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POLARIZED ION SOURCE DEVELOPMENT AT BROOKHAVEN*

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INTRODUCTION

The present AGS polarized H^- source employs a ground state atomic beam source and Cs° charge exchange ionizer. It produces 30-40 μA of $\vec{H}^-$ at 75-80% polarization, in 500 μs pulses, 0.5 Hz. Up to 60 μA has at times been produced when the cesium beam is performing optimally. Work in progress to produce a higher intensity $\vec{H}^-$ source includes cooling of the H° beam to 6 K and ionization of the polarized atoms via charge exchange with D^-. Experiments to test the possibility of spin selection and focusing of H° using a superconducting solenoid have been completed, and have led us back to the more conventional approach of sextupoles.

COLD ATOMIC BEAM

We have been successful in our attempt to produce a high flux, low velocity H° beam by passage of the atoms through a 6 K copper accommodator section at the exit of the rf dissociator. At 6 K, time-of-flight measurements of the velocity distribution showed that the beam had a most probable velocity of 680 m/s, a FWHM of approximately 200 m/s, and a forward flux of 9.4×10^{18} H°/sr/s. Complete details of the setup and experimental results have been given.[1] Subsequently, the atomic beam stage was further improved, and it is shown schematically in Figure 1. It differs from the setup in Ref. 1 in several ways. The volume of the pyrex dissociator was reduced, allowing us to operate with a higher rf power density into the dissociator (using the same power supply). The exit of the dissociator tube is cooled via a liquid nitrogen cooled copper clamp around the outside of the pyrex. Following this, there is a 0.3 mm gap, and then the liquid helium cooled copper accommodator. The teflon "transition" section between the dissociator and accommodator, used in the original design, has been eliminated. The accommodator channel now has a 15 mm long, 3 mm diameter nearly straight section, followed by a 15 mm long section which tapers out to a final diameter of 10 mm. This followed from a suggestion of T. Niinikoski,[2] and is based on the desire to keep the H° density in the accommodator below the point where one begins to lose significant flux due to three-body recombination. The flare is an attempt to keep the atom density constant while the H° velocity is decreasing. Finally, the initial atomic beam source had a skimmer which was coated with

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charcoal and cooled to < 4 K, providing cryopumping in a very critical region. In the new source, the skimmer was eliminated completely, and there is instead a stack of 10 cryopanels (< 4 K) immediately following the accommodator. This is very effective in keeping the pressure outside the accommodator low.

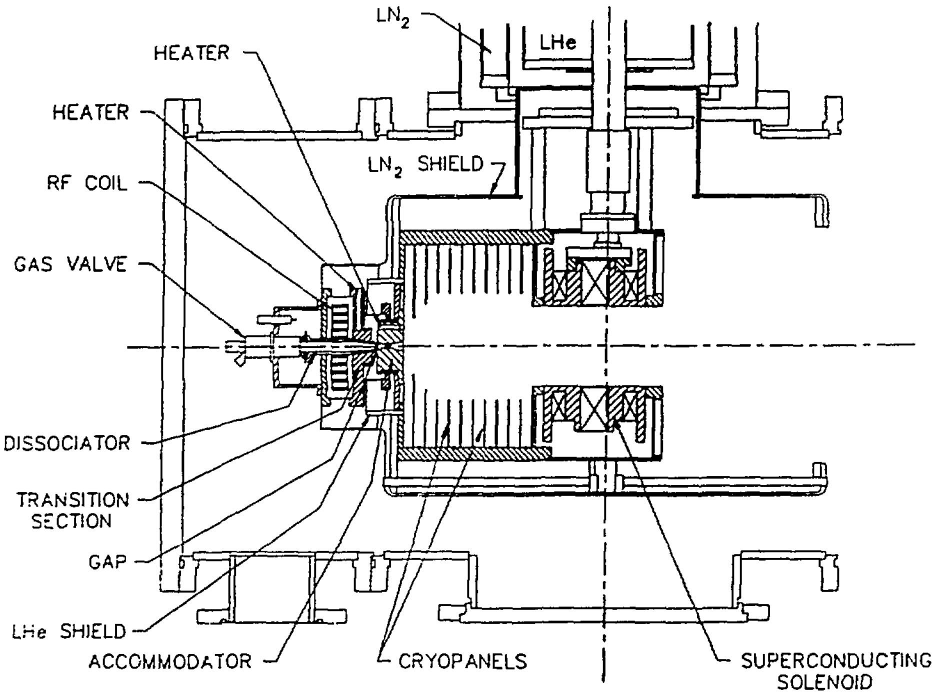

Figure 1. Schematic of the cold atomic beam and superconducting solenoid.

