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PRODUCTION OF INTENSE NEGATIVE ION BEAMS

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Production of Intense Negative Ion Beams*

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INTRODUCTION

Negative ion beams have long been of interest for various nuclear physics and accelerator uses. Recently, it has become evident that very intense D^- beams would be desirable for long-range controlled fusion applications — either for efficient high-energy neutral beam production^{1,2} or for direct injection³ into a fusion reactor for fueling or heating purposes. Preliminary experiments are reported on intense beam formation both by direct extraction of negative ions from a calutron type⁴ of ion source and by use of multiple electron pickup by a low-energy D^+ beam from a multiple aperture source⁵ passing through an alkali metal charge exchange cell such as cesium.^{6,7}

PREDICTED AND EXPERIMENTAL PERFORMANCE

Direct extraction of negative ions from a plasma is clearly limited by the relative negative ion population and the local density. Most of the cross sections involving negative ion production or destruction (e.g. $H_2 + e + H^- + \text{etc.}$) are known, but optimum conditions are difficult to attain because of the many coupled parameters, plasma interactions, and surface effects. Our expectations were that the H^- composition would be $\leq 5\%$ of the available H^+ density even under the best of experimental conditions.

The calutron (or cyclotron) type of ion source was chosen as the natural geometry for use as a negative ion source because ion extraction perpendicular to the magnetic field allows separation from the electrons.

*Performed under the auspices of the U. S. Atomic Energy Commission.

However, the electrons still must be handled on a suitably located and biased collector because they drain by $\vec{E} \times \vec{B}$ drift and would represent a major problem at full extraction energy.

The experimental geometry used with the calutron source is shown in Fig. 1a. The optimized total calorimetric yield was 11 mA H^- at 11 keV (total normal drain for H^+ operation of ~ 1 A) from a 5.7-cm by 3.2-mm slot. Of this total, 1.2 mA was available as a focused ± 1.4 deg beam. The best performance was achieved using a 0.17 mm arc-to-slot separation. The use of traces of NH_3 with the source gas appeared detrimental. Judging by the above yield, the relative H^- plasma composition appears to be $\leq 1\%$ under our conditions, thus limiting the expected performance.

Indirect negative beam production depends upon the availability of intense low-energy ion beams and the relative cross sections for electron attachment to form negative ions. Work in controlled fusion research for the Baseball II experiment⁸ had produced a steady state multipole aperture source (MATS),⁵ yielding over 1 A of nominally D^+ (defined below) at 1.5 keV in a 6.3-cm-diameter beam (> 32 mA/cm² averaged, including 46% transparency) with a divergence of approximately ± 4 deg. Recent cross section measurements^{6,7} for H^+ (or D^+ of equal velocity) in alkali vapors yield the thick target equilibrium fraction F_{∞}^- shown in Table 1. To obtain high efficiency with the low-energy MATS, we chose to use cesium. The predicted negative ion yield as a function of cesium cell thickness for incident D^+ or D^0 beams is shown in Fig. 2. For a cell thickness of 2×10^{15} cesium atoms/cm³ the

Table 1. Predicted equilibrium D^- fraction.⁶

Vapor	Optimum D^+ energy, keV	F_{∞}^-
Na	~ 7	0.12
K	~ 3	0.14
Cs	1.5	0.21 ± 0.04

calculated yield is 0.2. Also, since conversion is through D^0 formation, the D^- can be swept out and the D^0 beam passed through subsequent cesium cells, for higher net conversion to D^- (limited by scattering an estimated ~ 0.2 deg per cell,² and complications in D^- optics).

The experimental arrangement for the initial D^- tests is shown in Fig. 1b. Measurements were made of the $\pm$ beam components as a function of cell thickness (cesium oven temperature). The total nominal D^+ beam available through a system of 6.3-cm-diameter cell apertures on a 6.3-cm-diameter target located 95 cm from the source was 200 mA calorimetric. This yielded a maximum total D^- signal of 50 mA electrical or 42 mA calorimetric (explained in Table 2). Figure 3 shows comparative traces of the incident and emergent species in arbitrary units for mass calibration purposes. The amplitudes of the raw data require substantial correction for analyzer sensitivity (background gas, charge exchange, stray magnetic fields, and secondary emission coefficient). Table 2 summarizes the

Table 2. Detailed mass and energy analysis of nominal incident D^+ beam and emergent products.

Incident nominal D^+ beam composition, keV	Emergent beam (optimum cesium)
110 mA D^+ (1.5)	~ 32 mA D^- (1.5 keV)
30 mA D_2^+ (1.5)	~ 18 mA D^- (0.75 keV)
6 mA D_3^+ (1.5)	~ 1 mA D^+ (1.5 keV)
~ 40 mA D^0 (1.5)	trace D^- (0.5 keV)
~ 7 mA D_2^0 (1.5)	trace OD^-
~ 14 mA D^0 (0.75)	149 mA equiv D^0 and D_2^0
Total nominal D^+ beam 200 mA equiv.	Total 50 mA D^- electrical and 42 mA calorimetric (as part of D^- not at 1.5 keV)

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a. Direct extraction from a calutron-type ion source

b. Cesium vapor cell for electron attachment after magnetic focusing.

c. Cesium vapor cell for electron attachment without magnetic focusing.

Fig. 1. Test stands for negative ion production.

Fig. 2. Beam fractions (F^+ , F^0 , F^-) computed as functions of cesium cell thickness for 1.5 keV incident D^+ and D^0 beams.

Fig. 3. Magnetic analysis of neutrals and negative ions produced in a cesium vapor cell at 1.5 keV (raw data). The horizontal scale is proportional to $(m \cdot B)^{1/2}$.