"Flash" dynamics of energy release in a neutral current sheath

A. T. Altyntsev, V. I. Krasov, N. V. Lebedev, V. L. Papernyĭ, and V. G. Simonov
Siberian Institute of Terrestrial Magnetism, Ionosphere, and Radio Wave Propagation

(Submitted 7 April 1981)

Pis'ma Zh. Eksp. Teor. Fiz. **33**, No. 10, 518–522 (20 May 1981)

It is observed experimentally that electrons in a neutral current sheath of a theta-pinch plasma are heated and accelerated immediately after the sheath is formed when the temperature and acceleration efficiency increase rapidly, reach a maximum concurrently and then decrease sharply.

PACS numbers: 52.40.Kh, 52.55.Ez

It was shown in Refs. 1 and 2 that the energy dissipation in a neutral current sheath of a theta-pinch plasma is accompanied by the appearance of energetic electrons ($\epsilon > 2$ keV). This indicates that there is a mechanism in the sheath for acceleration and heating of particles. In this paper we present the results of a measurement of the temperature of the thermal part of the electron distribution ($\epsilon \lesssim 1$ keV) as well as the *dynamics* of energy release in the sheath.

1. The experiment was carried out using the "UN-Phoenix" facility. The initial plasma (hydrogen, $n_0 = 10^{12} - 10^{14}$ cm^{-3}, $T_{e_0} = T_{i_0} \approx 1 - 5$ eV) was placed in a quasi-steady-state magnetic field $H_0 = 10^2 - 10^3$ Oe that was oriented along the volume (16 cm in diameter, 150 cm in length). The plasma was rapidly compressed by a cylindrical magnetic piston 30 cm in width, $H = 1300$ Oe in amplitude, and ≈ 1.5 μsec repetition period, whose magnetic field was antiparallel to H_0. A neutral current sheath whose thickness in the steady state was $\sim 10\, c/\omega_{pe}$ ($\omega_{pe}^2 = 4\pi n_0 e^2/m_e$) and which converged at the center of the volume, was produced at the boundary of the plasma column at the time $\tau = 0$. The macroscopic structure of the sheath and its velocity were measured by magnetic probes. The dynamics of variation of the main parameters of the energy release: the temperature of the thermal part of the electron distribution and the acceleration efficiency of epithermal electrons, were studied by analyzing the x-ray bremsstrahlung of electrons in the current sheath on the target that was immersed in the plasma. The plasma parameters were selected in such a way that the magnetic structure of the sheath would be perturbed slightly by the introduction of the target, and the maximum potential of the sheath relative to the target, which was estimated by using the formula $\phi \leqslant m_i u^2/2e$ (m_i is the ion mass and u is the velocity of the sheath), should not exceed ~ 100 V.

2. The electron temperature in the sheath and the dynamics of its variation were determined in the following way. A pinhole camera (see Fig. 1a) was used to record an x-ray image of the target 1, comprised of a 5-mm-wide and 80-mm-long strip of tantalum foil, which was immersed into the plasma volume at an angle $\alpha = 60°$ to its axis. The image was formed at the surface of the detector by using two 1-mm-diam holes 2 (Fig. 1a shows one of the holes; the other hole is located behind the plane of

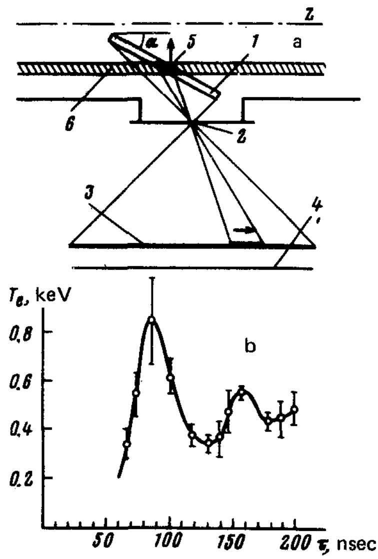

FIG. 1. (a) A circuit for recording an x-ray image of the target. The arrows indicate the radial motion of the emitting region of a current sheath and the corresponding motion of its image along the surface of the detector; (b) dynamics of the temperature variation of electrons in the sheath, $n_0 = 5 \times 10^{12}$ cm^{-3}, $H_0 = 450$ Oe.

the figure) which were covered by the absorbers. The use of a microchannel plate (MCP) as a detector 3, behind which a luminescent screen 4 was placed, enabled us to use 1- and 2-μm-thick transparent polystyrene films as absorbers, since an MCP is insensitive to plasma radiation in the optical range. The temperature of the electrons in the sheath (assuming that it has a Maxwellian distribution) was determined from the ratio of the signal levels on the photograms of two target images produced by x-ray bremsstrahlung that was transmitted through the absorbers. The estimates showed that thermal electrons with an energy $\leqslant 1$ keV accounted for the main contribution to the radiation intensity when the indicated absorbers were used. This was confirmed by the reduction of the signal level below the recording threshold when a 24-μm-thick polystyrene film was used as an absorber. The radiation source at each moment of time is that local region of the target 5, which is crossed by the neutral sheath 6 at that moment of time. As the current sheath moved radially, this region moved along the target, producing a "time-scan" image of the sheath, which gave information on the dynamics of temperature variation. Special measurements involving the target, which was oriented along the volume axis, showed that the sheath is nearly homogeneous along the projection of the target on the z axis (≈ 40 mm).

