METHOD OF MEASURING LOCAL PLASMA PARAMETERS WITH THE AID OF A BEAM OF FAST ATOMS

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A method is described for measuring the ion distribution function in a small fraction of the plasma volume, and of measuring the spatial profile of the plasma density by means of the atoms produced by charge exchange of the plasma ions with the fast atoms of the diagnostic beam. Results of measurements in an open trap with crossed E and H fields are presented.

The procedure for measuring the ion distribution function f(E) in a plasma by using the atoms resulting from charge exchange of the ions by residual gas [1] has many shortcomings in the case of a sufficiently dense, hot, and long-lived plasma. First, the function f(E) is averaged in the measurement over the plasma volume along the observation direction. Second, the charge-exchange target, the role of which is played by the residual gas, can be appreciably inhomogeneous in space and in composition. Indeed, in a plasma with concentration $n \gtrsim 10^{12}$ cm^{-3} and an electron temperature $T \gtrsim 20$ eV the mean free paths for ionization of the neutral atoms of the residual gas are much shorter than the characteristic plasma dimensions. In a hot plasma region, the target density n_0 can therefore be much lower than in the regions next to the walls, where the plasma is cold. In addition, at the considered plasma parameters, the gas atoms can be excited by electrons, and the dependence of the cross section σ_{10} for charge exchange with the excited atoms on the ion energy is usually unknown. Finally, a noticeable role can be played in the charge-exchange exchange process by impurity ions and atoms that enter the plasma from the walls. These shortcomings can be eliminated by using as the target a fast beam of neutral atoms [5] with velocity v_0 much larger than the thermal velocity v_T of the plasma ions. At an atom concentration in the beam

$$n_1 = n_0 \frac{\langle \sigma_{10}(v_i) v_i \rangle}{\langle \sigma_{10}(|v_i + v_0|)|v_i + v_0| \rangle} \frac{L}{\ell} \qquad (1)$$

the fluxes of the ions experiencing charge exchange with the beam and with the residual gas already become comparable (here L and ℓ are the dimensions of the plasma and beam, respectively, along the observation direction and v_i is the ion velocity). By choosing optimal values of v_0 and ℓ, and also by using electronic methods to separate the signal from the noise (for example, by modulating the beam current), it is possible to make the required ratio n_1/n_0 quite small, $\sim 10^{-2} - 10^{-4}$.

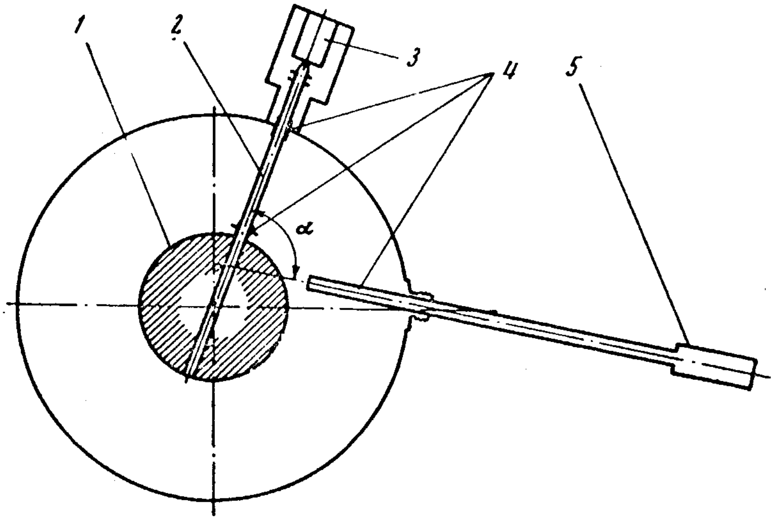

Fig. 1. 1) liner confining the plasma, 2) beam of hydrogen atoms, 3) arc source [3], 4) beam and analyzer collimators, 5) analyzer.

