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INFLUENCE OF DISPERSION EFFECTS ON THE STRUCTURE OF A SHOCK WAVE IN A MAGNETIZED PLASMA

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An important manifestation of the dispersion properties of a magnetized plasma are shock waves with an oscillatory profile. The solutions obtained in the theory depend on the inclination of the front to the magnetic field [1]. At angles $\theta \ll \sqrt{m_e/m_i}$ ("straight wave" [1]) the oscillations have a "length" $\delta \sim c/\omega_0$ and lag the main discontinuity on the front; when $\theta \gg \sqrt{m_e/m_i}$ ("oblique wave" [1,2]) the oscillations lead the discontinuity ($\delta \sim \theta(c/\Omega_0)$; m_e and m_i are the electron and ion masses; ω_0 and Ω_0 are the electron and ion plasma frequencies; c is the speed of light). The profile and the characteristic dimensions of the plasma perturbations observed in [3-5] have made it possible to identify them with the oblique [3] and straight [4,5] shock waves. However, in these and similar experiments [6] the inclination angle θ was not measured directly and its role in the wave processes was not investigated. Experiments of this type are described in this paper. We have correctly compared the value of δ for an oblique quasistationary wave with the theoretical value, whereas in the earlier papers [3,6] rather arbitrary estimates of θ were made on the basis of the experimental geometry. Registration of θ has made it possible to investigate the dispersion effects and the structure of the waves at angles $\theta \gtrsim \sqrt{m_e/m_i}$ and $\theta \lesssim \sqrt{m_e/m_i}$, for which there is no analytic description of the phenomenon. The influence of the dispersion was investigated under the conditions of a laminar and turbulent plasma.

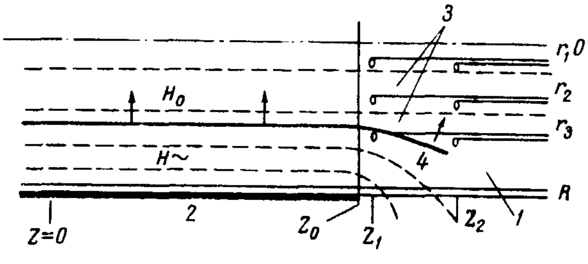

Fig. 1. Diagram showing excitation and registration of the shock waves. 1 - Vacuum volume (glass tube, R = 8 cm); 2 - shock coil (section exciting the field $H_{\sim}$ (z = 0 is the location of the central section, z_0 = 15 cm corresponds to the edge of the coil); 3 - magnetic probes (r_1 = 0.5 cm, r_2 = 2.9 cm, r_3 = 5.3 cm, $z_2 - z_1$ = 5 cm); 4 - wave front; H_0 = 0 - 2 kOe, $H_{\sim}^{0}$ = 1 - 5 kOe.

The experiments were made with the UN-4 setup [4,5]. A plasma placed in a quasistationary magnetic field H_0 was subjected to a fast ($\Delta t \sim$ 50 - 300 nsec) compression by an alternating magnetic field $H_{\sim}$ applied to its boundary (Fig. 1). The space-time evolution of the perturbations was recorded by a system of six magnetic probes. From the relative delays of the signals from the nearest probes, distributed radially (τ_r) and parallel to the axis (τ_z), we obtained the values of the radial and longitudinal velocity components $u_r(r, z) = \Delta r/\tau_r$ and $u_z(r, z) = \Delta z/\tau_z$ and the angle of inclination of the front $\sin \theta(r, z) = u_r \tau_z/\Delta z = (\Delta r/\Delta z)(\tau_z/\tau_r)$, averaged over the intervals Δr and Δz.

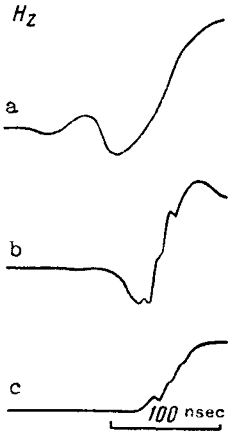

Fig. 2 [Left]. Dependence of the shock-wave profile on the inclination of the front to the magnetic field. Hydrogen. a) $\theta \approx 10°$, $n_0 \approx 2 \times 10^{13}$ cm^{-3}, $H_0 \approx 110$ Oe, $z_1 = 15$ cm; b) $\theta \approx 7°$, $n_0 \approx 3 \times 10^{12}$ cm^{-3}, $H_0 \approx 110$ Oe, $z_1 = 0$; c) $\theta \lesssim 2°$, $n_0 \approx 5 \times 10^{11}$ cm^{-3}, $H_0 \approx 170$ Oe, $z_1 = 0$.

