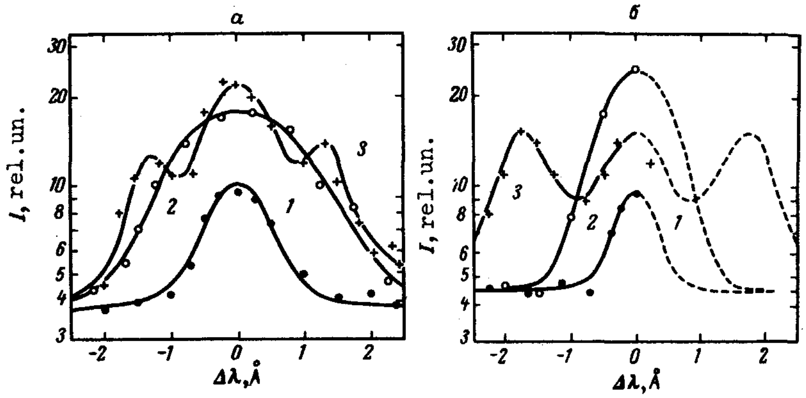

Fig. 2. Hβ line profiles obtained by protometry of the spectrochronograms a and b in Fig. 1. The solid curves in Fig. 2b show the profile sections obtained by photometry from the side of the red wing of lower-order interference on spectrochronogram b in Fig. 1. The dashed line represents the other half of the profile, drawn symmetrical to the first. Curves 1, 2, and 3 are plotted ahead, on, and behind the front of the shock wave, respectively.

Here λ_0 is the wavelength of the line and n and n' are the principal quantum numbers of the upper and lower levels.

3. Figure 1 shows the results of the measurement of the Hβ line profile in a non-equilibrium plasma produced on the front and behind the front of a collisionless magnetosonic shock wave. The measurements were made with the UV-2 apparatus [2] by the method of high-speed electron-optical spectrochronography [12, 13].

The light emerged from the end window of the discharge chamber and was analyzed with a Fabry-Perot interferometer crossed with an ISP-51 spectrograph. The shock circuit operated in the θ-pinch mode with a frequency 8×10^4 sec^{-1} at a magnetic field amplitude 5 kOe. The field on the piston increased during the time of wave propagation in the plasma to a value H_p. The shock wave could be excited both by a field H parallel to the field H_1 in the unperturbed plasma (Fig. 1a) and antiparallel to it (Fig. 1b). As seen from Fig. 1, in both cases a distinct splitting of the contour of the Hβ line is observed behind the shock wave front. The distances between the maxima (see the photometry results in Fig. 2) correspond to the average intensity of the non-equilibrium electric fields $E_{av} \approx 13$ kV/cm for the case of parallel magnetic fields, and 18 kV/cm for antiparallel fields[1]. This exceeds the average interparticle field $E_0 = 2.6\, eN^{2/3}$ by 17 and 20 times, respectively. (In case a, the initial pressure is $p_0 = 10^{-2}$ mm Hg, $N_1 \approx 8 \times 10^{14}$ cm^{-3}, $H_1 = 0.3$ kOe, and

[1]Non-equilibrium electric fields of approximately the same magnitude were obtained for a collisionless shock wave by measuring the Stark broadening of the hydrogenlike ion He^+ in [14]. The line profiles were registered there with the aid of a monochromator and photomultiplier from discharge to discharge.

$H_p \simeq 0.8$ kOe; in case b, $p_0 = 12^{-2}$ mm Hg, $N_1 \simeq 10^{14}$ cm^{-3}, $H_1 \simeq 0.5$ kOe, and $H_p \simeq -1.5$ kOe). By estimating the density of the thermal energy from alternating magnetic field absorbed by the plasma, $NT_e \simeq (1/3)H^2/8\pi$, we obtain for the turbulence level of the electrostatic oscillations $\xi_i \simeq 0.5 \times 10^{-2}$.

