§1. Characteristics of a Helium Ion Beam from a Multicusp Source and Study of Beam Transport

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With the goal to generate a high energy (1.7 MeV) He^0 beam probe for a burning plasma experiment, we have been developing an intense He^- ion beam. A He^- beam can only be produced effectively from He^+ via a two step elecetron capture process in an alkali metal gas cell, such as Li, Na, Mg, K, Rb, or Cs. Because the optimum energy for these processes was reported to be around 6 keV, the essential point of the development is extraction of an intense He^+ beam at relatively low energy. Another key issue is the transport of a high perveance beam, with a good focusing property onto an aperture of the charge exchange cell. The aperture should be small enough to minimize the alkali vapor leakage. In transporting a high perveance beam, the charge neutralization due to background gas pressure usually prevents the beam expansion. We cannot use this method in our experiment. The ionization cross section of He^+ is very low in this region (2×10^{-18} cm^2). At higher gas pressure, collisional charge exchange process of He^+ with the residual helium gas results into a ground state He^0. This cross section is 5×10^{-16} cm^2. A long-life, 10 – 300 μs, He^- (4Pj) is produced only through its metastable state. Therefore, in order to avoid any beam loss and produce He^- effectively, a low gas pressure, $<<10^{-2}$ Torr, should be maintained. One of the solutions of this problem is to employ an efficient transport system using eletrostatic lenses.

A schematic diagram of the test stand with a He^+ ion source and an electrostatic transport is shown in Fig. 1. A helium plasma is generated by two hair-pin type of tungsten filaments (0.4 mm-diameter) in an 8.5 cm-diameter and 10 cm-long compact multicusp ion source. An He^+ beam is extracted from a set of three electrodes of 6 mm-diameter. The ion source itself is biased at acceleration voltage, Vacc, and the second electrode is negatively biased (-Vdec), and the beam is accelerated to Vacc + Vdec in the first extraction gap. The third electrode is grounded, and the beam is decelerated by Vdec so that the final beam energy is eVacc. The electrostatic transport system, developed at Maryland, is composed of six ESQ lenses. There are several diagnostic ports. The diagnostic tools developed are: a large Faraday cup for total beam current measurement, a Faraday cup array for the beam profile, and three types of emittance gauge.

The normalized beam emittance (90%) of the He^+ beam extracted from the source is measured by the slit-and-multi-electrode emittance gauge, and it is about 0.08 π mm-mrad at the current density of about 5-15 mA/cm^2 at 6 - 9 kV. The pepper pot measurement gives the value of about 0.075 π mm-mrad.

In order to transport a diverging high-perveance beam, and to focus it onto the entrance of the charge exchange cell, an efficient low-energy beam transport system has been considered. A set of lens parameters, which can transport over about 50 cm, has been found after a wide range of parameter survey using a simulation code solving the K-V envelope equations. Fig. 2 shows the beam envelope in x and y directions in the ESQ, for a case of 1mA, 8kV beam with the initial beam radius, r, of 3 mm, and the initial beam divergence, r', of 10mrad.

An electrostatic quadrupole transport system (ESQ) is designed for this beam. Preliminary experimental results show that the ESQ has a potential to transport a beam without any significant emittance growth over a length of about 50 cm.
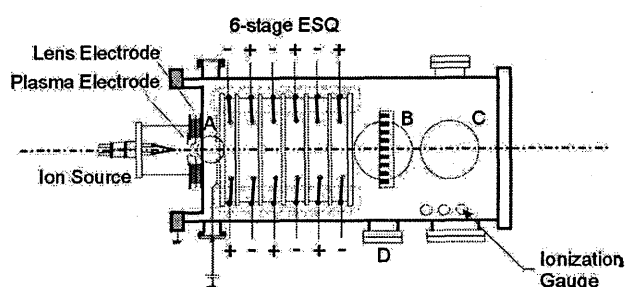

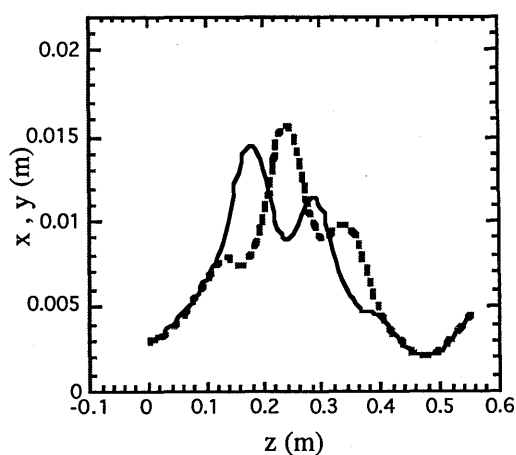Fig. 1 Schematic View of Experimental Arrangement

Fig. 2 The beam envelope in x and y direction in the ESQ, where z is the direction of the propagation, for a case of 1mA, 8kV beam with r = 3 mm, r'= 10 mrad.