Ion heating and fine structure of the potential in the interaction of a magnetic piston with a plasma

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We investigated experimentally ion heating and the structure of the potential following compression of a plasma ($n_0\approx0.7\times10^{12}-5\times10^{12}$ cm^{-3}) by a magnetic piston (H = 1200 Oe, $T/4=400$ nsec) in a θ pinch without an initial magnetic field. We demonstrate the existence of broad spectra of ions moving in a radial direction and scattered through 45°. A potential discontinuity of width ~50–100 Debye lengths is formed ahead of the magnetic piston. The results do not contradict the assumption that a turbulent electrostatic shock wave exists under the conditions in question.

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It is known that a shock wave can be used to heat a plasma rapidly to high temperatures. Fc thermonuclear research, greatest interest attaches to cases when it is the ionic component which : predominantly heated. The results of an experimental study of magnetosonic collisionless shoc waves[1,2] have shown that predominant heating of the ions takes place at large Mach numbei $M_A=U/V_A>M_c\approx4.5$ ($V_A=H_0/\sqrt{4\pi n_0 m_i}$) is the Alfven velocity, H_0 is the initial magneti field). It is of interest to investigate processes occurring under conditions when $M_A\to\infty$ ($H_0\to0$ Under these conditions, one must single out the situation in which a reflecting magnetic piston formed and produces opposing streams of ions of high intensity. When ion-ion instability develop the turbulent viscosity should lead to an effective collisionless energy dissipation. It is also interest to investigate the possibility of formation of an electrostatic turbulent shock wave in froi of the piston in the plasma; this shock wave was observed in experiments on the interaction of stream of tenuous plasma with a magnetic barrier.[3]

The experiments were performed with the "UN-Phoenix" installation in accordance with scheme described in[4]. A plasma with concentration $n_0=(0.7–5)\times10^{12}$ cm^{-3} ($T_e^0\approx T_i^0\approx0.5–10$ e $H_0\lesssim5$ Oe) in a cylindrical glass chamber ($d_1=16$ cm, $l_1=100$ cm) was subjected to rapi compression by a magnetic field ($H=1200$ Oe, $T/4=400$ nsec) excited by a surge loop ($l_2=$ cm). The parameters of the current sheath (width Δ_M, radial propagation velocity U, magnet field discontinuity ΔH) were measured with open-loop magnetic probes ($d_2=3$ mm) placed different distances from the axes. The potential discontinuity $\Delta\phi_m$ in the sheath and its structu were measured by floating electric probes. The use of probes similar to those described in[1] and broadband recording apparatus ($\Delta f\sim1$ GHz) has made it possible to obtain high temporal ($\lesssim$ nsec) and spatial ($\sim10^{-2}$ cm) resolution. The energy spectra of the ions, dn_i/dE were determin by measuring the fast charge-exchange atoms with an eight-channel neutral-particle analyz having a time resolution 10–30 nsec. To exclude cummulation effects, the neutral particles we extracted through a ceramic tube ($d_3=5$ mm) extending to a distance $r=2$ cm beyond t chamber axis.

Measurements of the magnetic field with five probes placed along the radius of the chamber equal intervals $\Delta r=1$ cm have shown that a quasistationary current layer is produced (U and remain practically constant over the recording length) with a width $\Delta_M\approx(2–4)c/\omega_{pe}$ (ω_{pe} is t

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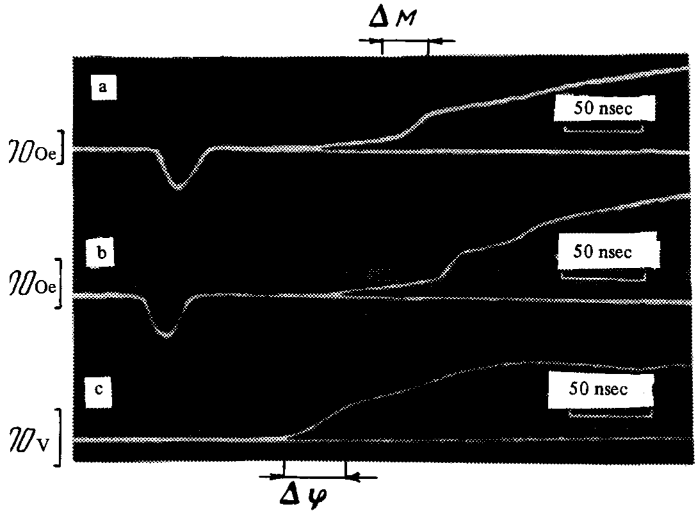

G. 1. Typical oscillograms of signals from magnetic probes installed at distances: a)$r_2=4.5$ cm, b) $=3.5$ cm from the axis and from an electric probe at $r_1=3.5$ cm (c) ($n_0=2\times10^{12}$ cm^{-3}, $U\approx3.8\times10^7$ ı/sec).