With this new atomic beam stage, and an accommodator temperature of 6 K, an H° density of 6 x $10^{11}/cm^3$ was measured 90.5 cm away. This density, measured via a quadrupole mass spectrometer and without any focusing of the atoms, was an improvement by a factor of 30 over the density measured with the atomic beam in Ref. 1. Velocity measurements could not be made in the new configuration. If one assumes that the most probable velocity is still 680 m/s, the forward flux from the new atomic beam is 3 x 10^{20} H°/sr/s (a higher velocity would imply an even higher flux). As will be discussed in the next section, this atomic beam may be too intense to be used effectively for the production of polarized H° atoms.

SPIN SELECTION AND FOCUSING

The use of a type of superconducting solenoid for focusing of H° atoms was proposed by T. Niinikoski (CERN), and is described in Ref. 3. With the high fields obtainable in such a coil, one could hopefully build a magnet having a suitable field gradient over a larger aperture than is possible in a conventional sextupole system. In collaboration with Niinikoski, such a solenoid was built and tested. The solenoid consists of three coils connected in series, with the current in the outer two (2100 turns in each coil), counter to the current in the middle coil (4600 turns). This gives a high field at the inner diameter of the coils and a weak field on axis, i.e., a larger magnetic field gradient, required for focusing of atoms. The three-coil system had an i.d. of 9.4 cm and an overall length of 10 cm. A field of 5.2 T was obtained at the coil i.d., at a current of 107 A. Field maps generated with the POISSON program for our geometry showed a disadvantage of the solenoid in that the gradient was very nonlinear (weak on axis), and because of this, track-tracing calculations of the H° beam through the solenoid showed large aberrations in the focusing. First tests of the solenoid with the H° beam, as shown in Figure 1, actually showed a slight decrease in the H° density, measured 65 cm away from the coil exit, when the solenoid was energized. Several runs were then made in which the accommodator diameter was reduced, in order to decrease the H° density (to see if H°-H° scattering was the problem). Figure 2 shows the "focusing factor" (the ratio of the H° density measured 65 cm from the solenoid with B = 4.38 T to the density with B = 0), versus the density at B = 0. Solenoid focusing was observed at lower densities, but fell off as the density was increased. We feel that this fall off is indeed a result of H°-H° scattering, and there is a preliminary indication that at low temperatures this scattering cross section could be as large as 10^{-14} cm^2. The fact that there is an upper density limit for magnetic spin selection, beyond which the mean free path for H° atom scattering becomes so small as to prevent the separation of the atoms of opposite electron spins, was previously considered.[4] With the solenoid, the situation is made worse because the defocused atoms hitting the inner bore of the solenoid (at 4 K) do not readily recombine and get pumped away, but rather scatter off the solenoid, raising the local H° density even further. Also, the solenoid gradient is higher at larger radii, so most of the focusing/defocusing occurs in the region near the walls.

Figure 3 shows H° profiles measured 22 cm from the solenoid exit for various solenoid currents. These were taken at a low density, and do demonstrate qualitatively the expected focusing. The measurements were made by scanning the beam with a 1 mm x 1 mm thermoflake H° detector.[5] The detector signal was normalized at B = 0, r = 0 to a mass spectrometer reading taken further downstream, assuming a $1/r^2$ falloff in density as one moves away from

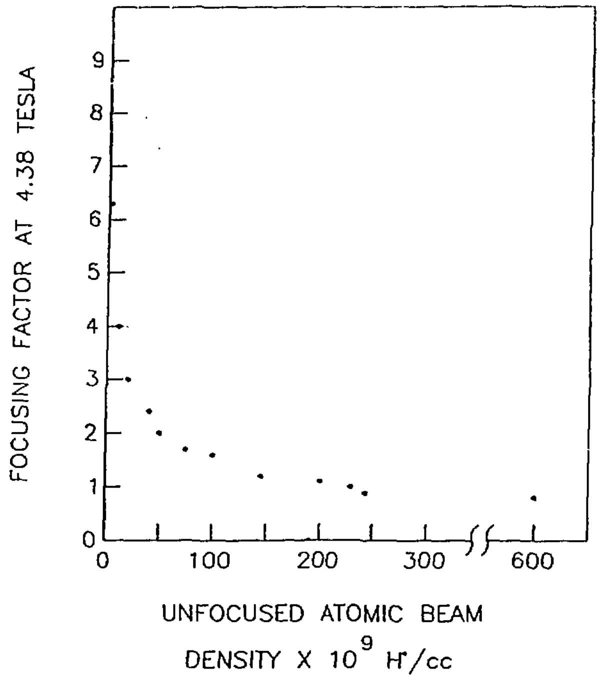

Figure 2. Variation of the focusing factor (ratio of H° density at B = 4.38 T to density at B = 0) vs. H° density at B = 0.

