IEEE Transactions on Nuclear Science, Vol. NS-26, No. 3, June 1979

POLARIZED ^{3}He ION SOURCE FOR A CN VAN DE GRAAFF

R.J. Slobodrian, C. Rioux and R. Pigeon
Université Laval, Département de Physique
Laboratoire de Physique nucléaire, Québec G1K 7P4, Canada

SUMMARY

It is shown that it is possible to produce directly in an R.F. ion source 260 nA of $^3He^+(2S)$ ions, which can be subsequently polarized by a Lamb Shift method. The ion source has to operate with a low extraction voltage gradient to avoid quenching of the metastable 2S state. It is possible to estimate a final on target current of 100 nA of polarized $^3He^{++}$ ions with 70% polarization utilizing the Sona adiabatic transition and strong field ionization.

INTRODUCTION

The interest of the development of polarized ^{3}He ion sources has been discussed before [1,2] and recently one type based on the Lamb shift method has become operational[3] yielding on target, after cyclotron acceleration, 0.15 nA with 38% polarization. An atomic beam method source producing polarized protons and deuterons has been successfully implemented for use with a 7 MV CN van de Graaff, despite the known difficulties within a H.V. terminal [4]. Hence we have pursued a study concerning the construction of a ^{3}He polarized ion source for such a machine [5]. The scheme used at the University of Birmingham [3] is based on the production of a $^3He^{++}$ beam in a primary ion source and subsequent capture of electrons in a gas canal in order to produce the metastable $^3He^+(2S)$ ions. Considerable simplification can be achieved if it were possible to produce the $^3He^+(2S)$ ions directly from a primary ion source, instead of the above mentioned two stage method.

Direct $^3He^+(2S)$ production in a primary ion source

The basic idea comes from the equilibrium equation of ions in the plasma

$$^3He^0 \rightleftarrows {}^3He^+ \rightleftarrows {}^3He^{++}$$

The $^3He^+$ population will consist of ground and excited states. The 2S state is metastable with a lifetime of 2×10^{-3}s and therefore there will be a stable population of $^3He^+$ ions in that state from the electron capture of the $^3He^{++}$ ions from the decay of higher excited states of $^3He^+$ to the 2S state or from inelastic collisions of electrons and ions. Figure 1 shows the level scheme of $^3He^+$ relevant to the ion source.

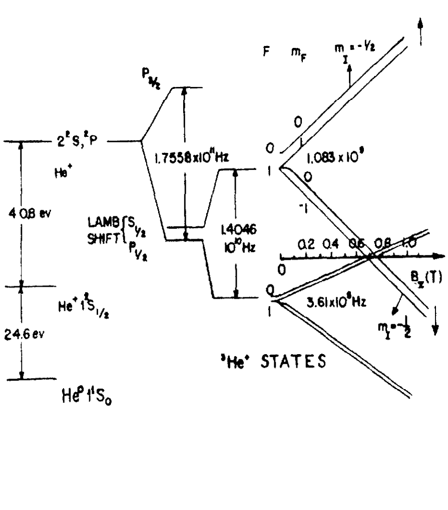

Fig. 1.- Level scheme of $^3He^+$ states.

Axial symmetry is usual in RF ion sources. It is also common to operate them with an axially symmetric magnetic field between 0.05 and 0.1 T, which produces a Zeeman splitting of states as shown in Fig. 1. Taking into account the dependence of the lifetime of the $^3He^+(2S)$ state on the electric field gradient and Zeeman splitting [6] it is possible to foresee that, using low extraction voltage gradients, in the range of 10 Vcm^{-1}, a significant fraction of $^3He^+$ ions can be obtained in the 2S state.