On the front itself, the Hβ line profile turns out to be anomalously broad compared with the profile ahead of the wave front (compare curves 2 and 1 of Fig. 2), but the characteristic dip in the center of the line is practically nonexistent. This indicates that non-equilibrium electric fields are present in the plasma and act on the atom non-adiabatically. The non-adiabaticity condition is satisfied only by the highest-frequency Langmuir oscillations ($\omega \gtrsim \omega_{pe}$), which lead in the case of a sufficiently high noise level $e^2/2n^4a_0T > \xi > \xi_T$ to the following frequency of the non-adiabatic transitions between the Stark components

$$\gamma_a \approx \frac{3}{4} \frac{n^4 a_o}{m_e \omega_{pe}} \{ \int E_k^2 \, dk \} \tag{3}$$

which is much higher than the electronic shock frequency

$$\gamma_a^{sh} \approx 3\pi N \frac{n^4 \hbar^2}{m^2 v_{Te}} \ln \frac{T_e}{\hbar n^2 \omega_{pe}} .$$

An estimate of the turbulence level of the high-frequency plasma oscillations on the front of the wave, obtained from Eq. (3), leads to a value $\xi_e \simeq 5 \times 10^{-3}$. As seen from Fig. 1, the splitting of the Hβ line, due to the low-frequency oscillations behind the wave front, increase gradually, and the diffuse profile broadening due to the Langmuir noise vanishes rapidly, i.e., the development of high-frequency noise is much faster than that of the low-frequency noise, and its relaxation takes place earlier.

Thus, the effect of Stark broadening of the spectral lines of hydrogen makes it possible, if the spectrum is scanned with sufficient speed, not only to determine the presence of turbulence in a shock wave and to measure its level, but also to determine the nature of this turbulence.

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DAVYDOV SPLITTING OF EXCITON LINE IN ANTIFERROMAGNETIC $RbMnF_3$

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$RbMnF_3$ is an ideal cubic two-sublattice antiferromagnet with T_N = 82.5°K and with an ordering direction along a threefold axis. The unusually small anisotropy field, $H_A \simeq 4$ Oe, and the large exchange field $H_N = 8.9 \times 10^5$ Oe cause the magnetic structure of $RbMnF_3$ to be easily realigned by a weak magnetic field while remaining collinear, but requiring very strong fields for a noticeable disturbance of the collinearity. It was reported earlier [1] that application of an external magnetic field leads to a doublet splitting of the magnetic-dipole 25 144.5 cm^{-1} line due to the optical transition $^6A_{1g} \rightarrow {}^4E_g(^4G)$ of the Mn^{2+} ion. The effect is strongly anisotropic and is determined by the orientation of the magnetic moments of the sublattices relative to the crystallographic axis. It was shown in [2] that allowance for the magnetoelastic interaction makes it possible to explain the observed doublet splitting as being due to the lifting of double orbital degeneracy of the $^4E_g(^4G)$ state when the crystal lattice is distorted. The doublet character of the splitting is retained also in the region of strong magnetic fields applied along the directions [100] and [110]. We report here on the behavior of th 25 144.5 cm^{-1} line in a strong magnetic field $\vec{H}$ || [111].

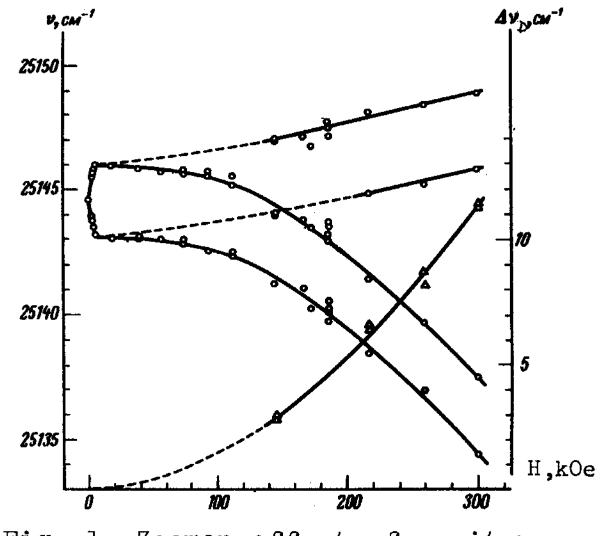

Fig. 1. Zeeman effect of exciton absorption line of the $^6A_{1g} \rightarrow {}^4E_g(^4G)$ transition of $RbMnF_3$ at 20°K in a field $\vec{H}$ || [111]. The triangles denote the field dedepdence of the additional splitting.

Figure 1 illustrates the field dependence of the observed splitting in unpolarized light at 20°K, as obtained with the aid of a pulsed solenoid. Figure 2 shows microphotometric curves of the considered region of the spectrum for certain characteristic values of the magnetic field. It is clearly seen that the doublet splitting, which appears even in a weak field, retains its value up to 300 kOe (as predicted when account is taken of the magnetoelastic splitting of the line), but is accompanied by additional doublet splitting of each of the components. The latter circumstance does not fit in the framework of the single-ion approximation, and calls for the use of exciton representations.