THE DARESBURY POLARIZED HEAVY ION SOURCE

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Abstract

The Polarized Heavy Ion Source at the Nuclear Structure Facility in Daresbury is described. The source produces polarized beams of ^{6}Li, ^{7}Li and ^{23}Na using the atomic beam method. The tensor polarization (t_{20}) on target of the ^{23}Na and ^{7}Li beams have been measured as 0.20 and 0.40 respectively. An upgrade, to increase the polarization of the beams, is in progress. The upgrade, which involves replacing the existing RF transitions with a laser system to optically pump the atomic beam, will result in a doubling of the polarization.

Introduction

The Daresbury Polarized Heavy Ion Source [1] (PHIS) is very similar in design to the polarized source at Heidelberg [2]. Originally funded in 1983, ^{23}Na was the first beam accelerated in May 1987. More development work followed with ^{7}Li being accelerated in November 1988 and ^{6}Li in January 1990.

Considerable effort was applied to the design of the sodium oven to improve reliability of operation. The results of this work together with a description of the present RF system and the planned upgrade are reported below.

Principle of Operation

The Daresbury Polarized Heavy Ion Source uses the atomic beam method to generate the polarization.

An atomic beam of the alkali metal is produced by heating the metal in a sealed oven to a temperature above its boiling point. The metal leaves the oven through a nozzle in the form of a jet. This jet passes through a quadrupole magnet that acts as a Stern-Gerlach magnet (figure 1) focusing the atoms with electron spin $m_J = + 1/2$ while those with $m_J = - 1/2$ are defocused and lost to the system. The electron spin polarized beam enters a series of RF transitions in which the electron spin polarization is transferred to the nucleus via the hyperfine interactions.

After the RF transition region the atoms strike a hot tungsten filament on which they are ionized to the + 1 charge state. The filament is heated to approximately 1250°C and is held at a high voltage (16 kV for Na and 4.5 kV for Li) to accelerate the positively ionized beam. The filament is in a strong dipole magnetic field (> 2 kG) to preserve the polarization during ionization.

The extracted beam is bent electrostatically 90° by a spherical condenser and passed through caesium vapour in the charge-exchange canal where the ions pick up two electrons to form negative ions for injection into the tandem accelerator. The canal is placed in a strong solenoidal magnetic field (1.2 kG) to preserve the polarization during the charge-exchange process.

The entire canal assembly is electrically isolated, enabling it to be raised to a negative voltage of up to - 5 kV. The normal operating voltage is - 2 kV for Na and - 0.5 kV for Li, which further accelerates the negative ion beam only, allowing it to be velocity separated from the positive ion beam in the Wien filter. The filament voltage and the charge-exchange potential are chosen to optimize the charge-exchange process which has an efficiency of approximately 3%.

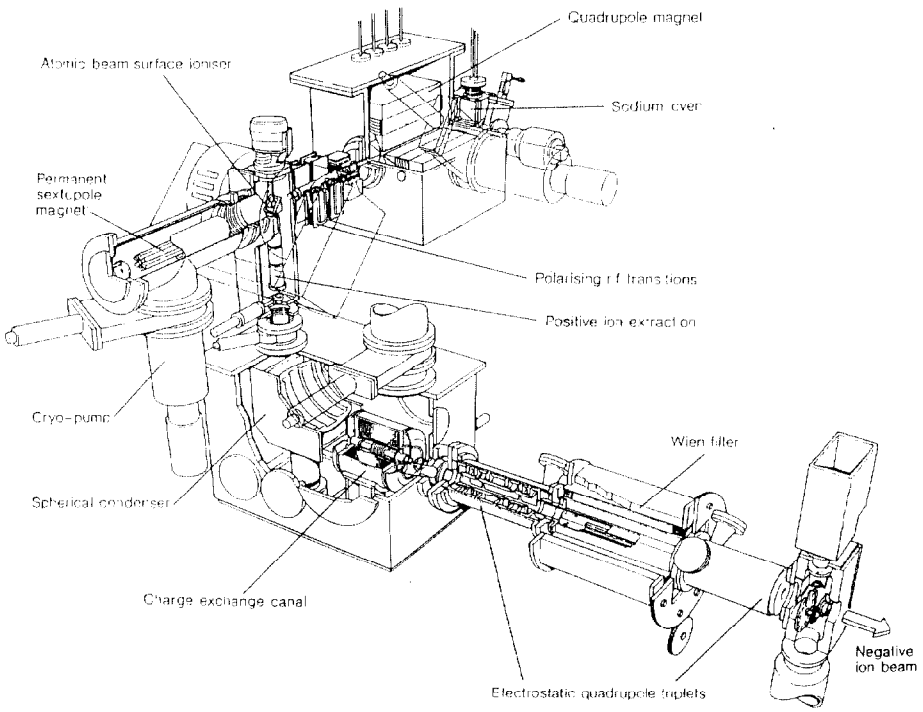

Figure 1. Cut away view of the Daresbury Polarized Heavy Ion Source.

