# Anomalous scattering of the energy of a plasma jet interacting with a gas target

K. B. Kartashev, V. I. Pistunovich, V. V. Platonov, V. D. Ryutov, and E. A. Filimonova

(Submitted January 31, 1974)
ZhETF Pis. Red. 19, 493–496 (April 20, 1974)

Anomalous scattering of the energy of a plasma jet interacting with a gas target has been observed. The observed phenomenon is manifest in the charge exchange of a plasma jet with current density $j \geq 10$ A/cm$^2$.

One method of heating plasma in tokamak installations is injection of fast neutral particles.[1–3] Calculations show that to heat ions in existing installations to a temperature $T_i \sim 1$ keV it is necessary to deliver to the ion component a power on the order of 1 W/cm$^3$. To realize such a regime in an installation having a volume of ~500 liters it is necessary to have atom fluxes with current densities $j \geqslant 1$ A/cm$^2$ and energy in the range 5–10 keV.[4]

An essential stage in the production of fast-atom jets is charge exchange of the ion jet with a neutral target. Since the target thickness is limited from above by Coulomb scattering, the charge exchange of a jet having the indicated parameters should produce in the target a plasma having a density comparable with the density of the target itself. This can lead to an additional interaction of the initial ion jet with the partly ionized target.

We describe here the results of an experimental investigation of the charge exchange of a jet of hydrogen plasma with a proton current density $j \geqslant 10$ A/cm$^2$ in different gaseous targets. It was shown earlier[5] that the charge exchange of a plasmoid with an ion density $n_i \approx 10^{11}$ cm$^{-3}$ ($j \sim 1$ A/cm$^2$) occurs in accordance with the pair-collision model. When the plasma-jet density was increased by more than one order of magnitude, we observed anomalously large energy losses in the jet passing through the target.

The experiments were performed with the INES installation.[6] The plasma jet produced by a coaxial plasma gun had the following parameters in the charge-exchange zone: average density $n \sim 10^{13}$ cm$^{-3}$, average proton velocity $u = 8\times 10^7$ cm/sec, energy density (energy transferred by the plasmoid through 1 cm$^2$ per pulse) $\epsilon \geqslant 0.1$ J/cm$^2$ (current density $j \geqslant 10$ A/cm$^2$ at a pulse duration ~2 μsec). The experimental setup and the arrangement of the diagnostic devices are shown in Fig. 1.

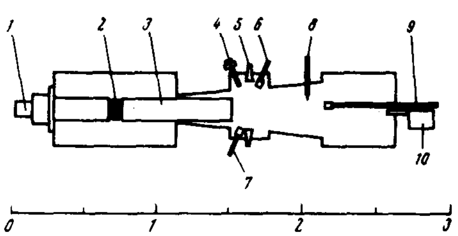


FIG. 1. Diagram of setup: 1—plasma gun, 2—supersonic magnesium nozzle, 3—plasma duct, 4—gas-target value, 5—microwave antennas, 6—lateral thermal probe, 7—lateral bolometer, 8—electric double probe, 9—straight thermal probe, 10—atom analyzer.

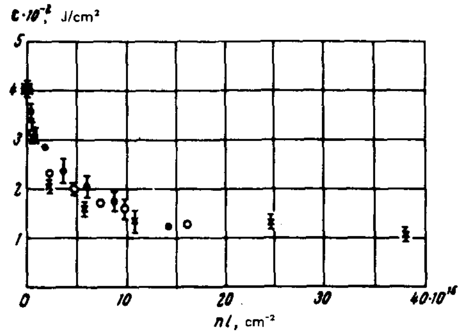


FIG. 2. Dependence of plasmoid energy density on the target thickness: —$H_2$ target, —Ar, —$CO_2$.

Experiments on the charge exchange with a supersonic jet of magnesium vapor have shown that a target of thickness $nl \approx 10^{15}$ cm$^{-2}$ decreases the energy density of the initial flux by a factor of 2. This attenuation, owing to the Coulomb scattering, can be expected at $nl \geqslant 10^{16}$ cm$^{-2}$. We investigated in this connection the character of the energy loss occurring in the passage of a plasma stream through various targets. Our purpose was to obtain the dependence of the attenuation on the charge of the scattering centers and on the velocity of the incident stream, i.e., on the principal parameters of the Rutherford formula.