The effectiveness of the proposed procedure was verified in measurements in a rotating plasma in a probkotron mirror machine [2]. A pulsed beam (200 μsec) of hydrogen atoms of energy 15 keV, equivalent current 300 mA, and 3 cm diameter was introduced perpendicular to the

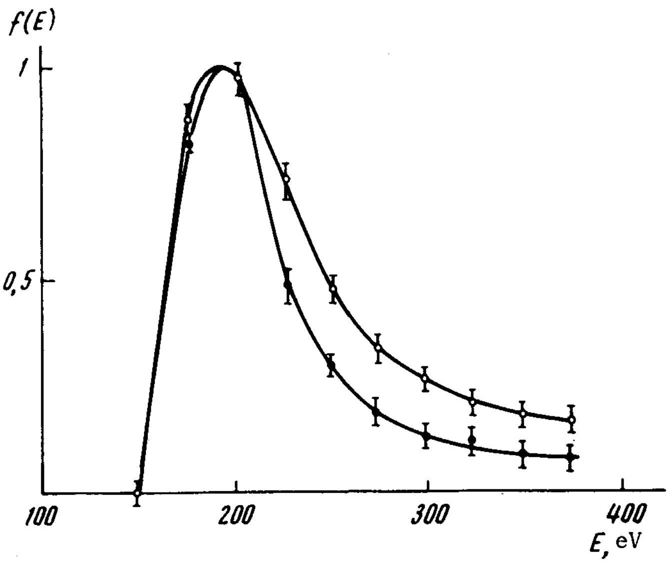

Fig. 2. o) Measurements with charge exchange on a beam, ●) measurements with charge exchange on residual gas; r = 7 cm; the shift along the E axis is due to plasma rotation.

probkotron magnetic field and crossed the plasma column along its diameter (Fig. 1). The analyzer for the plasma ion that becomes charge exchanged into atoms was placed at an angle $\alpha = 75° - 115°$ to the beam direction. The beam-analyzer system occupies an investigated volume $1.5\times3\times3$ cm^3 in the plasma. Since the chosen value of v_0 is in the region of the "plateau of the function $\sigma_{10}(v)$ and $v_0 > v_i$, it follows that $\sigma_{10}(|\vec{v}_i + \vec{v}_0|) \simeq \sigma_{10}(v_0)$. Therefore the atoms proquced by charge exchange from the beams should have the same velocity distribution function as the plasma ions. (This holds true also if the beam contains molecules or excited atoms of hydrogen). The analyzer used for these neutral atoms is described in [4]. The stripping is with a pulsed helium target, and the subsequent energy analysis is by the retarding-potential method. The ions that have passed through the retarding potential E_0 are converted into electrons, which then strike a scintillator connected with a light pipe to a photomultiplier. The photomultiplier current I is proportional to the current of the analyzed ions and is connected with f(E) by the relation

$$I(E_0) = \text{const}\, n_1 n v_0 \ell \sigma_{10}(v_0) \int_{E_0}^{\infty} f(E)\sigma_{01}(E)\sqrt{E}\,dE\,. \qquad (2)$$

Here σ_{01} is the cross section for stripping on helium.

The measurements were performed under the following conditions: a hydrogen plasma with $n \sim 10^9$ cm^{-3} was produced with a Penning discharge; the magnetic field at the center of the probkotron was 5 kOe; the radial electric field produced at the ends was $\sim$ 1 kV/cm; the pressure of the residual gas (hydrogen) was 1.5×10^{-5} Torr ($n_0 \sim 5\times10^{11}$ cm^{-3}); the diameter of the metal liner bounding the plasma was 20 cm and its length was 60 cm. The photomultiplier current during the time of injection of the fast atoms into the plasma was more than double the so-called "background" current due to charge exchange with the residual gas. This made it possible to perform the measurements without taking special measures to separate the signal from the background. The signal due to scattering of the beam by the parts of the apparatus and by the residual gas did not exceed 10% of the useful signal. The results of measuring f(E) are shown in Fig. 2, which gives also the f(E) plot determined from charge exchange with the residual gas. As expected, the curves are approximately equal in a plasma of so low a density. We note that the measurements could be performed at $n_i/n_0 \lesssim 2\times10^{-3}$.

