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POLARIZED H⁻ SOURCE DEVELOPMENT AT BNL*

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Abstract

The AGS polarized H^- source (PONI-1) now produces currents of 25-40 μA, and has operated reliably during polarized physics runs. A new polarized source, having as its goal mA's of $\vec{H}$, is now under development. An atomic hydrogen beam has been cooled to about 20 K with a forward flux of ~10^{19} atoms/s/sr. A superconducting solenoid having a calculated acceptance angle of 0.1 sr for the cold H° beam, is now being built. An ionizer for the resulting polarized H° beam based on resonant charge exchange of H° with D^-, is being tested. 500 μA of H^- have been produced by ionizing an unpolarized H° beam using this ionizer.

Introduction

The AGS has run a physics program with polarized protons for the past two years. PONI-1 produces 25-40 μA of $\vec{H}$ in 500 μs pulses. This source injects beam at 20 keV into an RFQ accelerator, and the 750 keV output beam is then injected into the 200 MeV linac. While the reliability of PONI-1 has been excellent, the intensity is three orders of magnitude below our normal H^- intensities. Therefore, there is presently an effort to develop a new polarized H^- source producing currents at the milliampere level. In the next section the present polarized source will be describe Following this, the plan for the mA source will be given. Three separate development efforts are now in progress to test individual features of the new source.

PONI-1

In this source, hydrogen atoms are polarized in a ground state atomic beam source, and then ionized via the reaction

$$Cs° + \vec{H}° \rightarrow Cs^+ + \vec{H}^- \quad .$$

The $\vec{H}°$ and Cs° beams are both pulsed.

The source is shown schematically in Fig. 1. H° atoms are produced in an rf dissociator, cooled to 90 K, and electron spin selected by four 10 cm long sextupoles. Two rf transition units, energized on alternate AGS pulses, produce nuclear polarized H° with spins parallel or antiparallel to $\vec{B}$ on a pulse-to-pulse basis. The beam then enters the strong field ionization region. At the opposite end, a 50 keV Cs^+ beam is produced by surface ionization of Cs vapor on hot porous tungsten. After extraction, it is neutralized by passage through Cs vapor. The Cs° beam then passes into the ionization region, overlapping the $\vec{H}°$ beam over a 35 cm length. $\vec{H}^-$ ions produced by charge exchange are extracted at 20 keV, travel through a 90° electrostatic mirror, and are transported to the RFQ, which is located approximately 4 meters downstream. Following the RFQ, the beam makes two 60° bends and enters the 200 MeV linac. More details of this source can be found in reference 1.

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PONI-1 Performance

The source output is 25-40 μA, with an average polarization of 70-75%. The normalized emittance is approximately 0.02 π cm-mrad. There is typically 75% transmission through the RFQ, and the intensity at 200 MeV is about 50% of the source output.

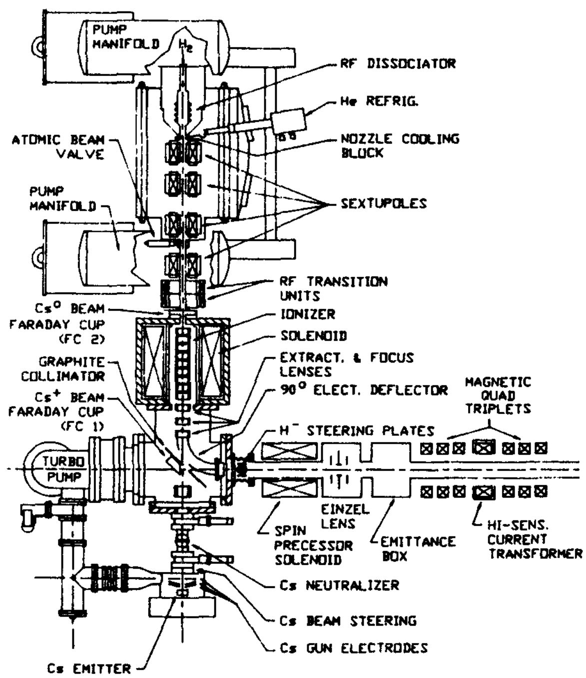

Fig. 1. Layout of the AGS $\vec{H}^-$ source.