The polarized negative ion beam enters a Wien filter, situated between two quadrupole triplet focusing elements. Using the magnetic field of the Wien filter, the nuclear spin-symmetry axis of the nucleus can be precessed to the desired direction for injection into the tandem. The Wien filter has been designed to rotate almost 360° to allow any direction of the symmetry axis to be chosen.

Lastly the source diagnostic facility houses the Beam Foil Spectroscopy [3] apparatus. This is used when investigating the polarization of the beams off-line. The beam foil spectroscopy method was used extensively for the commissioning of new beams but is not used in normal operation.

The Ovens

The source uses two different types of oven to generate the atomic beam. The ^{6}Li and ^{7}Li beams are generated using a single chamber oven that was designed and manufactured by Heidelberg [4]. In this oven, lithium metal is sealed in a container with a 0.8 mm nozzle. When the oven chamber is raised to approximately 800°C, lithium is forced out of the nozzle in the form of a jet. The beam is collimated with a heated skimmer (diameter 1.5 mm) and a heated collimator (diameter 3.0 mm) to give a well defined beam. The excess beam that strikes the collimator is lost on the walls of the vacuum chamber.

The maximum positive beam from the oven, measured in a Faraday cup after the ionizer, is 17 μA. The typical intensity maintained for extended periods (6 days) is 3 μA which produces - 30 nA of negative beam after the charge-exchange process.

The Na beam is generated using a two chamber recirculating oven (Figure 2) originaly proposed by Witteveen [5]. Sodium metal is loaded into a boiler chamber which is then raised to approximately 410°C. The sodium is forced out of a nozzle 0.75 mm diameter to form a jet. The beam is collimated by a 1.6 mm diameter heated collimator kept at 130°C, which is just above the melting point of sodium. The beam striking the collimator is collected in a funnel and returned to the main boiler chamber by means of a return pipe. This greatly increases the running time of the oven. Typical running time for the oven is 5 days with beam current of approximately 7-10 μA of +Na, which corresponds to - 100 nA of -Na after charge-exchanging the positive beam.

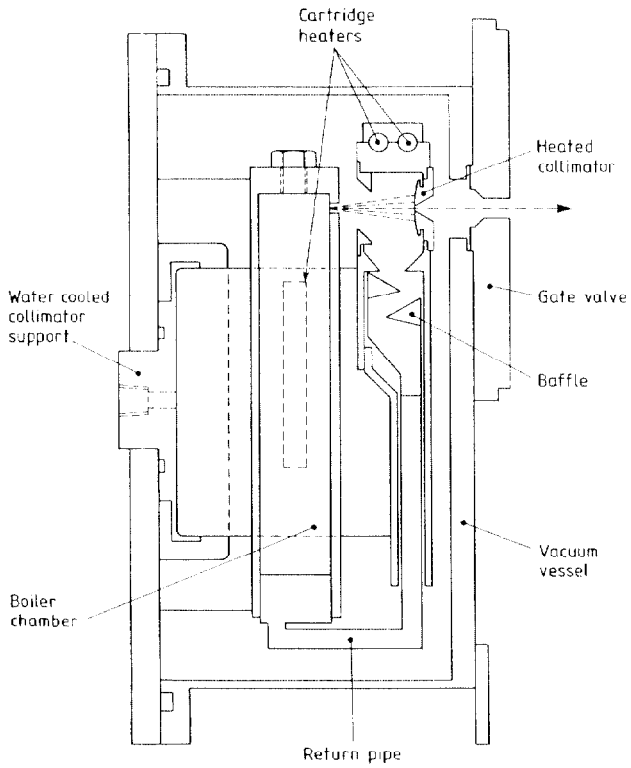

Figure 2. Assembly drawing of the sodium oven.

