IEEE Transactions on Nuclear Science, Vol. NS-30, No. 4, August 1983

POLARIZED ^{3}HE ION SOURCE BASED ON THE 2^3S_1 METASTABLE STATE

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Summary

This ^{3}He polarized ion source is based on the 2^3S_1 metastable atomic state. We produce an intense metastable beam, 6×10^{15}p.sec^{-1}.sr^{-1}, of energies between 0.07 and 0.1 eV, using a cold cathode discharge. The separation and focussing of Zeeman components ($F=\frac{1}{2}$ $m_F=\frac{1}{2}$) and ($F=\frac{3}{2}$ $m_F=\frac{3}{2}$) is effected with a sextupole of variable gap. An adiabatic RF transition enhances the nuclear polarization (theoretical) to 100%. Most design parameters of the source are now frozen for operation inside the H.V. terminal of a CN van de Graaff, but the source is of universal use in (+) ion accelerators.

Introduction

The development of polarized ^{3}He ion sources, despite their intrinsic interest[1)], has been slow[2)]. There is at present only one polarized ^{3}He beam at the Birmingham cyclotron[3),4)], produced by the Lamb shift method, and the recent performance is rather modest: 2 nA with 70% polarization. This method is based on the $^3He^+(2S)$ state, with a lifetime of 2×10^{-3}s. This state is easily destroyed by collisions and by perturbing electromagnetic fields.

A new scheme has been proposed recently[5)] using the 2^3S_1 state of the neutral atom, which is very long lived[6)], the transition to the ground state being doubly forbidden. An atomic beam of thermal metastables can be subjected to fairly standard techniques used with hydrogen or deuterium atoms, *mutatis mutandis*. Very high densities of metastables can be achieved at present. However, in our particular case we are constrained to the power and space available in the H.V. terminal of the Laval CN Van de Graaff. A basic criterion of economy has dominated our approach to the realization of this polarized ion source. There is a basic advantage in dealing with metastables as compared with hydrogen atoms, it is that one can derive an electric current from them, and hence diagnostics becomes simple.

Detection of metastables

The possibility of using the emission of electrons by a metallic surface upon contact by metastable noble gases was known since the forties. However, the quantitative mesure of secondary electron emission coefficients are rather recent. For a stainless steel gas contaminated surface the coefficient is $\gamma(2^3S) = 0.74\pm0.09$ [7)]. The mechanism of emission is simple: an electron from the metal surface is captured and forms the state 1^1S_0 with the 1s electron. The excess energy is spent in evaporating the 2s electron. In order to emit properly these electrons from the surface it is necessary to add an electric field. A gradient of 20 V/cm suffices for these purposes. We have constructed our metastable detectors using a cylindrical geometry, with provision for good pumping, using both stainless steel and copper (the latter differs little in its conversion coefficient). In what follows, however currents are quoted as measured directly, without using conversion coefficients.

Metastable production and velocity measurement

The ideal source of metastables is one producing low velocity (thermal) atoms with high intensity. Open avenues for such objectives that were explored are: 1) Deceleration and neutralisation of a $^3He^+$ beam, 2) Direct production a) in a RF discharge, simple and double. b) In a duoplasmatron source. 3) Electron beam production with a cold cathode discharge. For the purpose of measuring the velocity of the metastable beam we have built a chopper with five 8^0 slots on an aluminum disk. The rotation speed was slightly over 20,000 r.p.m. The details of this chopper may be found elsewhere[8)]. The reference signal was provided by an electroluminescent diode and a photodiode. The particle signals were obtained from the metastable detector. Both signals were displayed

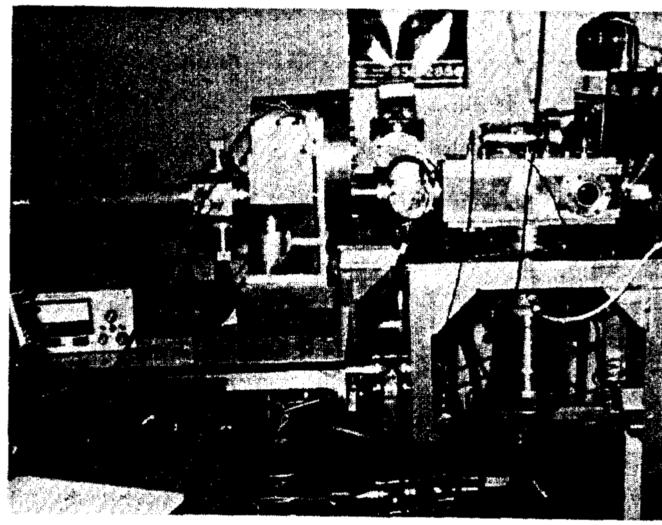

Fig.1 Chopper and cold cathode source.

