INTENSE POLARIZED ^{3}He ION SOURCE

R.J. Slobodrian, R. Labrie, R. Bertrand, R. Lapointe, L. Pouliot, G. Pigeon, C. Rioux, J. Giroux, J.-F. Meunier and R. Roy
Université Laval, Département de physique, Laboratoire de physique nucléaire
Québec, G1K 7P4, Canada

Abstract

This source is based on the atomic polarization of the 2^3S_1 metastable state of the neutral atom. A version suitable for operation on the high voltage terminal of a CN Van de Graaff has been constructed, bench tested and installed in the terminal of a 7.5 MV machine. The polarization of the atomic beam is higher than 90%. It is now fully operational and a current of $^3He^+$ of 300 nA has been measured after acceleration.

1. Introduction

The preliminary work on this source has been described in the literature [1] in some detail. The principle of operation of the source is common to other atomic beam sources: selection of hyperfine components by an inhomogeneous magnetic field (multipole). The difference resides in the use of atoms in an excited metastable state [2]. These are produced by a cold cathode discharge on a helium flow defined by a nozzle and a skimmer. Thus a beam of thermal metastables mostly in the 2^3S_1 state is produced and subsequently manipulated, with usual techniques in atomic beam sources. However, the challenge is to adapt the source to the hostile environment inside the HV terminal of a CN Van de Graaff, operating nuclear high pressure (10 atmospheres).

2. Review of the stages of the source

There are five stages in the production of $^3He^+$ polarized ions in the present source:

1) Production of metastables of He
2) Stern-Gerlach selection of hyperfine components
3) Radiofrequency transition
4) Ionization in a strong B
5) Spin rotation.

The cold cathode discharge produces a flux of 6×10^{15} $Ns^{-1}sr^{-1}$ atoms. The beam is defined by a

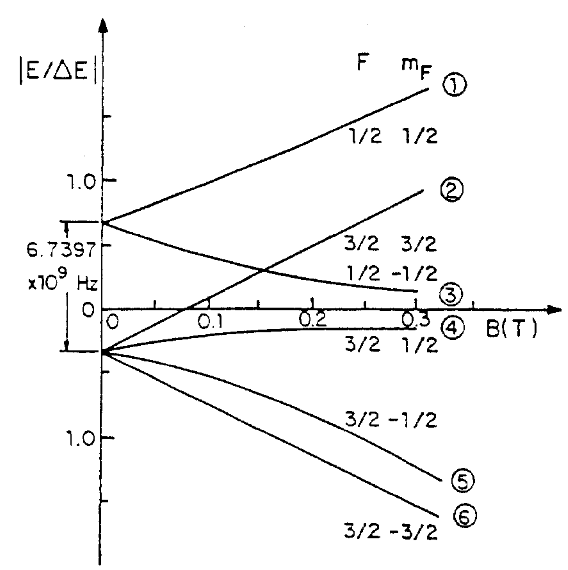

Fig. 1 Breit-Rabi diagram of hyperfine components.

0.17 mm ϕ nozzle and 0.6 mm ϕ skimmer, the energy is 0.085 eV, adequate for atomic beam techniques. The system (atomic electrons + nucleus) for the 2^3S_1 metastable state of ^{3}He yields a total angular momentum $\vec{F}=\vec{J}+\vec{I}$, where the symbols have the usual meaning. Figure 1 shows the six hyperfine components as a function of magnetic field. Stern-Gerlach selection of components ① and ② is effected by a sextupole with its poles in the sequence S-N-N-S-N-N, i.e. producing a field with quadrupole characteristics for small amplitudes. Figure 2 shows the metastable source and sextupole. The latter is a "short" sextupole 14 cm in length with a tapered section and a straight section, as shown in Fig. 2. The RF transition (adiabatic) following Abragam and Winter [3] transforming ① into ③ and ② into ⑥. In a strong B components ③ and ⑥

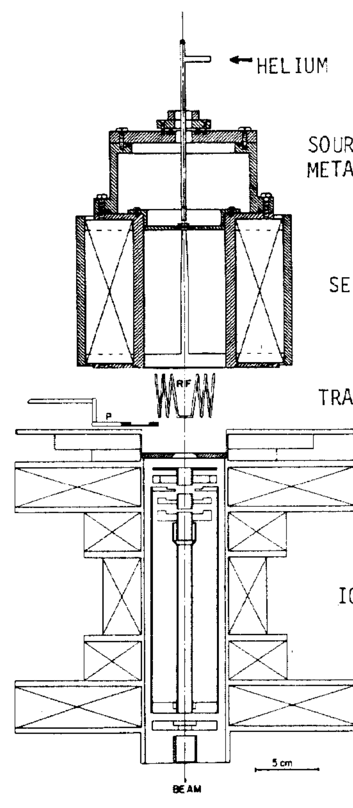

Fig. 2 Schematic of the source components

yield a nuclear polarization of 100% (theoretical). The radiofrequency field is generated by coils, perpendicular to the beam direction at 30 MHz and the power injected is 45w. The transition, producing reversal of the polarization of the atomic beam, was complete and instantaneous, as determined using Stern-Gerlach deflection methods [4]. An electron bombardment ionizer at a field B=0.2T follows the RF transition region. It is inspired by the ANAC "superioniser", although its design differs in several important details. Firstly, the dimensions are considerably smaller (Fig. 2). The magnetic field is generated by coils tailored to the requirement of a uniform B with minimum weight. The ionisation region is 15 cm long. The ionisation

