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THE BNL POLARIZED H⁻ ION SOURCE DEVELOPMENT PROGRAM*

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ABSTRACT

Polarized protons have been available for acceleration in the AGS for the high energy physics program since 1984. The polarized H^- source, PONI-1, has routinely supplied a 0.4 Hz, 400 μsec pulse having a nominal intensity of 40 μA. Polarization is ~80% out of the ion source.

After PONI-1 became operational, a program was initiated to develop a more intense source based on a cold ground state atomic beam source, followed by ionization of the polarized H° beam by D^- charge exchange. Various phases of this work have been fully reported elsewhere, and only a summary is given here.

INTRODUCTION

The development program for a milliampere polarized H^- source proceeded along the following lines:

1. Develop a cold ground state atomic hydrogen source.
2. Use a superconducting solenoid for spin selection and focusing of the cold atomic beam.
3. Ionize the H° by charge exchange with D^- in a ring magnetron ionizer.

The first two projects were meant to exploit the B/T dependence of the acceptance solid angle of the magnet used for spin selection and focusing in such devices. The third exploited the large cross section for H° - D^- charge exchange.

THE SOURCE DEVELOPMENT PROGRAM

Cold Atomic Hydrogen Beam

The acceptance solid angle of a spin selection magnet varies with beam temperature as B/T,[1] where B is the magnetic field and T is a characteristic temperature of the atomic beam. The ionization efficiency has a $T^{-1/2}$ dependence from the dwell time of the atomic beam in the ionizer. Thus, there is an overall theoretical $T^{-3/2}$ dependence of ionized beam intensity on atomic beam temperature in such sources, and, other things being equal, lower temperatures mean higher

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currents. Experiments down to liquid nitrogen temperatures have shown a weaker dependence on T, usually attributed to a loss in atomic beam flux as the beam is cooled.

We embarked on a program to produce an atomic hydrogen beam whose thermal velocity was close to the temperature of liquid helium. Several accounts of this work have been given elsewhere.[2] In Figure 1, we show results of time-of-fight measurements of the velocity distribution. For an accommodator temperature of ~6 K, the most probable velocity corresponds to a beam energy of ~18 K.

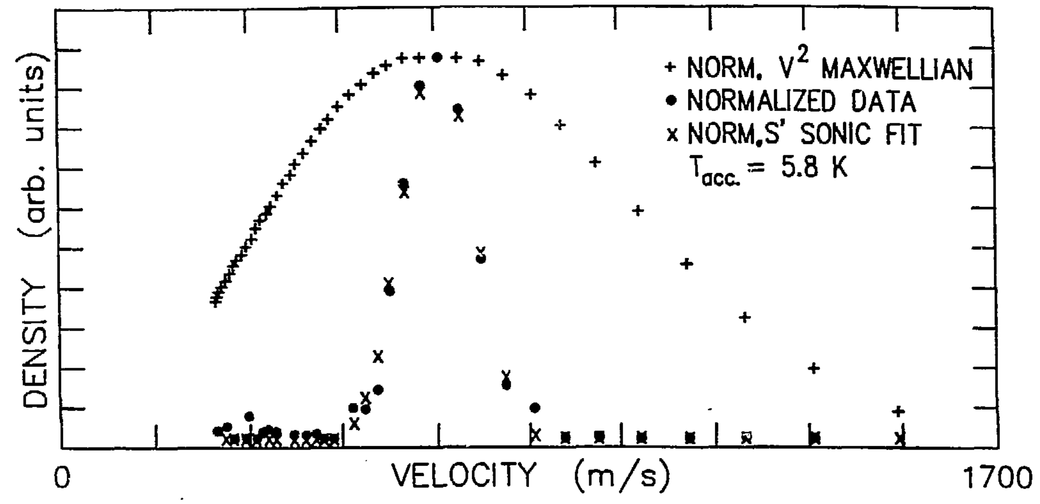

Fig. 1. Velocity distribution of the cold H° beam for $T_{accommodator}$ = 5.8 K. The most probable velocity and FWHM are ~18 K and ~1 K, respectively.