using an oscilloscope and recorded with a polaroid camera. A full account of the results for all the studied methods of metastable production is given in Ref.8. In the language of atomic beam technology 1) and 2) produced "hot" beams (i.e. 5 eV). The third method, producing metastables by electron bombardment, was used already long time ago by Holt and Krotkov[9)], in their determination of the cross section up to 23 eV incident energy. After this pioneering work there has been a host of experiments using electron or ion bombardment for the production of metastables. Fahey *et al.*[10)] and Rundel *et al.*[11)] produce beams of metastables around 0.07 eV by electron bombardment of an atomic beam. The fluxes cited are 3.5×10^{14} and 2×10^{14} sr^{-1}s^{-1}. The simplest method in that of Ref.10, whose authors used a cold cathode discharge with a current of 3 mA. We have constructed a similar discharge system which, after some improvement in the materials, like using quartz tubing and tungsten cathodes we have produced with a discharge of 30 mA, a flux of 6×10^{15} sr^{-1}s^{-1}. The set up for the measurement of the velocity is shown in Fig.1, together with the cold cathode metastable source at right. Fig.2 shows the discharge in detail. The scope display is shown in Fig.3. The path length is 60 cm the distance between the square reference pulses correspond to 600 µsec. In stable operation the flow of helium for the production of metastables is

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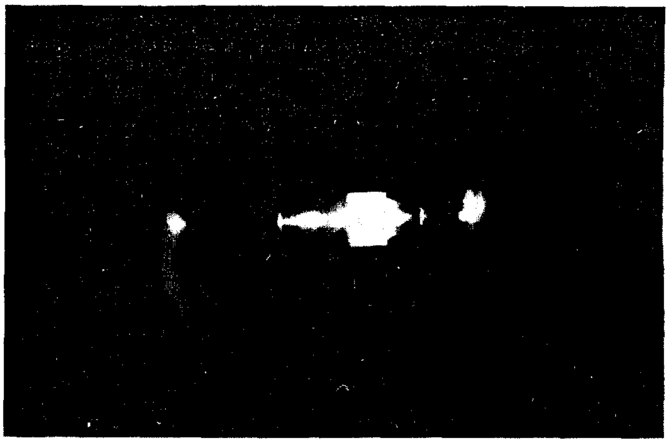

Fig.2 Detail of the cold cathode discharge.

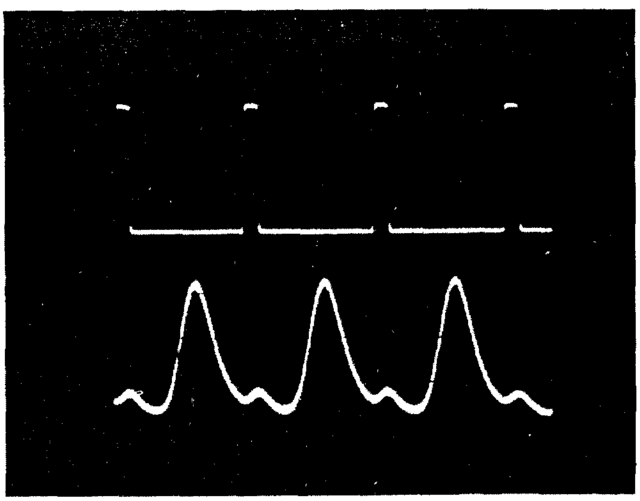

Fig.3 Time of flight pattern from the metastable beam. The square pulses are the reference signals, spaced 600 μs.

30ℓ at NTP per day. However, we have recirculated the gas in a closed circuit without any appreciable loss in intensity of metastable production. The metastable source is practically ponctual and thus criteria of geometrical optics are applicable to the formulation and analysis of trajectories.

Stern-Gerlach selection and R.F. transition

The coupling of nuclear and atomic moments yield six hyperfine components split in a magnetic field. Sextupole selection will focus two of them (strong field sextupole)

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

and

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

Fig.4 shows an example of sextupole focussing of the metastable beam with a 20 cm long magnet. The definitive sextupole is a 14 cm long variable gap magnet.

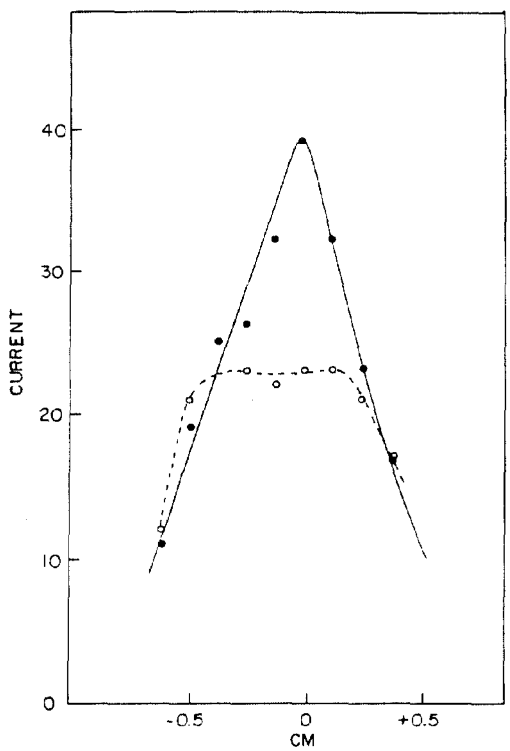

Fig.4 Metastable intensity with respect to the beam axis. The solid line is with the sextupole on, the dashed line with the sextupole off.