The source reliability has been very good. During AGS physics runs, the source normally operates unattended, with call-ins due to problems being relatively rare. The only routine maintenance is the changing of the porous tungsten ionizer at 2-3 week intervals during continuous operation. During this period, the Cs beam intensity drops to about 2/3 of its original value, caused, we believe, by a slow contamination of the tungsten surface. The total downtime to change the ionizer and restart the source is 6-8 hours.

High Current $\vec{H}^-$ Source Development

As mentioned previously, the PONI-1 source produces three orders of magnitude less current than is used for the normal AGS physics program. With increased polarized intensities, new polarized experiments, as well as concurrent running of polarized and unpolarized physics experiments, would be possible. We are presently testing three improvements, which, when combined in a new polarized source, should lead to $\vec{H}$ currents in the mA range. Improvements will be made to the $\vec{H}°$ beam intensity by better cooling the atoms, to the spin selection by the use of a superconducting solenoid, and to the $\vec{H}° \rightarrow \vec{H}^-$ ionization

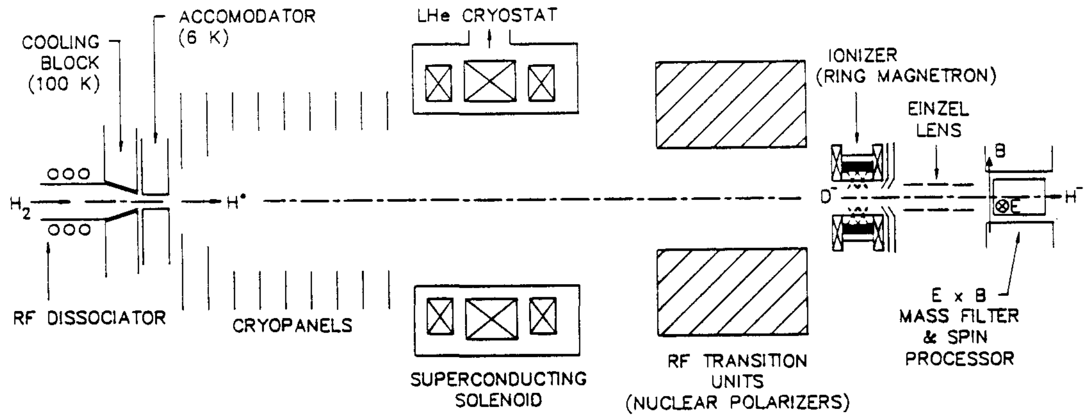

Fig. 2. Layout of the proposed milliampere $\vec{H}^-$ source.

through charge exchange with D^-. The planned source is shown schematically in Fig. 2, and the new features are described below.

Cold Atomic Beam

The decision to construct an intense cold H° source was based on the fact that the acceptance solid angle of the spin selection magnet depends inversely on the kinetic energy (kT) of the atoms. In addition, the ionization efficiency improves as the velocity of the atoms is lowered.

Figure 3 is a schematic of the apparatus we have used to study various aspects of the production of very cold H° beams. H_2 molecules are dissociated in a conventional RF dissociator. The H° atoms pass through two 2 cm long x 3 mm dia. channels in adjacent teflon and copper blocks. The teflon section is kept above 100 K. The copper block (accommodator) is attached to the base of a LHe cryostat and its temperature can be stabilized between 5 K and 30 K. The two blocks are separated by a 0.3 mm gap so there is no physical surface in the 100-30 K temperature range. (This is typically a temperature range where the recombination of H° on surfaces is usually high.) Below 20 K, a frozen H_2 surface forms, and recombination of H° on it is negligible. The gap between the two blocks must be kept as small as possible, since the gas flow in the channels is in the slip regime, and the beam would rapidly lose its collimation because of the high collisionality within it.

The density of the atomic beam is measured with a calibrated residual gas analyzer (RGA) about 70 cm downstream from the accommodator. Beam temperature is obtained from the velocity distribution which is measured using a conventional time-of-flight (TOF) set-up. Our investigations so far include:

1. Study of beam density as a function of the dissociator orifice diameter
2. The variation of density and velocity with accommodator temperature
3. Focusing of the beam with a conventional sextupole magnet
4. Beam density and velocity for different diameters of the accommodator.