Spin Selection/Focusing

Superconducting Solenoid

A superconducting solenoid was chosen as the spin selection magnet. It allowed us to produce a very high magnetic field (~5 T) in a 10 cm aperture, large enough that geometric acceptance would not be a limiting factor. The solenoid consisted of a large central coil between two smaller outer coils. The three coils were wired in series such that the current direction in the outer coils was counter to its direction in the middle coil. This arrangement produced high gradients within the aperture of the magnet. (The (de)focusing force on the atoms is a product of their magnetic moment and the gradient of the field).

The cold beam source and solenoid were combined so that the spin selection/focusing characteristics of the latter could be evaluated.[2] The figure-of-merit used in this evaluation is the focusing factor, F, which we define as the ratio of the beam density at the ionizer position with non-zero magnetic field to the beam density at the same position with zero magnetic field (n_u). Density was measured with a residual gas analyzer.

The results of this study are summarized in Figure 2a, where F is plotted as a function of the unfocused beam density with the solenoid field off. It is seen that at low beam densities, F ~ 10, but it drops very rapidly with increasing density.(Although these data were obtained with the solenoid field at 4.38 T, earlier studies had shown that, at low densities, F was still increasing as the field was raised to its maximum operating value of 5.2 T.) The sharp drop in focusing with increasing density pointed to the presence of severe H° - H° intrabeam scattering. A cross section of 100 A^2 at ~ 2 K, the FWHM of the velocity distribution, was obtained from an analysis of these results.[3] This value is greater than theoretical values reported in the literature over the last two decades.[3]

Additionally, computer simulations indicated that the solenoid produced aberrations that lowered the focusing factor below what was expected based on the acceptance angle of the solenoid.[2]

Sextupole Magnets

Two sextupole magnet configurations were tried in place of the solenoid. The first was a single 20 cm long permanent magnet sextupole which could be moved approximately 20 cm axially, as well as lowered out of the beam. Studies of focusing as a function of axial position indicated that the beam was being overfocused. Computer simulations reproduced the focusing results for a beam velocity of ~500 m/s.

The second configuration consisted of a 10 cm long permanent magnet having $B_{pole\text{-}tip}$ of 0.7 T, and an aperture diameter of 4 cm, followed by a 10 cm long variable strength magnet having $B_{pole\text{-}tip}$ of 0.68 T(0.8 T if pulsed), and an aperture diameter of 3.6 cm. The gap between them was 10 cm. This configuration is shown in Figure 3, which is a schematic representation of the final cold beam test setup, and its focusing behavior is shown in Figure 2b. While the reduction in F with increasing density is still observed, it is not as severe as with the solenoid; the more open geometry appears to improve pumping in the magnets, which in turn reduces intrabeam scattering. We estimate that this configuration gives a polarized H° density of 3×10^{12} cm^{-3} at the ionizer position.

An apparent advantage of the sextupoles over the solenoid in this type of application is that the magnetic field gradient in the former increases linearly with radius, whereas computer simulations of the magnetic field of the latter showed that the gradient is not linear with radius, thus giving rise to spherical aberration.

Ring Magnetron Ionizer

A description of the earlier work on this ionizer can be found in Reference 4. With an unpolarized H° beam density of 10^{12} cm^{-3} in the D^- ionizer, 500 uA of H^- was obtained by charge exchange. When mounted on an uncooled polarized H° source, the polarized H^- yield was only ~1/3 of the above. (This was approximately the same ionization efficiency as that of PONI-1, in which ionization is by charge exchange with a cesium beam.) The loss in ionization efficiency was attributed to poor pumping of D_2, leading to loss of H^- due to scattering and