ıngmuir frequency of the electrons and c is the speed of light) (Figs. 1a and 1b). The function $=f(n_0,\Delta H)$ is close to $U=\Delta H/\sqrt{16\pi n_0 m_i}$ (in the investigated range of n_0 the velocity U lies in e range 2.5×10^7–7×10^7 cm/sec). Simultaneous registration of the amplitude $\Delta\phi_m$ of the potenıl in the layer has yielded $2e\Delta\phi_m/mU^2\approx1$. The obtained relations agree with the conditions of tal reflection of the plasma by the magnetic piston.[5] When dn_i/dE is measured, a broad ectrum is registered in the radial direction, in the form of a plateau with a steep decrease at an ergy E_1 ($\sim$1900 eV) (Fig. 2, curve 1). Simultaneous measurements of the velocity of the sheath different n_0 have shown that energy E_1 is connected with U by the relation $E_1\approx m_i(2U)^2/2$, thus oviding an independent confirmation of the probe data on the process of reflection. An imporınt fact that points to the heating of the ions when the magnetic piston interacts with the plasma, the observed broadening of the spectrum.1) Measurements of the spectra of ions moving at an gle 45° to the axial direction (Fig. 2, curve 2) points to a turbulent character of the interaction of e reflected and incident plasma streams. From a comparison of curves 1 and 2 it is seen that the

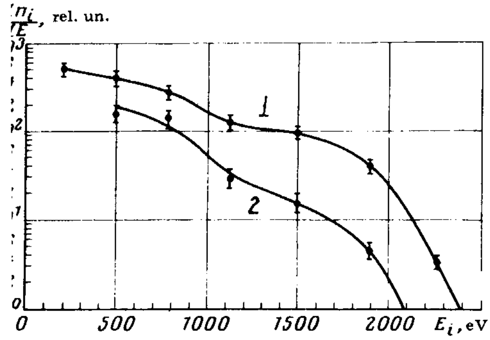

FIG. 2. Energy spectra dn_i/dE of ions moving in a radial direction (curve 1) and at an angle 45° to the axial direction (curve 2) ($n_0=3\times10^{12}$ cm^{-3}, $U=2.8\times10^7$ cm/sec).

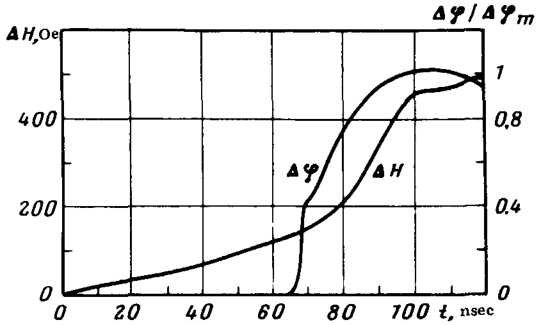

FIG. 3. Time sequence of the registration of the potential discontinuity $\Delta\phi$ and of the magnetic discontinuity ΔH ($r_1=3.5$ cm) ($n_0=2\times10^{12}$ cm^{-3}, $U\approx3.8\times10^7$ cm/sec).

relative fraction of the scattered stream is high enough, 10–50%, and according to estimates cannot be attributed to scattering by Coulomb collisions ($l_3/\lambda_C\sim10^{-2}$–10^{-4}, where l_3 is the thickness of the scattering target and λ_C is the Coulomb mean free path). It can be deduced from the measurements of the spectra that the ionic plasma component is turbulently heated. This behavior can be due to the development of ion-ion instability in a plasma with $T_e>T_i$ [6] [non-isothermy of the plasma, as shown by us, can be attained by Coulomb heating of the electrons ($T_e\sim30$ eV) in the pedestal ahead of the main discontinuity of the magnetic field (Figs. 1a and 1b)].

On the basis of the obtained experimental data, it can be suggested that under the conditions in question a turbulent electrostatic shock wave is produced when the ion-ion instability develops. To observe the front of this wave, the electric probe was placed at a distance 3.5 cm from the axis. The profile of the magnetic field in the piston and its propagation velocity were simultaneously monitored. Figure 1c shows an electric-probe signal oscillogram typical of the indicated range of n_0. A characteristic feature of the recorded potential profile is the presence of a jump of duration $\Delta\tau\approx2$–4 nsec, propagating ahead of the magnetic piston (Fig. 3). Estimates of the spatial width of this discontinuity, based on double the piston velocity, yield a value $\Delta\phi\approx(50$–$100)r_D$ (r_D is the Debye radius at $T_e=30$ eV and $n_e=n_0$).

Thus, the aggregate of the experimental facts demonstrates that when a reflecting magnetic piston moves in a plasma, effective collisionless heating of the ionic components is observed. A potential front of width $\Delta\phi\ll\Delta_M$ is observed ahead of the piston. The results agree with the assumption that a turbulent electrostatic shock wave exists under the considered conditions.

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[1)] The neutral-particle spectrum broadening, from which dn_i/dE is reconstructed, can be caused by ion charge-exchange effects at various points of the potential. However, in regimes with $n_0>5\times10^1$ cm^{-3}, where the width of the potential profile is much less than the charge-exchange path length, a broad spectrum is likewise recorded.

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