The results of the measurements described above are shown in Fig. 1b in which it can be seen that the electron temperature T_e of the sheath increases rapidly (i.e., during a short time compared with the existence time of the sheath), reaches a maximum value in ~100 nsec, and then decreases sharply.

3. The sensitivity of the described method turned out to be inadequate in the high energy region ($\epsilon > 2$ keV), which can be analyzed by using thicker absorbers. Therefore, the dynamics of variation of this part of the electron distribution were determined by using a six-channel, large-aperture (12-mm-diam input hole), x-ray analy-

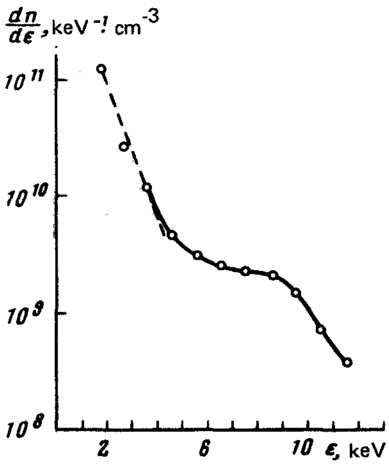

FIG. 2. Energy distribution of electrons in a neutral current sheath. The broken curve represents the thermal part of the distribution with $T_e \approx 1$ keV.

zer, which was also based on the MCP principle.[3] The small dimensions (5 X 5 mm) of the target made it possible to carry out local measurements. The energy of the radiation flux from the target at the time the current sheath passed through it was analyzed by using the absorption method. Polystyrene films 24 μm and 48 μm in thickness and aluminum films 7, 14, 21, and 28 μm in thickness were used as absorbers. The spectrum of the emitting electrons in Fig. 2 was reconstructed from the current signals from the output of the MCP.[3] This figure reveals the presence of a non-Maxwellian "tail" of accelerated particles in the energy range 4–12 keV. The efficiency of the acceleration mechanism is characterized by the parameter $w = (\epsilon_2 - \epsilon_1)\,\lg^{-1}\,[dn/d\epsilon\,(\epsilon_2)/dn/d\epsilon\,(\epsilon_1)]$ ($\epsilon_1 = 4$ keV, $\epsilon_2 = 12$ keV), which is determined by the average slope on the logarithmic scale of the spectrum of accelerated particles (specifically, w coincides with the temperature for the Maxwellian shape of the spectrum).

Figure 3 shows the dependence of w on the existence time τ of the sheath from the moment of its formation at the plasma boundary and before its arrival at the target. For a fixed location of the target (at a distance $\Delta r = 3$ cm from the plasma boundary) the different values $\tau = \Delta r/u$ were determined by varying the initial con-

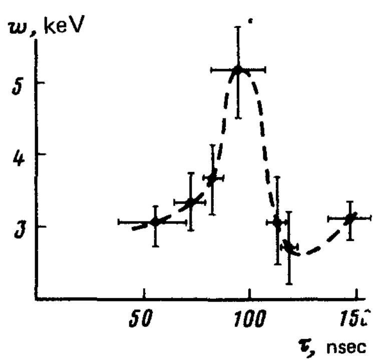

FIG. 3. Dynamics of variation of the efficiency of the mechanism of electron acceleration in the current sheath.

centration of the plasma, which determines the velocity u of the sheath. We can see in Fig. 3 that the dynamics of changing the acceleration efficiency of electrons are similar to the dynamics of heating the thermal part of the distribution.

4. We have thus showed experimentally that the energy release in a theta-pinch neutral current sheath has the highest efficiency at the initial stage of its existence. At this stage the main parameters of the process—the temperature of the thermal part of the electron distribution and the acceleration efficiency of epithermal electrons—vary in a "flashlike" manner (i.e., they rapidly reach the maximum values simultaneously and then decrease sharply) and can exceed substantially the average values during the time of the energy release in the sheath. The "flash" dynamics of this process were observed in a broad range of initial parameters (plasma density and magnetic field). Note that such studies, which are conducted in a neutral current sheath in a laboratory plasma with parameters that can be varied and controlled relatively easily, may facilitate the determination of the mechanism of energy release in some astrophysical phenomena such as solar flares.

1. M. V. Babykin, A. I. Zhuzhunashvili, and S. S. Sobolev, Zh. Eksp. Teor. Fiz. **60**, 345 (1971) [Sov. Phys. JETP 33, 188 (1971)].
2. A. T. Altyntsev and V. I. Krasov, Fizika plazmy 5, 906 (1979) [Sov. J. Plasma Physics 5, 556 (1979)].
3. A. T. Altyntsev, V. I. Krasov, I. B. Maksyutov, and V. L. Papernyĭ, Instruments and Experimental Techniques No. 6, 159 (1978).

Translated by S. J. Amoretty
Edited by Robert T. Beyer