Parameters of the Flow of Accelerated Particles Generated by the Ion Source with Closed Drift of Electrons[1]

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Abstract – At measuring the yields of nuclear reactions dd, pd, etc. at ultra-low collision energies (2÷6 keV in a centre-of-mass system) it is necessary to know the information about parameters of the flux of accelerated particles (ions of hydrogen, deuterium, …), falling on the target (CD_2, D_2O, the metal saturated with hydrogen or deuterium). In particular, the important parameters are: energy distribution of the accelerated particles and its angular dependence, the composition of accelerated particles of the flux. In the given work are presented the experimental results got with the time-of-flight method on the efficiency of the accelerated particles flux transportation on 105 cm base and over the 0÷20° range, the particle flux composition, energy distribution of particles in the flux.

1. Introduction

For the resolution of some fundamental problems existing in astrophysicists [1–5], great interest has been expressed at present to studying of nuclear reactions between light nuclei and in particular

$$p + d \rightarrow {}^3He + \gamma;$$

$$d + d \rightarrow He + n$$

in the range of ultra-low collision energies. To study the given reactions, a relatively great flux of the accelerated particles with controlled parameters is required.

The coaxial cone pulsed ion source with the closed drift of electrons was used for generating the flux of accelerated ions of hydrogen isotopes at studying the above-mentioned reactions. The detailed description of the source is presented in work [6]. The basic requirement to the source operating mode is minimum oscillations of the applied accelerating voltage. This requirement is provided: by selecting the gas loading of the initial ions source (the shock coil), plasma loading of accelerating gap (~ 7 mm), magnetic field value in the accelerating gap, time delays in the operation sequence – the gas valve → magnetic field → shock coil → accelerating voltage. The oscillating character (with increasing amplitude) of the shock coil operating determines the periodicity of the accelerating gap filling with plasma clots and, hence, defines the modulation of accelerated particles flux. The coaxial cone channel of the source allows providing certain ballistic focusing of the accelerated ions flux. The period of source operation at the given stage is ~ 1 min, and it is restricted to the time of reading information from a multichannel recording registering equipment. The quantity of the accelerated particles registered on a target during one operation is about $\sim 10^{14}$ particles. Here after the operating frequency will be brought up to 0.1 Hz. An increase of the quantity of the charged particles falling on a dielectric target is not advisable unless the problem of reliable removal of the ionic flux charge from dielectric targets is solved. The very problem does not exist for the metal targets saturated with gas (deuterium, hydrogen) if the target is earthed.

At measuring the yield of nuclear reactions dd, pd etc. at ultra-low energies interaction one needs maximum information on the parameters of the accelerated particles flux (protons, deutrons) falling on the target (CD_2, D_2O, saturated metals).

The results of investigations of the hydrogen accelerated ions flux carried out with the help of the time – of – flight method on the 105 cm base, are given in the work.

2. Experimental setup and results

The results of investigations of the hydrogen accelerated ions flux carried out with the help of the time-of-flight method on the 105 cm base, are given in the work.

At time-of flight measurements the reference signal was being removed from the flight ring placed before the drift tube (Fig. 1).

The first collector, with a hole of 1 cm in diameter in the centre, was located at a distance of 105 cm from

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[1] The work is supported by the Russian Foundation for Basic Research (Project No. 0602-17182-a) and the Fund of the Plenipotentiar of Poland at JINR.

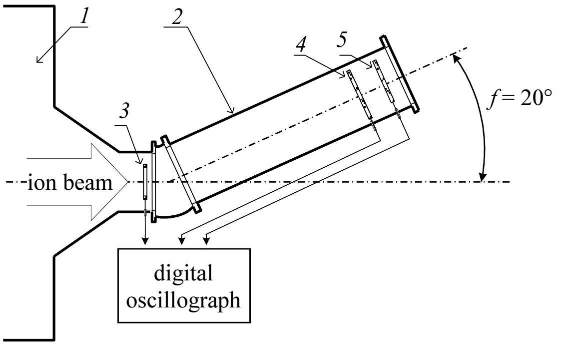

Fig. 1. The experiment diagram: *1* – the ion accelerator; *2* – the drift tube, *3* – the ring collector, *4* – the first collector, *5* – the second collector

the ring in the tube. One more collector was placed behind the hole. Geometrical sizes of the tube were as follows: the length 100 cm, the inside diameter 10 cm. They determined the flux angle of view for the first collector (≈ 11.4 °). The flux angle of view for the second collector was about 5°. The drift tube with the collector (without a flight ring) might be turned relative to the symmetry axis of the accelerator through an angle up to 25°. The measurements were carried out over a range of energies 4.5÷14 keV (in the lab. system) and angles 0÷20°.

Energy of the accelerated particles. Figs. 2 and 3 present the typical oscillograms of the signals of the ring collector and two collectors currents. For information, give the calculated values of time-of-flight of particles (atomic H^+ and molecular H_2^+ hydrogen ions) between the ring and the first collector on the 105 cm base.

At the voltage of acceleration 4.7 kV:

$$t(H^+) = 1100 \text{ ns}, \ t(H_2^+) = 1550 \text{ ns};$$

at a voltage of acceleration 14.3 kV:

$$t(H^+) = 632 \text{ ns}, \ t(H_2^+) = 885 \text{ ns}.$$

As it follows from the Figs. 2 and 3, time delays between the two reference points correspond, on the whole, to the applied accelerating voltage and the measured energy distribution of accelerated ions [6]. However, there are cloth of accelerated particles in which the energy of particles may exceed to some extent (superfast particles) the energy or, on the other hand, be less than the energy (slow particles) corresponding to the applied accelerated voltage.

