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8.10 Polarized ^{3}He Ion Source Based on a Metastable Atomic Beam

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This source is based on the use of a beam neutral metastable atoms of $^3He^*$ in the 2^3S_1 state[1] (with $\mu_F \cong 2\mu_B$), which have a very long lifetime (4166s), because the transition to the ^1S_o ground state is doubly forbidden. Polarized atomic beams of metastable He atoms are important in their own right for other fields of physics[2]. In order to obtain the polarization of the ^{3}He nucleus we have used magnetic multipole selection of hyperfine components (Stern-Gerlach method) followed by a RF transition and ionisation in a strong B field. Indicating the angular momentum of the ^{3}He atom by $\vec{F} = \vec{J}+\vec{I}$, where $\vec{J}$ and $\vec{I}$ are respectively electronic and angular momenta, the six Zeeman hyperfine components are represented by

$$|F=1/2,\ m_F=1/2\rangle = \sqrt{2/3}\,|m_J=1\rangle\,|m_I=-1/2\rangle - \sqrt{1/3}\,|m_J=0\rangle\,|m_I=1/2\rangle \quad (1)$$

$$|F=3/2,\ m_F=3/2\rangle = |m_J=1\rangle\,|m_I=1/2\rangle \quad (2)$$

$$|F=1/2,\ m_F=-1/2\rangle = -\sqrt{2/3}\,|m_J=-1\rangle\,|m_I=1/2\rangle + \sqrt{1/3}\,|m_J=0\rangle\,|m_I=-1/2\rangle \quad (3)$$

$$|F=3/2,\ m_F=1/2\rangle = \sqrt{2/3}\,|m_J=0\rangle\,|m_I=1/2\rangle + \sqrt{1/3}\,|m_J=1\rangle\,|m_I=-1/2\rangle \quad (4)$$

$$|F=3/2,\ m_F=-1/2\rangle = \sqrt{2/3}\,|m_J=0\rangle\,|m_I=-1/2\rangle + \sqrt{1/3}\,|m_J=-1\rangle\,|m_I=1/2\rangle \quad (5)$$

$$|F=3/2,\ m_F=-3/2\rangle = |m_J=-1\rangle\,|m_I=-1/2\rangle \quad (6)$$

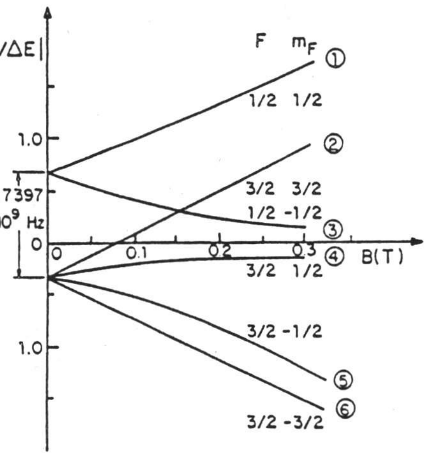

Fig. 1 Breit-Rabi diagram of hyperfine components

Fig. 1 shows the Breit-Rabi diagram of such components, the numbering corresponds to that of the equations components (1) and (2) selected by a multipole field. In a weak magnetic field they would yield a nuclear polarization (theoretical)

$$|P_n| = 0.33 \quad (7)$$

Using a transition of the Abragam-Winter[3] type, it is possible to transform components 1-2 into 3-6. The latter would produce a nuclear polarization (theoretical) $|P_n| \cong 1.00$ in a strong B field ($B \cong 0.2T$).

The source metastable atoms (Fig. 2) is of the cold cathode type, following the design of Fahey *et al.*[4]. The metastable flux is 6×10^{15} $\overline{ns}^{-1}$. The atomic beam is defined by a 0.17 mm ϕ nozzle and a 0.6 mm ϕ skimmer. Fig. 2 shows a schematic drawing of the sequence of operations: a) Metastable production, b) Stern-Gerlach selection of components, c) RF transition, d) Strong B ionization, Bench tests of the source were completed in August 1984 with good success. The adaptation in order to function within the terminal of a CN van de Graaff under 10 atmospheres pressure is by no means trivial nor staightforward. In addition ^{3}He is an expensive gas and it is necessary to recirculate it in a closed loop with adequate purification. There are three turbomolecular pumps and two mechanical pumps in the H.V. terminal in order to provide pumping in the stages a) through to d). Refrigerant liquid is conveyed to and from the terminal through heavy polyethylene tubing, the heat exchanger located at the base of the accelerator is cooled with freon. All the parts of the

