[1] A. Kastler, J. de Physique 11, 255 (1950).
[2] G.V. Skrotskii and T.G. Izyumov, Usp. Fiz. Nauk 73, 423 (1961) [Sov. Phys. -Usp. 4, 177 (1961)].
[3] A. Kastler and C. Cohen-Tannoudji, Progr. Opt. 5, 3 (1966).
[4] R.E. Drullinger and R.N. Zare, J. Chem. Phys. 51, 5531 (1969).
[5] J.H. Simpson, D.S. Bayley, and E.C. Eberlin, Bull. Amer. Phys. Soc., Ser. 11, 16, No. 1, 107 (1971).
[6] N.N. Kostin, M.P. Sokolova, V.A. Khodovoi, and V.V. Khromov, Zh. Eksp. Teor. Fiz. 62, No. 2 (1972) [Sov. Phys.-JETP 35, No. 2 (1972)].
[7] A.M. Bonch-Bruevich, N.N. Kostin, V.A. Khodovoi, and V.V. Khromov, ZhETF Pis. Red. 12, 354 (1970) [JETP Lett. 12, 242 (1970)].
[8] N.N. Kostin, V.A. Khodovoi, and N.A. Chigir', Opt. Spektrosk. (in press).

EXPERIMENTAL OBSERVATION OF ELECTRONIC SHOCK WAVES IN A COLLISIONLESS PLASMA

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The existence of collisionless thermal waves in a plasma was first demonstrated experimentally in [1]. The occurrence of ion-acoustic noise on the front of a thermal wave was noted in [2, 3], i.e., the feasibility of a stationary discontinuity was demonstrated [4].

In the present paper we considered experimental proofs of the existence of a stationary heat discontinuity in a collisionless plasma (electronic shock wave) and the connection of its parameters with the theoretical concepts [4, 5].

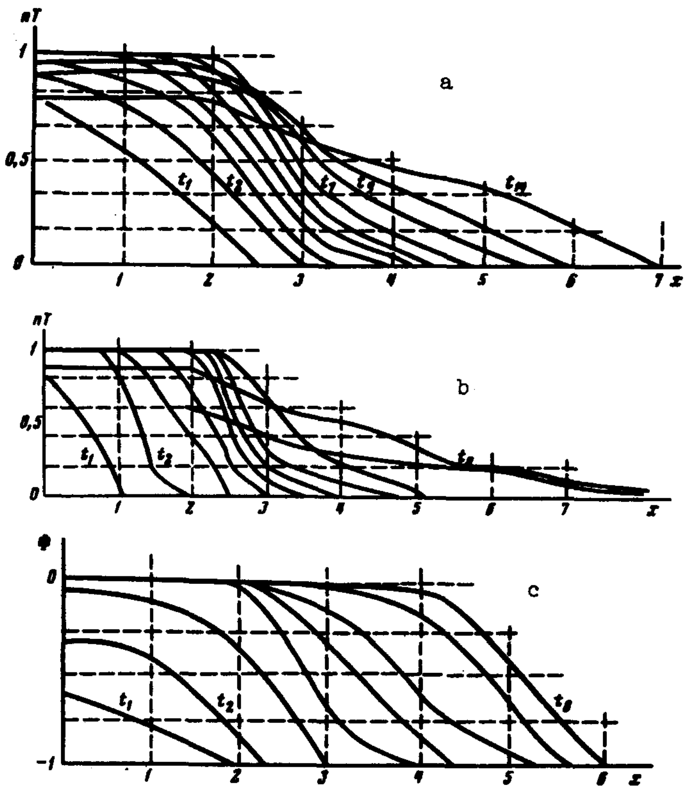

Fig. 1. a - Instantaneous profiles of $n_hT_h(x)$ for a discharge in hydrogen: $\Delta t = 10^{-8}$ sec, nT is in relative units, $\Delta x = 10$ cm; b - instantaneous profiles of $n_hT_h(x)$ for a discharge in argon: $\Delta t = 10^{-8}$ sec, n_hT_h is in relative units, $\Delta x = 5$ cm; c - instantaneous profiles of Φ for a discharge in argon: $\Delta t = 10^{-8}$ sec, Φ is in relative units, $\Delta x = 5$ cm.

Figure 1 shows the structure of the thermal-wave front, obtained with the aid of an internal diamagnetic probe introduced into the chamber during a discharge in hydrogen (a) and in argon (b). The initial plasma was produced by two high-frequency generators inside of a glass tube of 8 cm diameter and ∿250 cm length in a longitudinal homogeneous magnetic field 0.5 - 5 kOe. The initial gas pressure in the experiments was in the range $(4 - 10) \times 10^{-4}$ Torr, the charged-particle concentration was 2×10^{13} cm^3, and the initial electron temperature was 10 eV. The local heating of the plasma to the electron temperature ∿300 eV was with the aid of a narrow loop that generated an oblique magnetosonic wave of large amplitude, the energy of which was absorbed by the plasma in the region under the loop (the experimental setup is described in detail in [1, 3]).