We have obtained H° fluxes of 9.4 x 10^{18} and 1.1 x 10^{19} atoms/s/sr at accommodator temperatures of 5.8K and 26K respectively. These are comparable to fluxes from existing dissociators. The most probable velocity was 680 m/s for the 5.8 K case, and 980 m/s at 26 The distribution was much narrower than Maxwellian at 5.8 K, which is favorable for good H° beam optics. These are very encouraging results, demonstrating that we can cool the atomic beam while maintaining the high fluxes required for a polarized ion source. Presently, work is continuing on the optimization of the accommodator geometry. These experiments are described in more detail in Ref. 2.

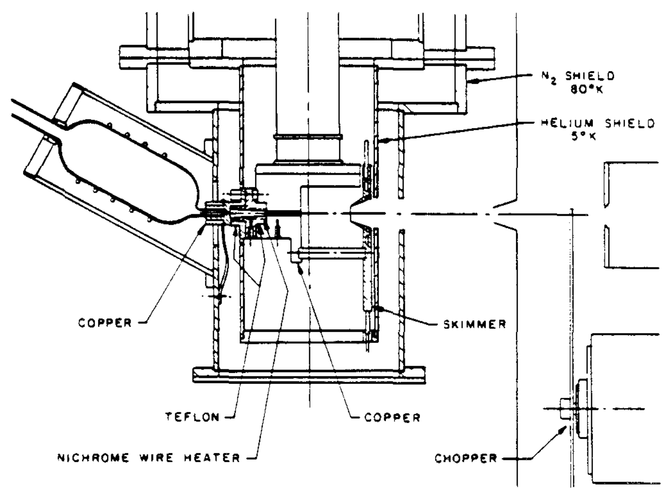

Fig. 3. RF dissociator and accommodator shown mounted to the base of the LHe cryostat. The RGA (not shown) is to the right.

Superconducting Solenoid

Existing polarized atomic beam sources use sextupole magnets to electron-spin polarize the H° beam. The magnet focuses the $m_j = +1/2$ component of the beam while defocusing the $-1/2$ component. The acceptance solid angle of a sextupole magnet is $\Omega = 2\mu_o B_o/kT$ (for an H° source at the magnet entrance). B_o is the pole-tip field and T is defined by $V_{mp} = \sqrt{(2kT/m)}$ where V_{mp} is the most probable velocity in the beam. For an accommodator temperature of 5.5 K, V_{mp} was 680 m/s and T = 28 K. Since a practical conventional sextupole magnet has Bo < 1 T, Ω < .05 sr. In an actual source, where the nozzle of the atomic source would be at least several centimeters away (as required for practical reasons), the acceptance angle would typically be smaller than given above by approximately a factor of 2.

The use of a superconducting solenoid in place of the sextupole magnet has been suggested because higher magnetic field gradients are obtainable over much larger apertures.[3] Using the computer program POISSON, field maps were generated for several solenoid geometries and exciting currents. To increase the focusing field gradient, the solenoid is made up of three coils, with the current in the middle coil flowing opposite to the outer two. A second program tracked H° atoms through these fields. The result of a track tracing calculation is shown in Fig. 4. The large size of the beam after the solenoid will require a redesign of the RF transition units.

A 5 T solenoid, 10 cm long and 9.5 cm i.d., is

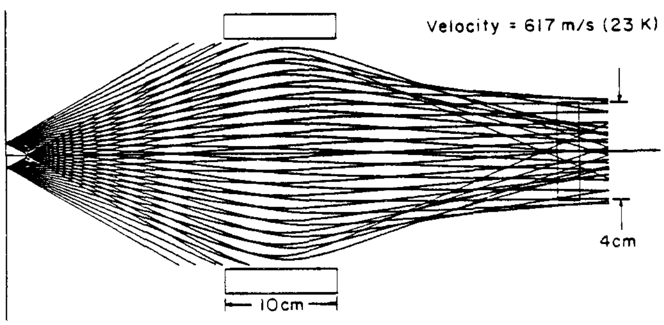

Fig. 4. Output of the track-tracing program for $B_0 \sim 5T$ and R = 5 cm at the mid-plane of the solenoid.

being constructed. The calculated solid angle acceptance for this solenoid is 0.1 sr. Coupling this solenoid with the cold atomic beam, we estimate that we can get a flux of 2.7×10^{17} atoms/s within a 1 cm radius at the ionizer, with an average density of 1.3×10^{12} atoms/cm^3.