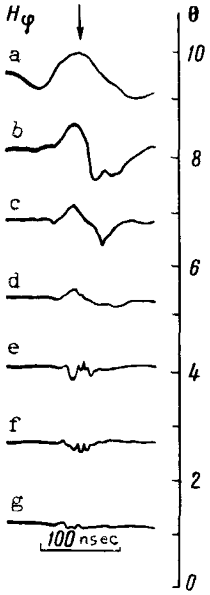

Fig. 3 [Right]. Transformation of the φ-component of the magnetic field with variation of θ. Hydrogen. a) $n_0 \approx 2 \times 10^{13}$ cm^{-3}, $H_0 \approx 110$ Oe, $z_1 = 15$ cm; b,c) $n_0 \approx 3 \times 10^{12}$ cm^{-3}, $H_0 \approx 110$ Oe, $z_1 = 0$; d - j) $n_0 \approx 5 \times 10^{11} - 10^{12}$ cm^{-3}, $H_0 \approx 110 - 170$ Oe, $z_1 = 0$. The arrow indicates the region of the main discontinuity of H_z.

The observations have shown that the tilting of the front is governed by the initial configuration of the skin layer of the plasma, which plays the role of a piston. When the plasma is sufficiently homogeneous, the bending of the piston is due to the inhomogeneity of the pressure $H^2 \sim (z)/8\pi$ at the edge of the shock coil (Fig. 1). In this region ($10° \lesssim \theta \lesssim 30°$) the process has the following characteristic features: If the initial perturbation is made sufficiently steep, then a "rarefaction" wave becomes detached from it. Under the constant pressure of the piston, a train of alternating-sign oscillations grows ahead of the discontinuity. The phase velocity of the oscillations increases with increasing wavelength (in an argon plasma it could exceed $10v_A$, where $v_A = H_0/\sqrt{4\pi n_0 m_i}$ is the Alfven velocity).

Under certain conditions $(c\sqrt{m_i}/\sqrt{4\pi n_0 e^2})\theta \ll R$ and $\Delta t \ll (R\sqrt{4\pi n_0 m_i}/H_0)$ a quasistationary phase is established, when the transport rate inside the train becomes practically constant, and the dimension of the last oscillation corresponds well to the value of $\theta(c/\Omega_0)$ (Fig. 2a). The component H_φ (which is perpendicular to H_0 and u, Fig. 3a) has approximately the same amplitude as H_z (Fig. 2a) and differs in phase from it by $\pi/2$. All the indicated regularities agree with the theory for $\theta \gg \sqrt{m_e/m_i}$ [1,2].

The tilt of the piston inside the shock coil is small ($\theta \sim 0 - 10°$) and is the result of the inhomogeneity of the plasma. With decreasing θ, the number and amplitude of the leading oscillations decrease, and oscillations with $\delta \sim c/\omega_0$ increase in the region of the discontinuity and behind it (Fig. 2b). This points to a simultaneous appearance of opposing dispersion effects, which do not cancel each other, and form a profile in the form of a hybrid combination of an oblique and straight wave.

At angles $\theta \lesssim 2\sqrt{m_e/m_i}$ (i.e., earlier than in the case of $\theta \ll \sqrt{m_e/m_i}$), dispersion due to electron inertia predominates, as indicated by the lagging oscillatory train and by $\delta \sim c/\omega_0$ [1] (Fig. 2c). The deviation from the stationary form of the normal wave is associated with cumulation [5].

The foregoing results agree with the numerical solution obtained in [7] if the general parameter is chosen to be $\theta/\sqrt{m_e/m_i}$.

The registration of H_φ makes it possible to establish more precisely the mechanism shaping the width of the discontinuity at small angles. It turns out that even after the vanishing of the leading oscillation, a dispersion contribution with $\delta \sim \theta(c/\Omega_0)$ remains, as is evidenced by the H_φ perturbations localized in the vicinity of the main discontinuity (Figs. 3c, d). Predominating in the "normal" wave are the lagging hf oscillations of H_φ, with $\delta \sim c/\omega_0$; as $\theta \to 0$ we have $H_\varphi \to 0$ (Figs. 3e, f, g).

The development of small-scale instabilities at $n_0 \sim 10^{13}$ cm^{-3} "smears out" the oscillations with $\delta \sim c/\omega_0$, but the effective skin depth $\delta_s \sim 10(c/\omega_0)$ [4] does not prevent the formation of "oblique" oscillations, since $[(c/\Omega)/\theta]/\delta_s \gtrsim 1$ even when $\theta \gtrsim 10\sqrt{m_e/m_i}$. In such a mode, with $\theta \to 0$, we observed a transition to an aperiodic profile (the plasma turbulence was determined independently from the noise emission and scattering of an external beam of electromagnetic waves). A Joule dissipation effect comparable with the effect of the dispersion ($\theta \gg \sqrt{m_e/m_i}$) was observed only at very low degrees of ionization ($p_0 \sim 10^{-2} - 10^{-1}$ mm Hg, $n_0 \sim 10^{13}$ cm^{-3}).

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SHAPE OF WAVE FRONT AND SPATIAL EMISSION COHERENCE IN A RUBY LASER GIANT PULSE

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The shape of the wave front and the spatial coherence have been thoroughly investigated experimentally for lasers in the free mode, but no such research was carried out for the