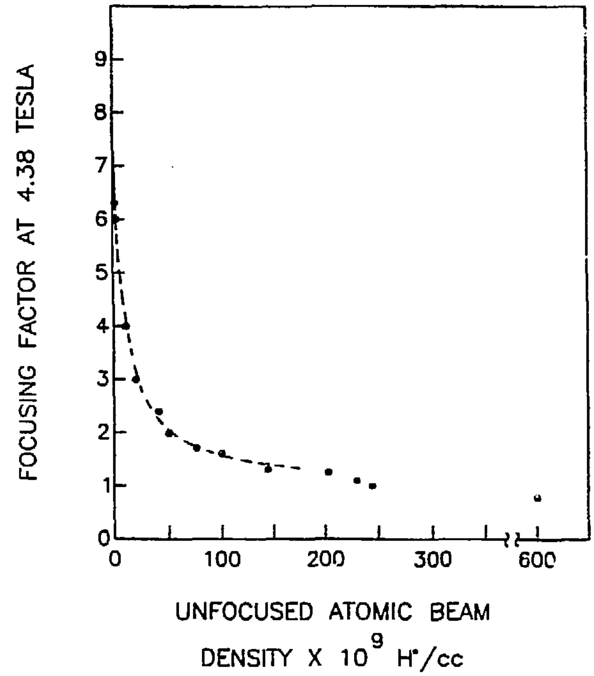

Fig. 2(a). Focusing factor, F, vs unfocused beam density, n_μ, for the superconducting solenoid. The dashed curve is a fit based on calculations in Reference 5.
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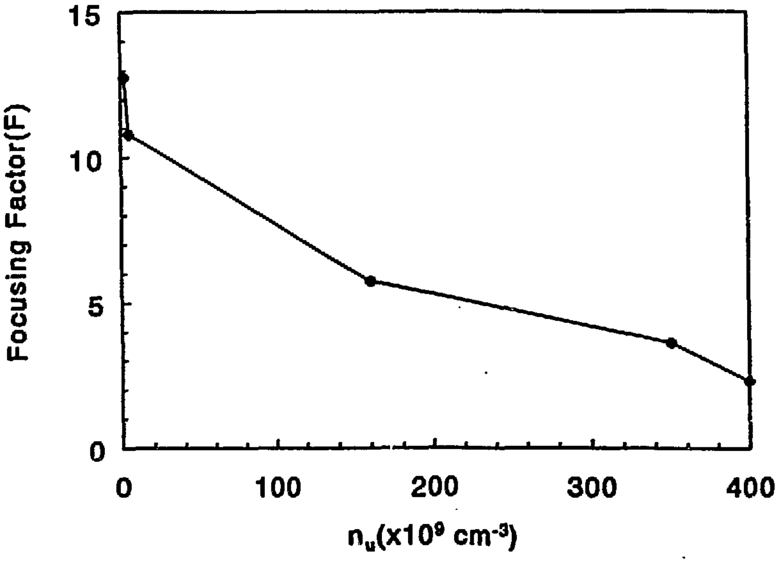
Fig. 2(b). Focusing factor, F, vs n_μ, for the two sextupole magnet configuration. ↓