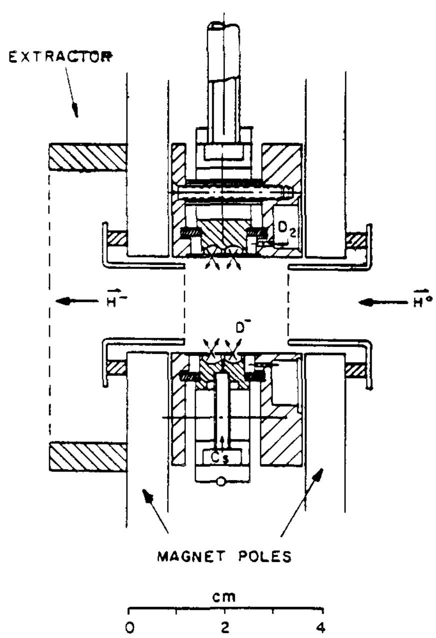

Fig. 5. Schematic of the ring-magnetron ionizer.

Ring Magnetron Ionizer

With this ionizer, $\vec{H}^\circ$ is converted to $\vec{H}^-$ by charge exchange with 200 eV D^-, rather than with 50 keV Cs° as is done on PONI-1. (D^- is used rather than H^- so that subsequent mass analysis can separate the polarized H^- from the unpolarized ionizing ions.) A schematic of a prototype ionizer now being tested is shown in Fig. 5. The cathode is the outer and the anode the inner of two concentric cylinders. D^- ions are produced on the low work function cathode, accelerated by the -200 V cathode voltage, and pass through slits in the anode and into the center of the ring. The polarized H° passes axially through the ring and is ionized by charge exchange with D^-. Polarization is preserved during ionization by a 1 kG axial magnetic field. $\vec{H}^-$ ions are then extracted and mass analyzed to eliminate any D^- component.

One advantage of this approach is the large resonant charge exchange cross section with D^-. In addition, the Cs° current, limited by the geometry and the fact that one must accelerate and neutralize the beam, is much less than the large "self-extracted" D^- current one can obtain from a surface-plasma source. Finally, this ionizer has a length of only 2 cm, compared to the 35 cm ionization length on PONI-1 with the Cs beam. This gives the ionizer a larger acceptance for the polarized H° beam.

Self-extracted D^- currents of up to 0.7 A have been detected in the center of the magnetron. On a test stand, the ionizer was placed after a dissociator and unpolarized H° was injected into the center of the ring. H^- was extracted at 2-3 kV and mass analyzed. With an estimated H° density in the ionizer of $10^{12}/cm^3$, an H^- current of 500 μA was produced by resonant charge exchange. This is approximately a factor of four improvement in ionization over the Cs ionizer on PONI-1, but is still 2-3 times below what we eventually hope to achieve. More details of the source geometry and initial experiments can be found in reference 4.

The magnetron ionizer has now been mounted after the atomic beam stage of a polarized source. Operation is with 20 keV extraction, followed by an einzel lens and an ExB mass filter (which also precesses the spin into the proper direction). The beam then enters a polarimeter developed at Yale University,[5] with which we will measure the H^- polarization at 20 keV. These experiments are in the initial stages, and so far only very small H^- currents have been detected. The problem appears to be a loss of H° flux into the ionizer due to the large gas load from the magnetron. We hope to improve the situation by improved differential pumping in the ionizer section.

Summary

The performance of the AGS polarized H^- source has been very good. While its intensity has exceeded initial expections, we now feel that an improved source can be built, delivering $\vec{H}^-$ currents in the mA range. The cold H° test stand is operating at levels considerably improved over the PONI-1 atomic beam. A large acceptance superconducting solenoid for spin selection is now being built, and will be tested with the cold atomic beam. The ring magnetron D^- charge exchange ionizer is now operating on a separate test stand with a room temperature polarized H° beam, where we will try to optimize the ionization efficiency and test to make sure polarization is preserved during ionization. Following these tests, the ionizer will be combined with the cold beam and solenoid to test the overall performance of the prototype source.

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