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Abstract

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ENERGY SPECTRA OF A PLASMA INTERACTING WITH A TRANSVERSE MAGNETIC FIELD

1. Earlier investigations of the interaction of plasma bunches with a transverse magnetic field ([1,2]) showed that part of the bunch produced by the injector passes through the transverse magnetic field, while part is captured by the field and moves along it. Study of the mass composition of the plasma with a Thomson mass spectrograph ([2]) indicated that the plasma of the bunch propagating along the magnetic field has a much greater relative hydrogen content than the bunch produced by the source. It was found that heavy impurity ions penetrate comparatively easily through the transverse magnetic field. Measurement of the velocities of plasma motion by electric probes showed that, when the plasma passes through the transverse field, its average propagation velocity decreases, whereas the average velocity of plasma motion along the magnetic field turned out to be greater than the velocity of the plasma produced by the injector. In view of the difference in the mass composition of the plasma propagating along the field and of the ejected plasma, the latter result required more detailed verification. The effect of an increase in the plasma velocity could be purely illusory, associated with an increase in the percentage content of faster light particles.

2. The experimental apparatus for elucidating the interaction of plasma bunches with a transverse magnetic field is described in ([2]). In the present work, using a mass analyzer ([3]), a detailed analysis was made of the ionic component of the plasma produced by a conical source ([4]), and of the plasma that had passed through the transverse magnetic field and was captured by the field. The distribution of plasma ions by energy and mass was studied. The energy analysis was carried out with an electrostatic analyzer, and the mass analysis with a time-of-flight mass spectrometer.

Generation of the bunch occurs within a comparatively short interval at the beginning of the first half-period of the discharge current, and the widths of the pulses on the mass spectrograms are sufficiently small. From the flight path (the distance between the plasma source and the detector of the mass

Fig. 1 and Fig. 2

Figure 1: Fig. 1 and Fig. 2

spectrometer) and the flight time, it was possible to monitor the values of the registered energies.

3. Study of the spectrum of ions in the plasma produced by the source showed the presence of hydrogen ions, carbon ions of various charge states (from C^+ to C^{4+}), oxygen (from O^+ to O^{4+}), as well as aluminum and iron (the materials of the source electrodes). The energy spectra of hydrogen, C^+, and Al^+ are presented in Fig. 1. The same figure shows the energy spectra of hydrogen, carbon, and aluminum ions in the plasma that had passed through transverse magnetic fields of various strengths. As follows from Fig. 1, the number of hydrogen ions that pass through even a very small transverse magnetic field (~ 25 G) is small: protons with energies above 600 eV do not pass through at all. When the magnetic-field strength is increased to 150 G, the passage of hydrogen ions with energies greater than 200 eV practically ceases completely. The decrease in the passage of carbon ions with increasing magnetic field is not so sharp, and an even weaker dependence is observed for aluminum ions.

In general, the passage of plasma ions through a transverse magnetic field increases with increasing ratio m/Z (m is the ion mass, Z is the charge) and with decreasing ion energy.

As follows from the mass spectra of plasma that has passed through a transverse magnetic field, the widths of the pulses do not change in comparison with the pulses obtained in the absence of the field. Moreover, the time of flight of ions of a given recorded energy also remains constant (within the measurement error, $\sim 10\%$).

The decrease in the relative content of light ions of high energies can be recorded as a decrease in the mean velocity of plasma motion as it propagates through a transverse magnetic field.

Fig. 1. Energy spectra of H^+, C^+, and Al^+ ions of the source plasma and of the plasma that has passed through transverse magnetic fields of various strengths: 1 –0 G; 2 –25 G; 3 –75 G; 4 –150 G; 5 –300 G; 6 –500 G. For different ions and magnetic fields the scale along the ordinate axis is different

Fig. 2. Energy spectra of H^+-plasma moving in the direction of the magnetic field. 1 $-H = 500$ G; 2 $-H = 300$ G; 3 $-H = 25$ G. The scale along the ordinate axis is different for different values of the magnetic-field strength

4. The study of the mass composition of the plasma captured by the magnetic field showed that it has a much larger relative hydrogen content compared with the plasma produced by the source. Increasing the magnetic field leads to an increase in the fraction of impurities (mainly multiply charged

carbon and oxygen ions), but they are observed only in the region of low energies.

The energy spectra of hydrogen ions of plasma moving in the direction of the magnetic field are shown in Fig. 2 for different values of the magnetic field. As follows from comparison of the curves in Figs. 1 and 2, the energy spectra of hydrogen ions of plasma that has passed through a transverse magnetic field and of plasma captured by the field are, in a certain sense, mutually complementary: with increasing strength of the transverse magnetic field, the energy spectrum of hydrogen ions of the plasma that has passed through the field shifts toward lower energies, whereas the energy spectrum of protons of the plasma moving along the magnetic field shifts toward higher energies. At a field strength of 500 G, the values of d^2n/dw^2 for hydrogen ions of plasma moving along the magnetic field coincide with the corresponding values for protons of the plasma produced by the injector at energies below 400 eV. The relative content of higher-energy protons in the plasma captured by the field decreases more rapidly with increasing energy than in the case of the initial plasma. At a field strength of 500 G, in the plasma moving along the magnetic field, hydrogen ions with energies greater than 600 eV are completely absent. Probably, the reason for this phenomenon is that the density of the fore-

of the plasma front, where hydrogen ions of high energies are located, is insufficiently large, and when the plasma enters the transverse magnetic field a rupture of the leading part of the bunch occurs.

It follows from the mass spectra of the plasma moving along the magnetic field that the widths of the recorded pulses do not change in comparison with the pulses produced by the source plasma in the absence of a magnetic field. In addition, the time of flight of the plasma (to an accuracy of 10%) corresponds to the recorded energy and to the distance from the plasma source to the detector of the mass spectrometer. When the plasma moves in a transverse magnetic field, a very rapid transformation of the ion velocity vector $v_\perp$ into the longitudinal velocity $v_\parallel$ takes place.

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Note: Figure translations are in progress. See original paper for figures.