As seen from Fig. 1, there exists a region of values where an nT wave, of the shock-wave type, is produced with a sufficiently steep pressure drop. The velocity D of such a wave depends on the mass of the gas ions and decreases to about one half when a discharge in argon is used.

A similar structure of the wave (see Fig. 1c) was obtained from measurements with the aid of a double electric probe of special design. The double probe at electrodes with equal gathering surfaces, shifted relative to each other by a distance Δz, much shorter than the characteristic scale of the wave in the direction orthogonal to the surface of the front.

Control experiments performed on the afterglow plasma with electron temperature ∿0.5 eV have shown that the length of the front and the velocity of the wave remain the same, i.e., they are independent of the initial temperature T_{0e}. The detailed structure of the front, however, is altered somewhat, namely, the pedestals vanish and as a result the front as a whole becomes steeper.

The velocity of the internal wave can be written in the form [4]

$$D = \alpha V_o \sqrt{\frac{m}{3M_o} \frac{n_o}{n_{oh}}}, \qquad \frac{mV_o^2}{2} = e\Phi_{max}, \tag{1}$$

where $\alpha = (M/m)^{1/4}$ [5]. Consequently, the velocity of the thermal wave should depend on the mass of the ions like $M^{-1/4}$. Since in the experiments the quantities Φ_{max} and n_0/n_{h0} are conserved at a specified geometry, initial pressure, and surge-circuit voltage, the mass dependence should become manifest in explicit form if one satisfies the requirement concerning the establishment of the spectrum of the ion-acoustic noise over the width of the discontinuity.

The experimental values measured on the nT profiles were $D_H = 2.5 \times 10^8$ cm/sec and $D_{Ar} = 1.2 \times 10^8$ cm/sec and those measured with a double electric probe were $D_H = 2.7 \times 10^8$ cm/sec and $D_{Ar} = 1.3 \times 10^8$ cm/sec. In both cases $D_H/D_{Ar} \sim 2.1$, as against the theoretical value 2.4.

In experiments with a xenon plasma, the wave velocity decreases in accordance with the relation given above.

The width of the thermal-wave front can be obtained by recognizing that the current velocity of the cold electrons u depends on the potential Φ produced by the hot electrons. This dependence becomes manifest when account is taken of the effects of induced scattering of ion-acoustic waves by ions.

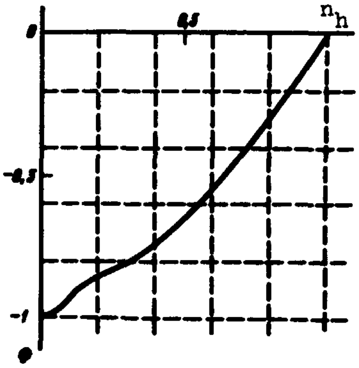

Fig. 2. Dependence of the potential Φ on the density of the hot electrons n_h, argon. Φ = 60 V, n_h is in relative units.

Using the equation for the growth of the noise energy

$$\frac{\partial W}{\partial t} = \omega_{pi} W \left[\frac{|u|}{v_{Te}} - \frac{\omega}{k v_{Te}} - a \frac{\omega}{k v_{Te}} - b \frac{W}{n_0 T_x} \right] \quad (2)$$

and Ohm's law

$$u = \frac{e \frac{\partial \Phi}{\partial x}}{m \nu_{eff}}, \quad (3)$$

where

$$a = \left(\frac{M}{m}\right)^{1/4} + 1, \quad b = \frac{k}{\Delta k} \frac{T_i}{T_x},$$

and also the system of equations

$$\begin{aligned} &\frac{3}{2} \frac{dT_x}{dt} = e \frac{\partial \Phi}{\partial x} \\ &\frac{\partial n_h}{\partial t} = n_0 \frac{\partial u}{\partial x} \\ &n_h = \int_{-\infty}^{+\infty} \left(f \frac{mv^2}{2} - e\Phi \right) dv \end{aligned} \quad (4)$$

we can determine the density profile n_h of the hot electrons.

The main section of the stationary front ($n_h T_h$ or Φ) is determined by the expression

$$\Delta x = 21 \frac{M}{(a+1)^3} a \sqrt{\frac{\Phi_0}{4\pi n_{h0} e}}, \quad a = \frac{k}{\Delta k}. \quad (5)$$

Consequently, $\Delta x \sim (M/m)^{1/4}$. The experimental values give a ratio $\Delta x_{Ar}/\Delta x_H \sim 2$, which agrees sufficiently well with the calculation. The experimental values $\Delta x_H \sim 5 - 7$ cm and $\Delta x_{Ar} \sim 15$ cm likewise do not contradict the estimate (5).