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efficiency for metastable atoms of He should be close to 30%. Fig. 3 shows a view of the glow of the ionizer from above. The atoms are singly ionized at the ionizer: $^3He^+$. Due to the difference in ionization energy between metastables and ground state atoms it is possible to discriminate the polarized atoms from the unpolarized background. Spin rotation is possible with a small magnetic field, around 10 gauss, which is provided by an electromagnet following the ionizer. Two

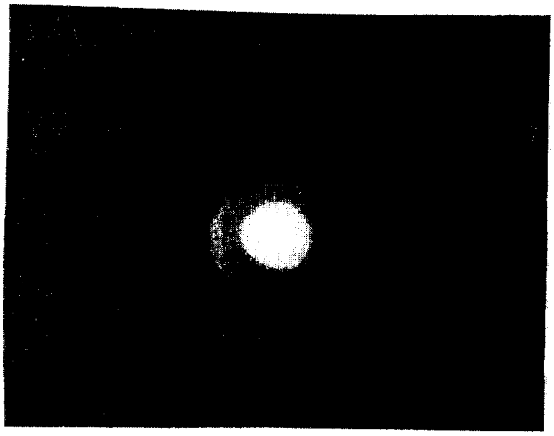

Fig. 3 Ionizer glow viewed from above.

pairs of electrostatic plates at 90° with respect to each other follow the spin rotation, permitting the centering of the beam in the accelerating tube. The mechanical, electrical and electronic components of the source have been all constructed at the workshop of the Van de Graaff laboratory. Fig. 4 shows the sextupole and its proud builders. Note that the coils are

Fig. 4 Sextupole magnet and builders.

outside the vacuum, where only the pole pieces are located. Although atomic beam techniques are well known and used for polarized ion sources of hydrogen isotopes and other atoms, in the present case all steps had to be checked and verified, as this source is the first of its kind. In this respect, the fact that metastables impinging on a metal produce an electric current due to electron emission, was of paramount usefulness in order to effect a diagnostics of beam selection, focussing and radiofrequency transitions.

3. Engineering details

Bench tests of the polarized ion source were completed in August 1984 with good success. Nevertheless the adaptation of the source to function within the terminal of a CN Van de Graaff, under a presence of ten atmospheres is by no means trivial nor straightforward. There are space and power limitations. The ^{3}He gas is expensive, hence it is necessary to recirculate and purify it. We believe that some original engineering solutions have been established in order to overcome then problems.

3.1 Gas injection to the metastable source and pumping

The system to feed the cathode discharge in order to produce the metastable beam is a closed loop which recirculates the gas. The region of the discharge is pumped by turbomolecular pump (Leybold-Heraeus) with a pumping speed of 360 ℓs^{-1} for air. The helium gas is recompressed and returned to the imput of the metastable source by a sealed mechanical pump (Alcatel-ZM 20122AH) with a 200 ℓ min^{-1} pumping speed. An activated carbon filter is placed after the mechanical pump. The injection pressure is 50 torr. The pressure is controlled by a piezoelectric valve. Additional gas is injected using a solenoid activated valve. The pressure in the discharge region is around 2×10^{-4} torr. At the exhaust of the turbo pump it is 0.2 torr. The tubing is made of stainless steel and the couplings (type KF) also.

A second turbo pump (same model as above) pumps the sextupole region, where a pressure of 3×10^{-6} torr is maintained. Its exhaust is sent via a molecular sieve filter to the head of the turbo pump at the metastable source. This arrangement is very efficient and the net flow of helium is in the range of a few cc per hour, less than in the operation of a conventional impolarized helium ion source.

A third turbo-pump with a mechanical pump is located below the ionizer and provides a vacuum of 3×10^{-6} torr at the head of the accelerating tube, whereas such region has normally a vacuum of 2×10^{-5} when pumped via the bottom of the tube. The exhaust of the mechanical pump is sent to a bottle with a capacity of 2.5 ℓ, sufficient for some 350 hours of operation.

The mechanical pumps are driven by belts coupled to the main belt axle in the HV terminal.