Superfast particles. At the plasma flux interaction with a magnetic barrier, localized in the field of the accelerating gap, there occur the charge separations. The electrons are more strongly moderated by a magnetic field, and ions fly forward, losing the energy in the field being formed at charge separation. As a result, the formation of an ionic layer occurs in the region of magnetic barrier. The effective accelerating field is increased by the ionic layer potential. The time of the accelerating gap filling with plasma is less then 40 ns, then it is impossible to form the localized ionic layer.

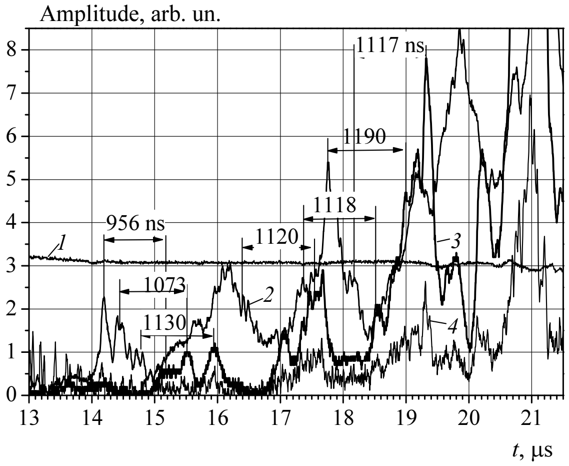

Fig. 2. Oscillograms of accelerating voltage and the collectors currents at the value of accelerating voltage 4.7 kV and at the turning angle of a drift tube of 20°: *1* – accelerating voltage; *2*, *3*, and *4* – collectors currents: the ring collector, the first and second one, respectively

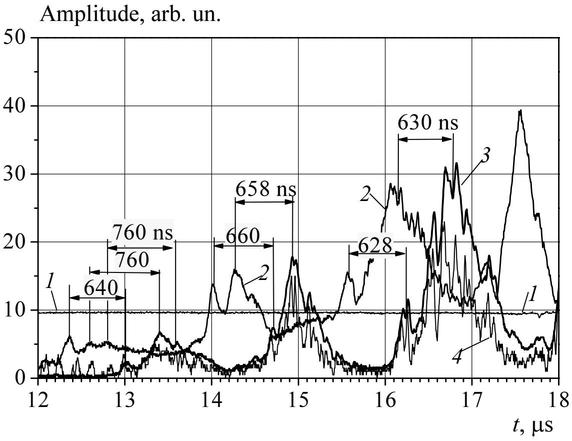

Fig. 3. Oscillograms of accelerating voltage and collectors currents at value of accelerating voltage 14.3 kV and at the turning angle of the drift tube of 12 °: *1* – accelerating voltage; *2*, *3*, and *4* – collectors currents: the ring collectors, the first collector and the second one, respectively

Slow particles. A slower component of accelerated particles may be formed at penetrating into the accelerating gap of neutral gas which ionization (an acceleration start) may happen in any place of the accelerating gap.

The estimations (with regard to a Lorentz force) show that a magnetic field ~ 4 kGs can "release" hydrogen ions with the escape velocity more than 108 cm/s from the accelerating gap and from the conical drift channel. As the velocity decreases, the yield efficiency is reduced rapidly and at the energy of ~ 1 keV there occurs a complete blocking of particles. With an increase of the magnetic field, the boundary of the particle "cut-off" shifts to large energies. The particle angle separation has not been observed.

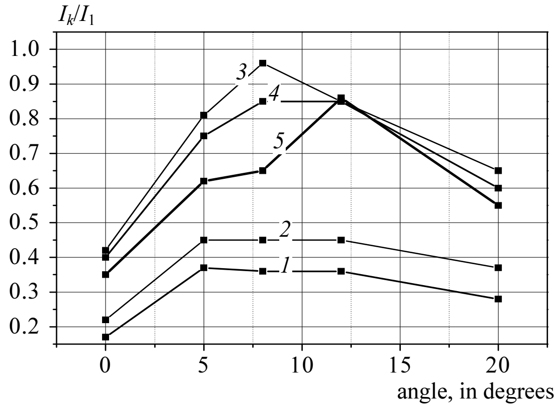

Fig. 4. Dependence of the relative flux transportation efficiency of ions on the drift tube turning angle: *1* – 4.6 kV; *2* – 6.3 kV; *3* – 9.5 kV; *4* – 11.7 kV; *5* – 14.3 kV

The beam composition. The measurements carried out at different angles and different energies of H^+ have not discovered the noticeable presence of the impurity of the molecular hydrogen ions in the accelerated particle flux (see time delays in Figs. 2 and 3). At the same time, the quantity of fast neutrals in the flux of accelerated particles falling on a target was determined with the help of the multigrid energy analyzer and according to the procedure developed by us. The proportion of fast neutrals formed as a result of exchange charge processes is being changed for different experiments conditions from 10 to 30% [7].

Transportation of the accelerated particles on the 105 cm base. As it follows from Figs. 2 and 3, the signals from first and second collectors, obtained at angular resolution of 11.4 and 5°, respectively, do not differ from another by the shape. It points to good flux mixing. Fig. 4 shows the flux transportation efficiency determined through ratio first current collector to the flight ring current (I_{c1}/I_r) from the drift tube turning angle at different acceleration voltages.

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