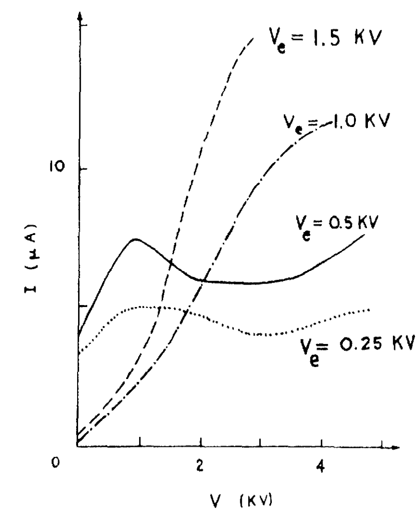

Fig. 2.- $^3He^+$ current from the ion source as a function of the gap-einzel lens voltage for different values of the extraction voltage V_e.

Figure 2 shows the output of magnetically analyzed $^3He^+$ beam obtained from the ion source. Particularly important are the curves for V_e=0.25 kV and V_e=0.5 kV, which correspond to gradients between 10 and 20 V cm^{-1}. We have performed a series of experiments in order to determine and optimize the $^3He^+(2S)$ current, and its fraction with respect to the total current of $^3He^+$ ions. Preliminary, measurements were carried out following the method of preferential ionization of Karban, Oh and Powell [7] and encouraging results were obtained [8]. However, it was felt that a direct measurement of photon yield from the quenching of the 2S state was preferable. Such photons lie in the far UV region, at 304 Å, and special techniques are required.

Figure 3 shows a horizontal plane projection of the experimental set-up in its final form. The beam from the ion source is subject to a 30° magnetic analysis and focussing is achieved by a gap-einzel lens arrangement, producing a beam with about 50 mm mrad phase space at 4 KeV. A gas canal is used for calibration purposes as explained below. The McPherson monochromator is used to measure the frequency spectrum of photons emitted in the quenching region, by automatic rotation of the diffraction grating. Photons are detected with a Bendix channeltron. The photon pulses are accumulated on a multichannel analyzer which sweeps uniformly through the storage channel while the monochromator sweeps the frequency at constant speed. The

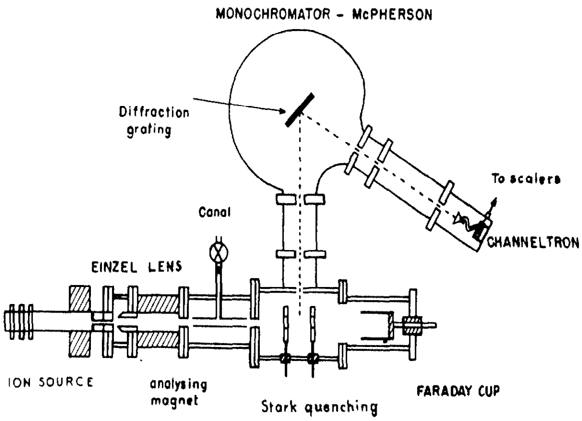

Fig. 3.- Experimental set-up for the measurement of the yield of 304 Å photons from the $^3He^+$ beam.

analyzer produces thereby a photon spectrum histogram. The system was calibrated producing firstly $^3He^+(2S)$ ions via the electron capture by a $^3He^{++}$ beam at 30 keV. This process takes place in the gas canal shown in figure 3. Both hydrogen and nitrogen gas was used. Electrodes with a gradient of 4 kV cm^{-1} produce the quenching of over 95% of the metastable ions at the corresponding velocities. We have verified that the photon spectrum peaks at 304 Å, as it should from quenching of the 2S state. The background was small, less than 7%. The gas flow was varied and an optimum yield was obtained, corresponding to .30 mTorr cm as established by Shah and Gilbody [9] for the maximum electron capture yield. Using their values it is possible to convert the photon yield into absolute $^3He^+(2S)$ current. It is also possible to perform a measurement of the integral of the photon spectrum by placing the diffraction grating at a total reflection angle, in such case it suffices to scale the channeltron pulses. Turning off the quenching field a measure of background is obtained. It is evident that, in view of the Stark effect quenching and the dependence of the metastable ions on the electric field gradient and Zeeman splitting, [6] the optimum production of $^3He^+(2S)$ ions should be found for modest extraction voltages and gap-einzel lens gradients. We have obtained a photon spectrum from the $^3He^+$ ion source produced beam, and found again a peaking at 304Å, proving the presence of ions in the 2S state. Subsequently, measurements were carried out in the total reflection condition, yielding directly the integral of the photon spectrum, with and without quenching field, in order to subtract background. Fig. 4 shows results of our measurements close to optimum conditions for $^3He^+$ (2S) ion production. The current reaches a maximum of 260 nA, this being 4.5% of the total $^3He^+$ current.