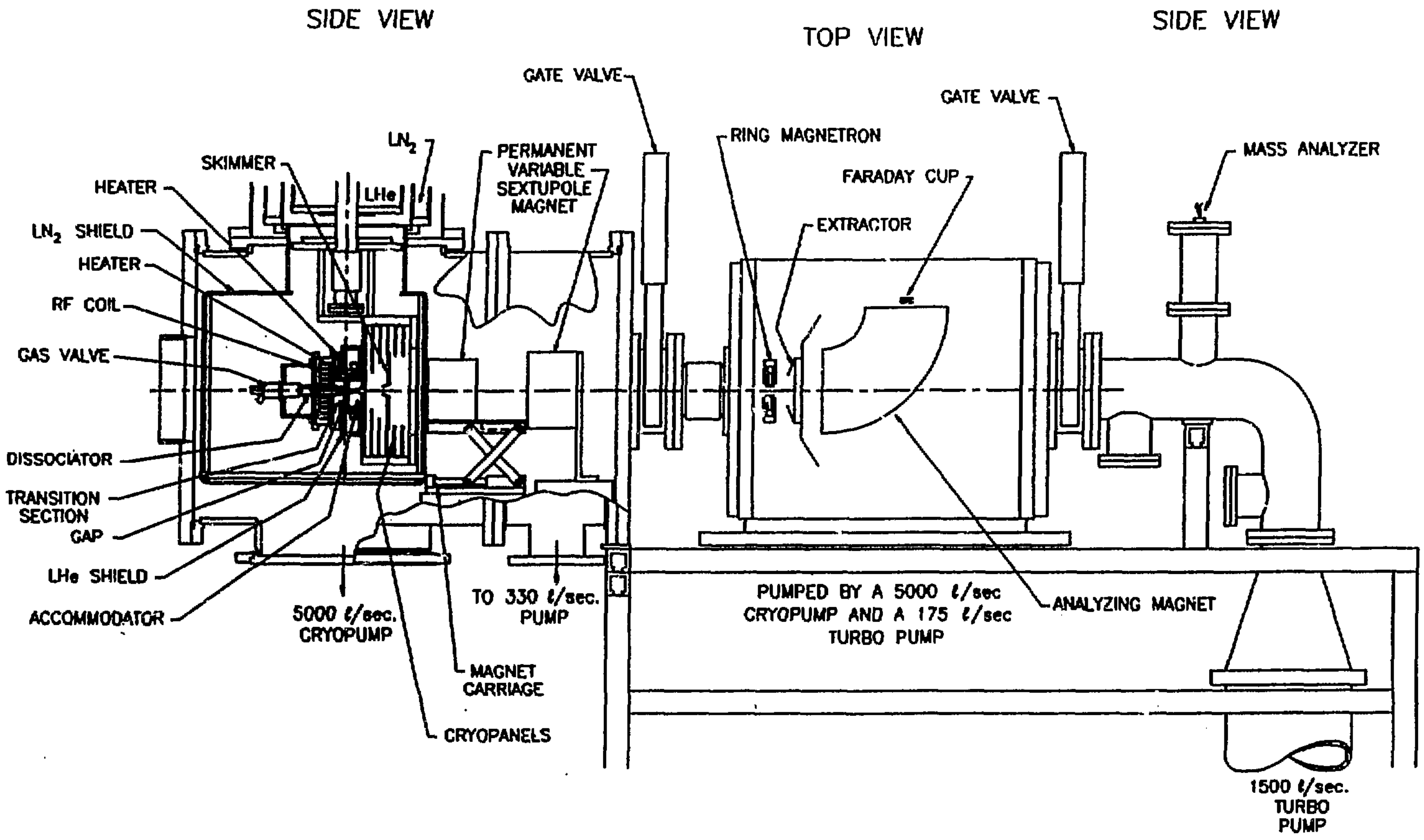


Fig. 3. Final setup to test polarized H$^-$ production by the combination of the three phases of the project.

stripping. From observations of the H° beam attenuation when the ionizer gas was pulsing, but with the discharge off, the D_2 line density along the ionizer axis during typical source operation was determined to be $\sim 5 \times 10^{14}$ cm^{-2}.

The ring magnetron was redesigned in order to improve the pumping of D_2 away from the ionizing volume. Its effective length was reduced from 5 cm to 1.2 cm, and the structure was made as open as possible. This ionizer was placed after the sextupole magnets of the cold atomic beam source (without the 'rf transition units' for nuclear polarization, which are usually located between the spin selection magnet and the ionizer, see Figure 3).

Tests of this stage of the development showed that as the accommodator temperature was lowered from liquid nitrogen to liquid helium temperatures, the measured polarized H° density at the ionizer increased from 7×10^{10} cm^{-3} to 27×10^{10} cm^{-3}, but the polarized H^- yield decreased from 5 uA to 0.6 uA. We attribute this to the increased scattering at lower velocity of the incoming polarized H° beam by D_2 from the ionizer.

CONCLUSION

To realize the initial objective of a milliampere polarized H^- source, the problems of scattering in the spin selection/focusing magnet(s) and in the ring magnetron ionizer must be overcome.

Replacing the solenoid with the two-sextupole configuration improved the observed focusing, indicating that a more open design, for example with several short sextupole magnets, which does not sacrifice focusing, will solve the problem of scattering in the magnet.

Scattering in the ionizer presents a more difficult problem since D_2 is intimately associated with D^- production. Unless it can be solved, the ring magnetron will not be a viable ionizer for low velocity H° beams.

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