Finally, we note that from the $\Phi(x)$ and $nT(x)$ plots in Fig. 1 we can plot the function $n_h(\Phi)$ (see Fig. 2), from which it follows that the condition $d(\partial\Phi/\partial n_h)/dn_h > 0$, obtained in [4], is satisfied for the section with stationary profile.

We have thus shown that a stationary electronic shock wave exists in a collisionless plasma. The electronic shock wave can arise also in other situations, for example if a relativistic strong-current beam is effectively decelerated in a plasma [4, 6].

[1] A.A. Ivanov, L.L. Kozorovitskii, and V.D. Rusanov, Dokl. Akad. Nauk SSSR 4, 189 (1969) [sic!].

[2] A.A. Ivanov, Ya. Istomin, L.L. Kozorovitskii, and V.D. Rusanov, Phys. Lett. 33A, 509 (1970).
[3] A.A. Ivanov, Ya. Istomin, L.L. Kozorovitskii, and V.D. Rusanov, PMTF No. 1, 51 (1971).
[4] A.A. Ivanov, V.D. Rusanov, and R.Z. Sagdeev, ZhETF Pis. Red. 12, 29 (1970) [JETP Lett. 12, 20 (1970)].
[5] G.E. Vekshtein, D.D. Ryutov, and R.Z. Sagdeev, Zh. Eksp. Teor. Fiz. 60, 2142 (1971) [Sov. Phys.-JETP 33, 1152 (1971)].
[6] A.T. Altyntsev, A.G. Es'kov, O.A. Zolotovskii, V.I. Koroteev, R.Kh. Kurtmullaev, V.L. Masalov, and V.N. Semenov, ZhETF Pis. Red. 13, 197 (1971) [JETP Lett. 13, 139 (1971)].

SURFACE MAGNETIC SUSCEPTIBILITY OF METALS

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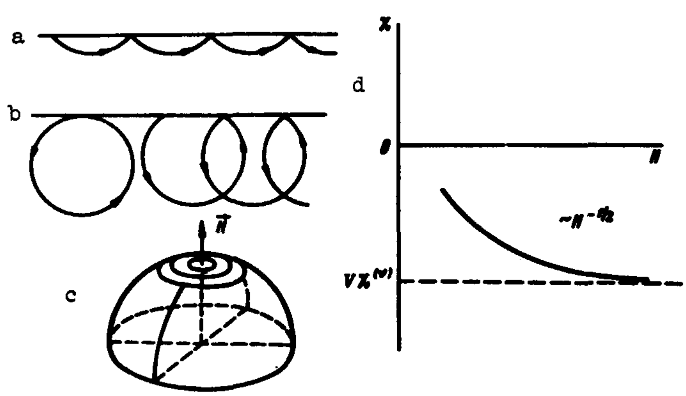
1. It is known [1] that the energy spectrum of the conduction electrons in a metallic plate placed in a parallel magnetic field $\vec{H}$ differs significantly from the energy spectrum of the bulky sample. Besides the magnetic Landau levels, there exist [2] magnetic surface levels due to the electrons skipping along the surface of the metal (see Fig. a). The dependence of the magnetic surface levels on H exhibits characteristic features, but these turn out to be inessential [3, 4] when the thermodynamic properties of metals are considered. (A more detailed analysis of the literature [3, 5 - 7] concerning this question can be found in [4].)

When considering the contribution of the magnetic surface levels to the thermodynamic quantities, it is necessary, as demonstrated in [3], to take into account the deviation of the magnetic surface levels from their quasiclassical values. The surface part of the magnetic moment $M^{(s)}$ is written in the quasiclassical approximation in the form

$$M^{(s)} = \alpha^{(1)}_{\text{quas}} H^{-1/3} + \alpha^{(2)}_{\text{quas}} H^{1/3} + \dots \quad (1)$$

Calculations [4] using the exact values for the magnetic surface levels have shown that $\alpha^{(1)} = 0$. Analogously, the author calculated the next term in the expansion (1), and it turned out that $\alpha^{(2)} = 0$. Thus, the electrons skipping over the surface of the metal (Fig. a) make no essential contribution to the thermodynamic properties of the metals. As will be shown below, an appreciable contribution to the thermodynamic quantities is made by electrons that are tangent to the surface of the metal (see Fig. b).



2. Assuming a quadratic isotropic dispersion law $\varepsilon = p^2/2m$ of the conduction electrons in the plate we obtain for the thermodynamic potential $\Omega(H, T)$ in the temperature region $T \ll \varepsilon_F$