A lower extraction voltage of 0.25 kV produces also a satisfactory yield.

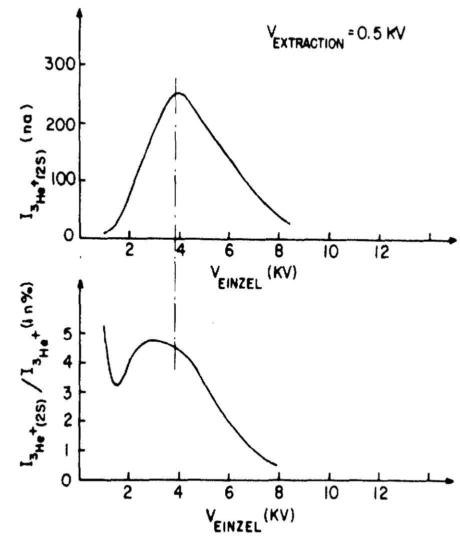

Fig. 4.- $^3He^+(2S)$ ion current and percentage to total current at V_{ext} = 0.5 kV as a function of gap-einzel lens·V.

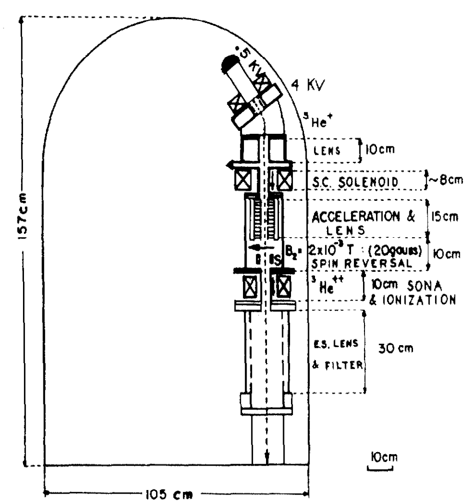

Fig. 5.- Schematic diagram of the polarized ion source

Sketch of the polarized ion source

The $^3He^+$ (2S) ions can be polarized in electron spin by quenching of unwanted Zeeman components at a magnetic field of 0.7T there is degeneracy of the two lower S states with the upper P states, as shown in Fig. 1. A modest superconducting coil can achieve such a field and a small static electric field would depopulate those components by transition to the 2P-1S states. Figure 5 shows graphically all the systems within the H.V. terminal.[3] After restoration of the hyperfine coupling, the $^3He^+(2S)$ ions would have a theoretical polarization of 50%. With the Sona [10] adiabatic transition and strong field ionization the theoretical polarization can be boosted to 100%, and we plan to incorporate it in our source.

Acknowledgements. We wish to thank our colleagues atomic physicists R. Drouin and E. Knystautas for their invaluable help with the far UV measurements, and the staff of the van de Graaff Lab. for their very keen interest and involvement.

1. J.B.A. England, Techniques in Nuclear Structure Physics (Macmillan, London, 1974)
2. W.E. Burcham et al. Nucl. Instr. and Meth. 116, (1974)
3. K. Allenby et al. Exper. Suppl. 25, 867 (1976)
4. T.R. Donoghue et al. Exper. Suppl. 25, 840 (1976)
5. Proposal to NRC Canada, van de Graaff Laboratory, Université Laval (1977), unpublished.