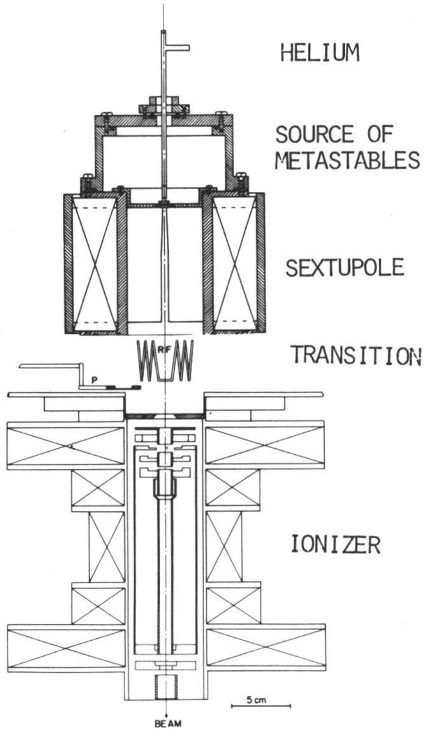

Fig. 2. Schematic of source components.

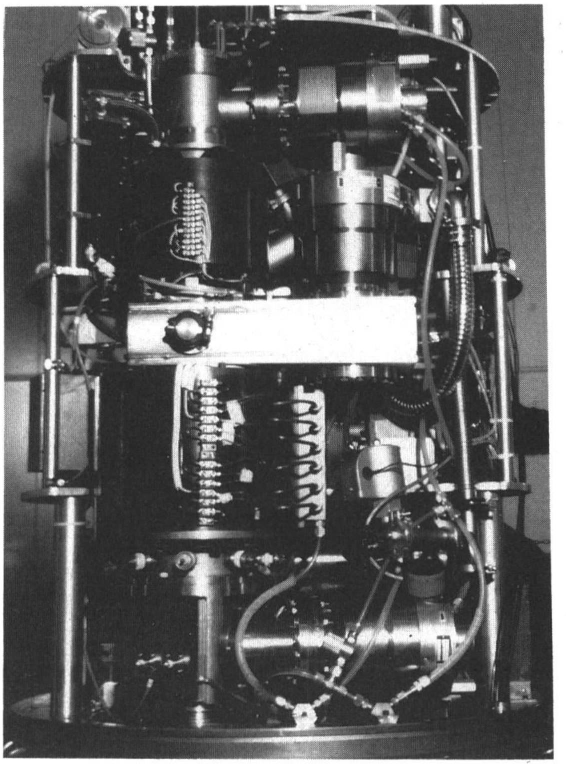

Fig. 3. Source installed on the van de Graaff.

polarized ion source have been built in house, including the electron bombardment ionizer. The sextupole is an electromagnet with a tapered gap over the initial 70 mm from 5 mm to 10 mm, and straight gap over the following 70 mm. It is polarized in a non-conventional way: N-S-S-N-S-S (N: north, S: south). It has proven to produce a selection with a gain of a factor of three in intensity. The maximum intensity of atomic beam recorded is 680 particle-nA. The polarization of this beam (in electronic spin) was determined by Stern-Gerlach deflection in a inhomogeneous dipole field: $P_Z \equiv 0.95$[5]. The RF transition is effected at 30 MHz and the injected power is 45 W. Reversal of the m_F value is instantaneous and complete[5]. The ionisation potential of the helium metastables is only 4.6 eV. This allows in an electron bombardment ioniser the discrimination against ground state helium atoms. The source has been operated inside the reservoir of the accelerator and preliminary values of nuclear polarization are between 50 to 70%. The maximum accelerated current stands at 300 nA of $^3He^+$. Fig. 3 shows a photograph of the source installed on the accelerator. Leaks of the insolation gas into the source under full pressure has been the major cause of delays during testing and commissioning of the source. A main valve has been added, permitting to isolate the region of the polarized ion source from the accelerating tube. This allows a better and quicker diagnostic and servicing of the source, while reducing significantly the down time of the machine.

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