the accommodator. The largest focusing effect observed, when the solenoid was at its maximum field of 5.1 T and at low H° density, was only a factor of 10 increase in H° density over the B = 0 value. This relatively low value is probably indicative of the problem of the aberrations in the focusing. The alternative of focusing with a sextupole is now being pursued. Track-tracing calculations have shown that one can form a much better focused beam with the sextupole. These track-tracing calculations, however, neglect gas scattering effects which appear to be quite important at our high densities and low velocity. We will attempt to make the sextupole as open as possible so that the defocused atoms will not interfere with the primary beam.

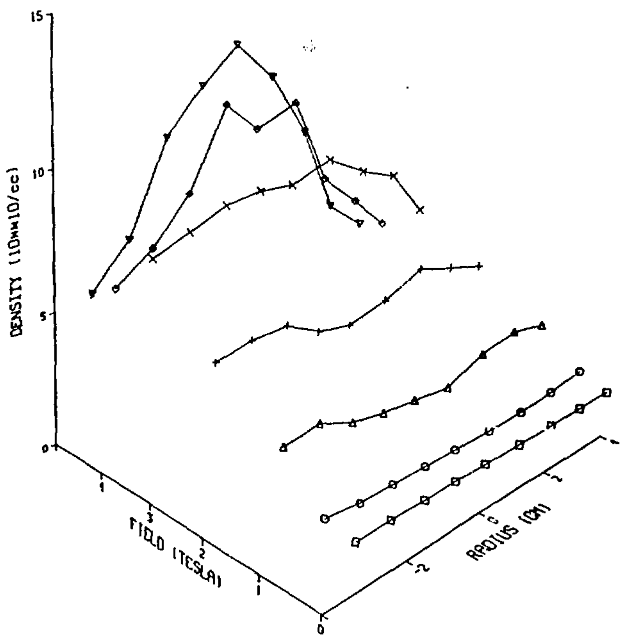

Figure 3. H° density profiles vs. solenoid field, measured 22 cm from the solenoid exit, taken at a low H° density.

RING MAGNETRON IONIZER

In the ring magnetron ionizer, H° atoms are ionized via charge exchange with D⁻ ions produced in a magnetron surface-plasma source. Details of this compact, large acceptance ionizer (approximately 2 cm long by 2 cm diameter ionization region) are given in Ref. 6. In initial tests of the ionizer, 500 μA of H⁻ was produced by charge exchange, with an estimated H° density in the ionization region of 10^{12} cm^{-3} (unpolarized). The ionizer was then installed in place of an electron bombardment ionizer on a polarized atomic beam source. The beam is extracted at 10 keV, and transported through two Einzel lenses, a Wien filter for mass selection, and a polarimeter chamber, before reaching the Faraday cup 157 cm from the ionizer. The present performance is 50 μA of H⁻ extracted with an H° density (unpolarized) in the ionizer of 3×10^{11} cm^{-3}. This H° density was determined by measuring the density downstream of the ionizer with a quadrupole mass spectrometer, and the ionizer off, and then assuming a $1/r^2$ falloff with distance from the dissociator (there were no sextupoles). This efficiency is now approximately the same as the Cs ionizer on PONI-1, but less than that measured on the test stand. The most critical factor affecting the efficiency of the ionizer seems to be the high D_2 pressure in the ionizer region. The pumping of D_2 from the ionizer is presently not very good due to poor conductances in the vicinity of the magnetron. From measurements of the H° density downstream of the ionizer with and without the ionizer D_2 gas pulsing, we estimate a D_2 target thickness to the H° beam of $nl = 5.4 \times 10^{14}/cm^2$. We are planning a redesign of the magnetron to decrease the D_2 pressure. Experiments with a polarized beam, to test for any depolarization, are also planned.

CONCLUSIONS

The performance of the 6 K H° beam source has exceeded expectations. H° gas scattering and aberrations seem to be problems in the superconducting solenoid, so we will be testing a permanent magnet sextupole for spin selection. The resultant H° density one will obtain at the ionizer is difficult to estimate, since it may still be limited by H°-H° scattering in the spin selection region. The polarized atomic beam will then be combined with an rf transition unit and the ring magnetron ionizer, and if $\vec{H}^-$ intensities of at least several hundred microamperes are obtained, we will make the improvements necessary to turn this into an operational source for the AGS.

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