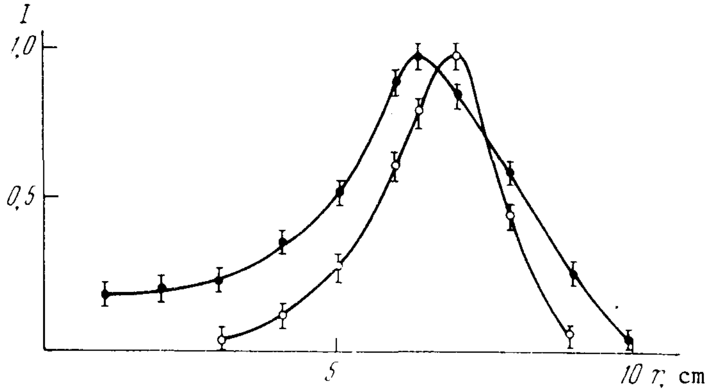

Fig. 3. The notation is the same as in Fig. 2.

By varying the angle between the beam and analyzer axes one can scan small plasma volumes at small radii r of the plasma column. The measurements have shown that the integral in (2) is practically independent of r ($E_0 = 0$). Under this condition it is very easy to measure with the aid of the beam the plasma density profile n(r). Indeed, up to $n \lesssim 10^{14}$ cm^{-3} the beam-atom mean free paths with respect to charge exchange, ionization, and excitation are much larger than the plasma-column diameter, and the beam penetrates through the plasma without undergoing qualitative or quantitative changes. Consequently, the current I at $E_0 = 0$ is proportional to n at all r. Figure 3 shows the plasma density profile $n(r) \propto I(r)$, measured in this manner. The figure shows also the radial dependence of the flux of the atoms produced by charge exchange with the residual gas. It is easy to show that the difference between this curve and n(r) agrees qualitatively with the expected difference.

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DEPENDENCE OF MULTIPLICITY OF SECONDARY PARTICLES ON THE ATOMIC NUMBER OF THE TARGET NUCLEUS AND ON THE ENERGY OF THE INCIDENT PARTICLE

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The growth of the multiplicity in the energy interval 50 – 3000 GeV fits satisfactorily a logarithmic law for many substances (H, CH_2, Cu). The coefficient of the logarithm increases with increasing atomic number. The data agree with the semi-inclusive scaling predictions.

Investigations of such nuclear-interaction characteristics as the distribution of the multiplicity n_s at ever increasing energies can cast light on the dynamic picture of the interaction. A study of the lower moments of the distribution, such as the average multiplicity $\langle n_s \rangle$, the variance, etc., and also of the correlation functions of the multiplicity, can reveal the main features of these processes and their connection with such fundamental characteristics as the cross sections. By the same token, more opportunities arise for narrowing down the class of acceptable models. On the other hand, a study of the dependence of the multiplicity on the atomic number of the target nucleus in a wide range of energies yields information on the high-energy processes in nuclear matter. The investigations in this direction used mainly the nucl nuclear-emulsion procedure. The shortcomings of this procedure, namely the indirect determination of the in-eraction energy, the lack of pure target nuclei and the resultant lack of distinct criteria for separating interactions with "light" and "heavy" nuclei, all decrease greatly the value of these laborious experiments.

The aim of our experiment was to investigate the aforementioned problems with the aid of pure targets, with good resolution of the secondary particles and with an independent estimate of the interaction energy. The work was performed with the new functioning section of the high-mountain setup of the G. E. Chikovani laboratory, situated in the southern Caucasus at an altitude of 2500 m.

Since the start of operation of the installation, in January 1973, some 12000 photographs were obtained, from which 375 events in a polyethylene target and 175 events in two copper targets of different thicknesses (18 and 8 g/cm^2) were selected. All events were broken up into three energy intervals with mean energies 70, 170, and 600 GeV. We measured the multiplicity of the secondary relativistic particles.