UNSTABLE STATES OF A PLASMA IN A TRAP WITH COMBINED FIELD

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At the Culham conference it was reported, in a paper devoted to experiments on hot-ion plasma accumulation with the PR-5 apparatus [1], that under certain injection conditions distinct unstable states of the plasma are observed in a trap with combined field ("minimum B" type). A characteristic feature of such states is that they occur spontaneously, a long time after the termination of the injection, during the time of free decay of the plasma with charge exchange. The instability is manifest in a rapid decrease in density, in the form of an abrupt jump or drop (Fig. 1); in rarer cases several drops that follow one another are observed.

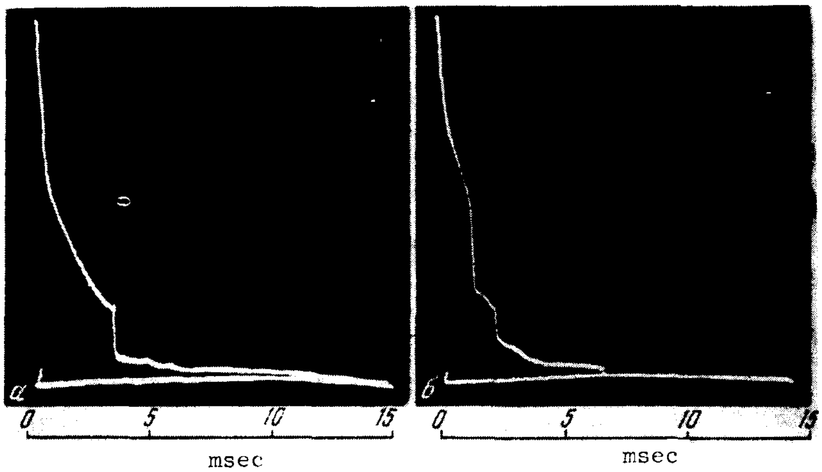

Fig. 1. Oscillograms of flux of neutral particles due to charge exchange, illustrating the drops in density during the plasma decay: a - single drop, b - three successive drops.

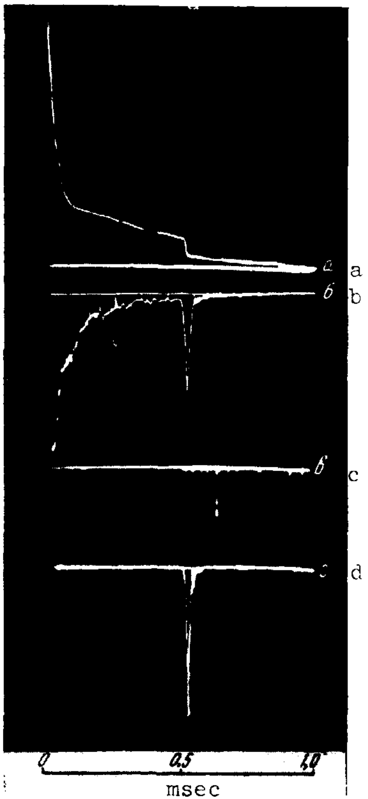

Fig. 2. a - Flux of neutral particles due to charge exchange, b - ion current to the side wall of the chamber, c - signal from energy spectrometer (E = 36 keV), d - signal from loop antenna.

The plasma parameters and the experimental conditions under which such instability is observed are detailed in [1]. In this note we present information obtained in a more detailed investigation of this phenomenon, and indicate a possible interpretation of the physical nature of the instability.

1. It has been established that each density drop (Fig. 2a) is accompanied by the appearance of high-frequency fields in the plasma. A loop antenna installed near the trap wall registered a burst of electromagnetic radiation whose spectrum consists of the ion-cyclotron

frequency and its harmonics (Fig. 2d); the frequency corresponds to the magnitude of the magnetic field in the central region of the trap. The burst duration, as well as the duration of the drop itself, is 15 - 20 μsec.