6. W.E. Lamb and M. Skinner, Phys. Rev. 78, 539 (1950).
7. O. Karban, S.W. Oh and W.B. Powell, Phys. Lett. 31, 109 (1973).
8. Polarized Ion Source Project, Progress Report, van de Graaff Laboratory, Université Laval, January 1978, unpublished.
9. M.B. Shah and H.B. Gilbody, J. Phys. B7, 256 (1974).
10. P.G. Sona, Energia Nucleare 14, 295 (1967).
11. R.J. Slobodrian, C. Rioux and R. Pigeon (to be published).

APPENDIX

The separation of $^{3}He^{++}$ from $^{3}He^{+}$ ions is simple after acceleration at the analyzing magnet. In view of the experience of the Birmingham group [3], the yield curves of Shah and Gilbody [9] and the simplicity of acceleration in a van de Graaff accelerator, without injection and extraction difficulties, the polarized $^{3}He^{++}$ beam intensity on target should be 20% of the $^{3}He^{+}(2S)$ ion flux, that is close to 100 nA, with a polarization of 70%. Figure 6 shows details of the ion source assembly at the time of this writing. However, it now appears that promising simplifications of the ion source are possible, permitting the direct production of $^{3}He^{+}(2S)$ ions with spin polarization at the RF ion source, using an axial field of 0.3T and the field emission of electrons at the corresponding cyclotron frequency [11].

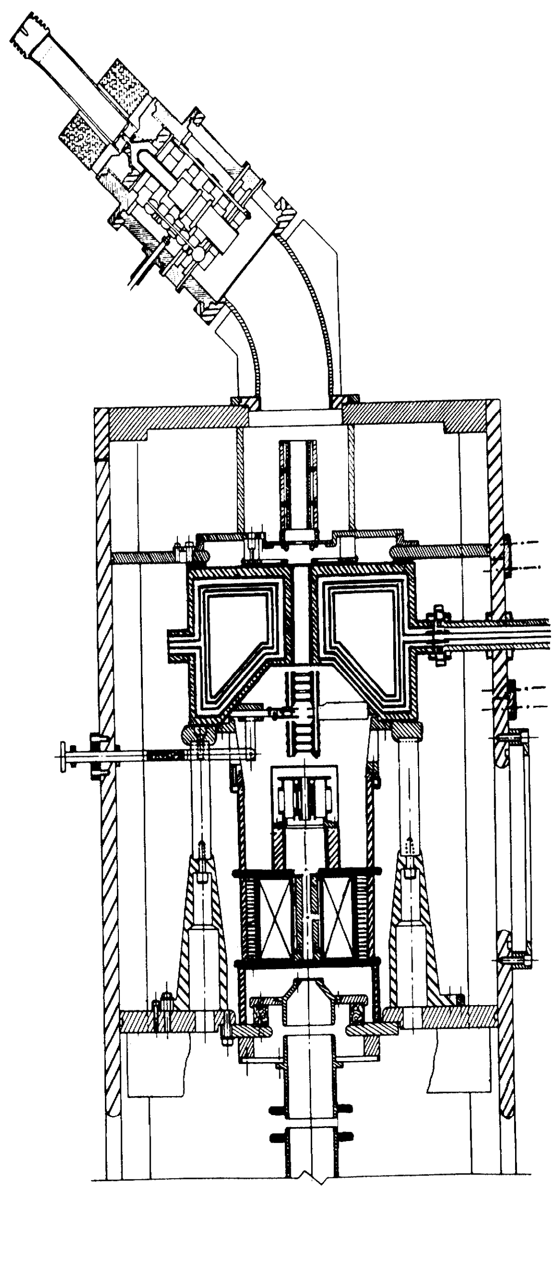

Fig. 6.- Detailed design of the polarized $^{3}He^{++}$ ion source corresponding to the schematic of Fig. 5-