The choice of the target material was determined by the feasibility of effective charge exchange of a proton of energy 2–4 keV and the essential difference in the effective charge of the scattering centers. The targets

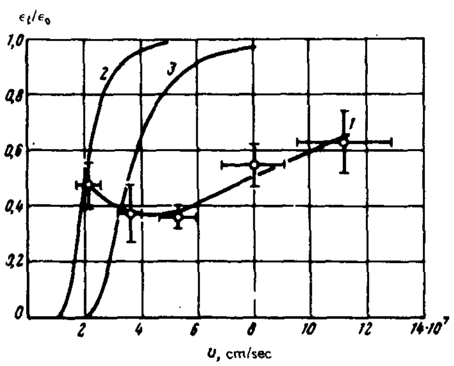


FIG. 3. Dependence of the ratio $\epsilon_t/\epsilon_0$ on the plasmoid velocity, measured at a hydrogen-target thickness $2\times 10^{15}$ cm$^{-2}$ (curve 1), $\epsilon_t$—energy density of plasmoid passing through the target, $\epsilon_0$—energy density without target. Curves 2 and 3—theoretical at hydrogen-target thicknesses $2\times 10^{15}$ and $2\times 10^{16}$ cm$^{-2}$, respectively.

  

argon.

Figure 2 shows the dependence of the energy density of the plasmoid passing through the target on the target thickness, for different gases. The plasmoid energy density was measured with the aid of a thermal probe with a resolution time $\tau < 1\ \mu sec$, and the target thickness was determined with a pulse manometer. We see that the attenuation is practically independent of the type of gas, whereas in Coulomb scattering one should observe a significant difference in the behavior of the curves. In addition, the observed decrease of the jet energy density and the amount of energy scattered through 80 and 120° cannot be attributed to scattering in pair collisions.

Figure 3 shows the ratio of the plasma jet energy density passing through a hydrogen target of thickness $nl = 2\times10^{15}\ cm^{-3}$, to its initial energy, as a function of the plasmoid velocity. The figure shows also the calculated values of this ratio for two target thicknesses, assuming Coulomb scattering at an angular aperture of the receiver $\theta = 0.1$, corresponding to the experimental conditions. The experimental curve differs in form from the relation typical of Coulomb scattering.

The energy lost by a plasmoid passing through a gas target can be due in principle to the deceleration of the plasmoid as a unit by the plasma electrons produced in the target. However, as shown by calculation, this effect should be small under the conditions of our experiment. Indeed, turning on the target does not lead to a time shift of the signals of the electric double probe and of the thermal probe, which are located behind the target, thus indicating that there is no noticeable change in the velocity of the particles passing through the target. This is also evidenced by the similarity in the shapes of the fast-atom spectra obtained with and without the target.

Thus, the presented experimental facts demonstrate that the observed decrease of the plasma-jet energy density is not connected with Coulomb interaction.

The observed phenomenon is probably due to the development of instability when the plasma jet interacts with the plasma produced in the target.


[1]L. A. Artsimovich, Usp. Fiz. Nauk 91, 365 (1967) [Sov. Phys.-Usp. 10, 117 (1967)]

[2]M. V. Nezlin, ZhETF Pis. Red. 16, 112 (1972) [JETP Lett. 16, 78 (1972)].

[3]T. Stix, Plasma Phys. 14, 367 (1972).

[4]V. I. Pistunovich, Tokamak with Fast-Neutral Injection, Preprint, Atom. Energ. Inst., 1972, Moscow.

[5]K. B. Kartashev, V. I. Pistunovich, V. V. Platonov, and E. A. Filimonova, Zh. Eksp. Teor. Fiz. 59, 779 (1970) [Sov. Phys.-JETP 32, 426 (1971)].

[6]I. N. Golovin *et al.*, Paper CN-28/6-9, Internat. Conf. on Plasma Physics And Controlled Thermonuclear Fusion, Maidson, 1971.