3.2 Cooling system of pumps and coils

It consists of a closed circuit with a pump, a heat exchanger and tubing transporting the cooling fluid to and fro the HV terminal. The pump (turbine type, Aurora CO_4) develops a flow of 2 Zℓ/min for a water column of 46 meters. The heat exchanger can be cooled with ordinary water from the mains or with refrigerated water. The cooling fluid is a silicone liquide (DC 200) with low viscosity, with a dielectric rigidity of 120 KV cm^{-1} cooling is provided for the three turbo pumps, the sextupole and the ionizer coils.

3.3 Turbomolecular pumps operation

These pumps located in the HV terminal require a three-phase power supply with 42 V at 750 Hz. The standard supplies from the manufacturer are inadequate for operation inside the terminal. It has been necessary to develop a supply that ocild be utilized reliably there. This consists of a Delco-Remy alternator, modified by lifting the rectifiers and connecting in star configuration the stator windings. Setting the rotation speed at 5625 t min^{-1} and adjusting the excitation voltage it has been possible to obtain the voltage and frequency required by the synchronous motors.

3.4 Electronics and controls

Ruggedized electronics is essential for operation inside the HV terminal, due to the transients provoked by sparks of the accelerator. Particularly vulnerable are silicon rectifiers. Firstly, circuits are enclosed in thick metal boxes, leads are fed through using capacitive connectors, and varistor voltage limiters have been developed in a redundant fashion in order to protect the circuits. Controls are selsyn driven variacs and pots. Switches are controlled by electromagnetic plungers. Readouts are digital and transmitted via optic fibers from the HV terminal to boxes outside the pressurized reservoir housing the machine.

4. Initial operation

The first full operation of the source on top of the terminal of the machine (open, unpressurized) was accomplished in December 1984. A current of $^3He^+$ of 50 to 100 nA was measured at the bottom of the accelerating tube, at about 10 keV energy. Fig. 5 shows the source as assembled on the terminal.

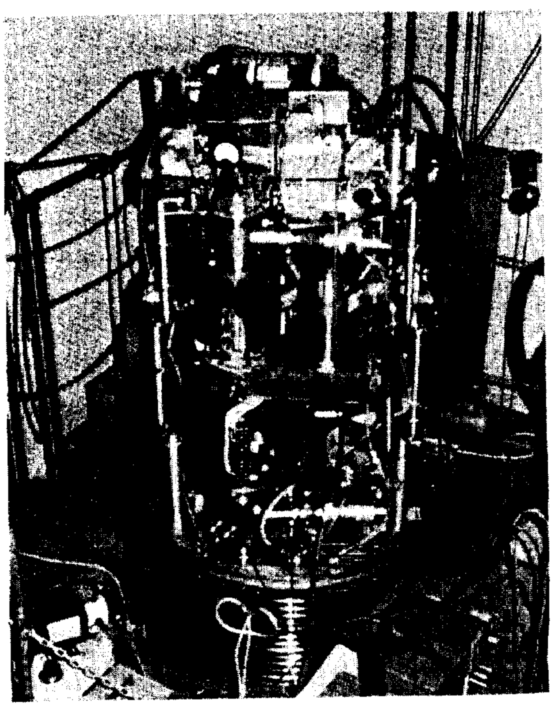

Fig. 5 Source installed on the terminal of the Van de de Graaff.

The operation inside the pressurized reservoir has encountered some problems due to the difficulty of diagnostics of leaks and the fact that the ensueing poisoning of ^{3}He gas in the recirculation loop destroys the metastable population.

A main valve separating the ion source from the accelerating tube remains to be installed and should aid significantly to improve leak hunting and reconditioning of source parts, like the metastable producing dicharge section, filters, tubings, etc.

The ion source beam optics at extraction has been improved and presently the current of $^3He^+$ at the bottom of the machine stands at 300 nA. Some preliminary measurements of asymmetries in $^2H(^3He,p)^4He$ before improvement of the beam optics indicate a high ^{3}He polarization, between 50 and 70%. These values should improve as the source and the accelerator enter into a stage of routine operation.

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References

[1] R. J. Slobodrian, R. Labrie, R. Lapointe, L. Pouliot, J. Giroux and Y. Gagnon, IEEE Trans. on Nucl. Sc. NS-30 (1983) 2731.

[2] R. J. Slobodrian, AIP Conf. Proceedings 69 (1983) 797.

[3] A. Abragam and J. M. Winter, C.R. Acad. Sc. 255 (1962) 1099, Phys. Rev. Lett. 1 (1958) 375.

[4] R. J. Slobodrian, J. Giroux, R. Labrie, R. Lapointe, Y. Gagnon and A. Singh, J. Phys. E.: Sci. Instrum. 16 (1983) 1162; J. Giroux, R. Lapointe and R. J. Slobodrian, J. Phys. E.: Sci. Instrum. 17 (1984) 957.