An adiabatic transition following Abragam and Winter[12] permits to transform (1) and (2) into the $|F=1/2,\ m_F=-1/2\rangle$ and $|F=3/2,\ m_F=-3/2\rangle$ components. The latter, if ionisation takes place in a strong magnetic field (.2T) yield 100% nuclear polarization, as shown in Ref.5 and 6.

Pumping System

It consists of turbomolecular pumps Leybold-Heraeus having a speed of 360 ℓ s^{-1} over an extended pressure range. The gauge pressures are 10^{-4} torr in the discharge region and 3×10^{-6} in the sextupole region. Both turbo - pumps are backed by mechanical pumps.

Ionisation

The ionisation potential of metastables is quite low, 4.6 eV and the cross section ions rises quickly to 6×10^{-16} cm^2. The efficiency of an electron bombardment ioniser for this case should come close to 12% according to ionization potential scaling laws[13,14]. Taking into account the high cross section with respect to the ionization of hydrogen, the efficiency is still higher. Excellent discrimination with respect to background is expected.

Photoionisation is also feasible in this case, using mean UV radiation, for example the light from the low pressure Hg discharge. The cross section near threshold is high: 7×10^{-18} cm^2 [15], and corresponds well to the Hg resonance line at 2537 Å. In this case discrimination from background would be absolute.

Conclusion

The ion source is under construction according to the drawing in Fig.5. Ionisation to $^3He^{++}$ will be effected via stripping with a 12 μg C foil ahead of the Wien filter, at 50 keV. The metastable beam after the Stern-Gerlach and RF transition has an intensity close to 10^{13} p.s^{-1} and a current of $^3He^+$ of 100 nA seems assured with the ionisation efficiencies at hand. The source is scheduled to be installed in the terminal of the Van de Graaff in 1984.

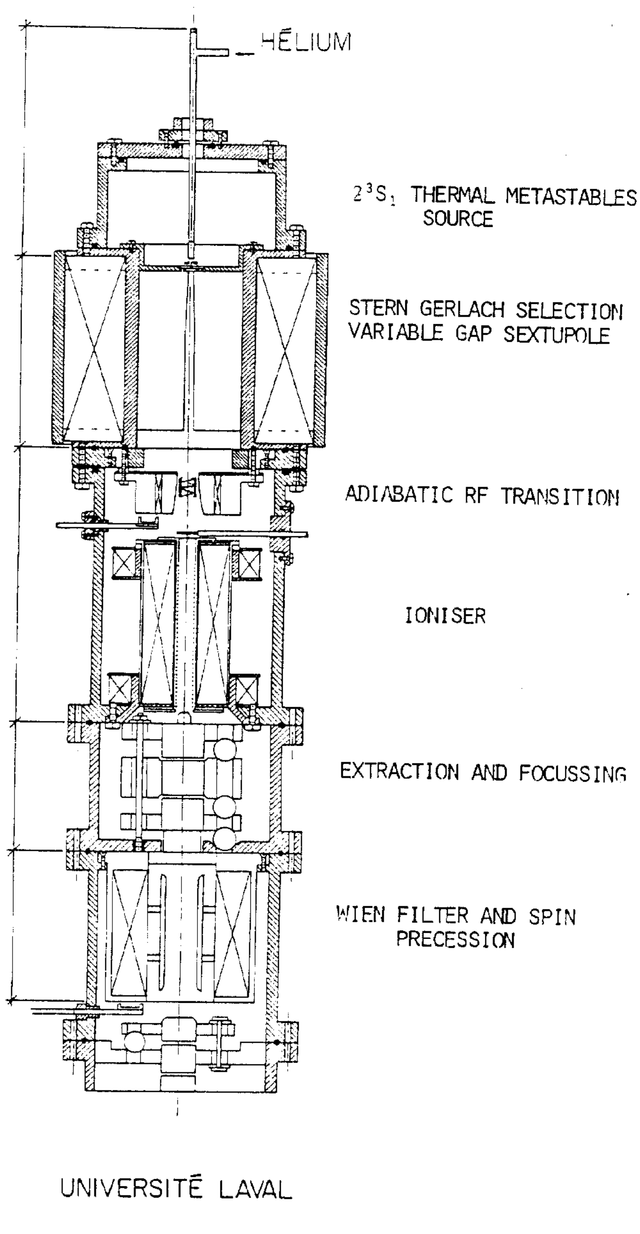

Fig.5. Layout of the source

Acknowledgements

The authors are indebted to the Faculté des Sciences et de Génie of Université Laval for the support in the initial stages of this project and to CRSNG Canada for a grant to construct the polarized ^{3}He ion source.

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