2. A second fact closely connected with the instability in question is the change in the energy spectrum of the ions in the plasma. During the time of the drop some of the ions are accelerated in a transverse direction to high energies, amounting to several times ten keV. Figure 2c shows by way of illustration an oscillogram of the flux of neutral atoms produced by charge exchange and possessing an energy of 36 keV. We see that at the start of the plasma decay there are no ions with this energy, and that their appearance coincides exactly with the instant of the jump. (An energy of 40 keV corresponds to proton Larmor orbits with diameter equal to the radius of the vacuum chamber. According to the conditions of collimation of the flux of charge-exchange products enetering the spectrometer, protons with higher energies could not be registered in these experiments.)

3. To observe directly the plasma loss during the time of the drop and to ascertain the localization of this loss, we measured the flux of particles from the plasma to the walls of the chamber. We installed on the inner surface of the chamber a total of 26 plate electrodes with which we could register the ion current to different elements of the wall surrounding the plasma. The measurements have shown that short-duration ejection of particles, both to the ends of the trap and to the side wall, occurs in synchronism with the density jumps (Fig. 2b). From a comparison of the signals at the different electrodes it follows that the loss occurs predominantly along the force lines of the resultant magnetic field through the end and radial mirrors.

The aggregate of the presented data shows that the density jumps are due to a short burst of instability of the ion-cyclotron type. This is evidenced both by the frequency spectrum of the produced alternating fields and in the appearance of a group of ions acclerated to high energies in a transverse direction. The acceleration of the ions is apparently produced in resonant fashion in fields of cyclotron frequency that are produced in the plasma, and in this respect it is completely analogous to the acceleration observed in traps with external injection when the Harris anisotropic cyclotron instability is excited [2,3].

Mikhailovskii [4] pointed to the possible interpretation of the described phenomenon as constituting cyclotron instability due to the nonequilibrium ion distribution function relative to the energies of transverse motion, $f(\mathcal{E}_\perp)$. He has shown that at plasma densities in the interval $(m_e/m_i)^{2/3} < c^2/c_A^2 < (a/\rho_i)^{3/2}$ (c_A = Alfven velocity, a = dimension of the density gradient, ρ_i = ion Larmor radius) the instability of oscillations with frequency $\omega \approx \omega_{Hi}$ is due not to the anisotropy of the ion velocities and not to drift currents, but to the deviation of $f(\mathcal{E}_\perp)$ from a Maxwellian distribution (to the presence of a section with $\partial f/\mathcal{E}_\perp > 0$ in the distribution function.

This circumstance is noted also in [5]. The presence of the jump is attributed to the fact that, at a specified plasma length L, the most unstable waves with $\lambda_\perp \sim \rho_i$ can be excited only starting with a sufficiently low plasma density, determined by the relation

$$\frac{4\pi n T_i}{H^2} \lesssim 4 \frac{m_e}{m_i} \frac{\omega_{Hi}^2}{c^2} L^2.$$

Instability sets in when the plasma density decreases during the course of the decay to this value.

The plasma parameters in our experiments satisfly this relation ($L = 75$ cm, $T_i \approx 1$ keV, $H = 3000$ Oe, $n \simeq (0.5 - 1.0) \times 10^{10}$ cm^{-3}).

In conclusion we note that density jumps outward similar to those described in this article were observed also in a decaying plasma with hot electrons [6,7]. In this case the instability develops at electron-cyclotron frequencies.

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NEW PHASE OF BISMUTH

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Because of its unusual properties, bismuth occupies a special place as an object of research in solid-state physics. The existence of several phase transitions in bismuth, in a broad range of pressures, has made it an indispensable substance for the calibration of high-pressure apparatus. The phase diagram of bismuth is very complicated and has been investigated many times [1-6]. The results of investigations of various authors are in sufficiently good agreement. However, the melting curve of BiII, as obtained by all investigators, has a somewhat unusual form. We have therefore investigated the P-T diagram of bismuth 1) up to 30,000 kg/cm^2 by the thermal analysis method. The pressure was produced by compressing gasoline in the multiplicator described in [7]. The packing for the piston and for the electric leads of the high-pressure chambers was of O-shaped rubber rings together with metallic protecting rings. The temperature was measured with a chromel-alumel thermocouple. The thermocouple leads were also made from chromel and alumel alloys, making it possible to reduce the extraneous thermal emf to a minimum [8]. The signals from the ordinary and differential thermocouples were amplified and recorded with an EPP-09 chart recorder. The temper-