Keeping the collimator temperature low is important to limit the amount of sodium vapours escaping from the collimator chamber. These vapours tend to cause thermal shorts putting a large load on the cartridge heaters. To avoid these thermal shorts the colimator chamber is stepped in below the funnel (figure 2) to widen the gap between it and the oven and a baffle is added in the funnel to trap the vapours.

RF Transitions

The RF transitions consist of one weak-field transition for the vector polarization and two strong-field transitions to produce tensor polarization with opposite signs.

The vector polarization is produced by the interchange of the population of the m_F state with the $-m_F$. The weak-field transition operates at 10 MHz for all three nuclei.

To produce the tensor polarization a strong-field transition is induced. For ^{7}Li and ^{23}Na the transitions induced are either the 2-8 transition or the 4-6 transition [6]. For ^{6}Li the transitions are either 2-6 or 3-5. The operating frequencies of the transitions are for ^{23}Na 1989 MHz and 1621 MHz, for ^{7}Li 907 MHz and 833 MHz, and for ^{6}Li 327 MHz and 307 MHz. The system allows fast switching between the different alignments controlled by a beam current integrator monitoring the target current.

The maximum polarizations possible for both the vector and tensor polarization is 66% for the I=1 nucleus of ^{6}Li and 50% for the I=3/2 nuclei of ^{7}Li and ^{23}Na. The Beam Foil Spectroscopy method only gives a relative measure of the polarization but it is thought that the polarization of the ions are close to these maxima. The tensor polarization (t_{20}) for ^{7}Li and ^{23}Na was measured in the polarimeter after acceleration in the tandem as 0.40 and 0.20 respectively. The loss of polarization of the ^{23}Na beam is caused by the inability to fully strip the beam with a terminal potential of 20 MV. The sodium +9 charge state is always selected, but if either of the two remaining electrons is in an excited state, the electronic spins couple to the nuclear spin causing depolarization.

The Laser Upgrade

The present polarization method has two main limitations. The first is that the maximum attainable polarization is 50% for ^{23}Na and ^{7}Li and 66% for ^{6}Li. The second is that 50% of the usable atomic beam from the oven is lost when the quadrupole defocuses the electron spin m_J = - 1/2 atoms.

Therefore to enhance the performance of the ion source it is presently being upgraded by the installation of 2 ring dye lasers to optically pump the atomic beam. The laser light will interact with the atomic beam between the oven and the quadrupole pumping the atoms into a single magnetic substate (m_I = + 3/2 for I = 3/2 and m_I = + 1 for I = 1) and electron spin m_J = + 1/2. The light will be brought up to the ion source by means of optical fibre and will have a wavelength of 589.6 nm for Na and 670.8 nm for Li.

A second fibre will be brought up to the ion source between the dipole and the sextupole to determine the polarization of the beam by laser induced fluorescence in a strong magnetic field. When diagnosing the polarization one laser will pump the atomic beam and one will be used for the fluorescence. After the polarization has been determined, the laser used for fluorescence will be coupled into the pump fibre to allow pumping on both lines (F = 1 and F = 2 for I = 3/2 and F = 3/2 and F = 1/2 for I = 1). Pumping on both lines is needed to pump all of the atoms into a single magnetic substate and m_J = + 1/2 state.

With this upgrade to optically pump the atomic beam, the polarization should be very close to 100% with the additional bonus of doubled beam intensity.

Conclusion

A summary of some of the operational parameters of the source are listed in Table 1. The PHIS is now in regular operation at the Nuclear Structure Facility with a polarized beam experiment being run approximately one every four weeks. Last year a total of 11 experiments were performed (5 of ^{23}Na, 5 of ^{7}Li, and 1 of ^{6}Li).

Table 1

	Li Oven	Na Oven
Oven temp.	800°C	420°C
Max. positive beam	17 μA	22 μA
Typical positive beam	3 μA	10 μA
Typical negative beam	- 40 nA	- 110 nA
Running time	6 days	5 days
Beam on target	10-14 pnA	2-7 pnA
	^{7}Li	^{23}Na
Maximum polarization	0.50	0.50
Polarization on target	0.40	0.20

Work is now in progress on the optical pumping upgrade of the source. This upgrade will result in an increase in the polarization to almost 100% and a doubling of the beam current.

For the future the possibility of producing polarized potassium is being investigated.

References

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