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POLARIZED H^- ION SOURCE DEVELOPMENT FOR THE AGS*

Peter F. Schultz, D. Read Moffett, and Eugene P. Colton
Argonne National Laboratory
Argonne, Illinois 60439

Ahovi Kponou and Vernon W. Hughes
Yale University
New Haven, Connecticut 06520

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Summary

The polarized H^- ion source that Argonne National Laboratory and Yale University are building for the AGS polarized beam facility is based on the crossed-beam concept in which a polarized atomic-hydrogen beam, $H^o_{\uparrow}$, is ionized to H^- by a fast neutral cesium beam, Cs^o. We describe our studies which will aid in achieving a high intensity polarized H^- beam. In particular, we describe time-of-flight studies on the atomic beam and the effect of dissociation nozzle cooling on the velocity distribution. The cesium gun design is described, and a brief discussion of the $H^o_{\uparrow}$-Cs^o interaction region is given.

Introduction

Argonne National Laboratory and Yale University are developing an ion source of polarized H^- ions ($H^-_{\uparrow}$) for the Brookhaven National Laboratory AGS polarized beam facility. The design of the ion source is based on the crossed beam principle, a concept developed by W. Haeberli at the University of Wisconsin,[1,2] in which $H^-_{\uparrow}$ ions are created in the reaction of fast cesium atoms with a polarized atomic hydrogen beam:

$$Cs^o + H^o_{\uparrow} \rightarrow Cs^+ + H^-_{\uparrow} .$$

The Wisconsin source produces 1-3 µA dc of ~90% polarized H^- ions. Using techniques developed for the ZGS polarized source,[3,4] the AGS source should produce up to an order of magnitude higher intensity with the same polarization.

Figure 1 illustrates the construction of the new source. The atomic hydrogen beam is produced by a (pulsed) RF discharge in H_2 gas in the dissociator. The sextupole magnets and RF transitions produce the polarized H^o beam ($H^o_{\uparrow}$) which is focused by the sextupoles into the interaction region where it is ionized by a fast, 40-80 keV, neutral cesium beam. The $H^-_{\uparrow}$ ions are then accelerated to 20-50 keV, extracted from the solenoid (which preserves the polarization), and deflected by the 90^o electrostatic mirror. A second solenoid magnet rotates the spin into the vertical direction.

The neutral cesium beam is produced from a Cs^+ beam passing through the cesium vapor-filled neutralizer canal where the resonant charge exchange reaction $Cs^+ + Cs^o \rightarrow Cs^o + Cs^+$ takes place.

The final polarized $H^-_{\uparrow}$ ion current $I(H^-_{\uparrow})$ is given by the expression:

$$I(H^-_{\uparrow}) = n \cdot \sigma \cdot L \cdot I(Cs^o) \quad (1)$$

where:

n = density of $H^o_{\uparrow}$: atoms/cm^3 ,

σ = cross section for the reaction $Cs^o + H^o_{\uparrow} \rightarrow Cs^+ + H^-_{\uparrow}$: cm^2 ,

L = length of interaction region : cm, and

$I(Cs^o)$ = neutral cesium beam current : Amp.

Given the configuration of the ion source, it is seen that increases in $H^-_{\uparrow}$ intensity can be obtained in two ways: (1) increase the atomic hydrogen density n, and (2) increase the neutral cesium current $I(Cs^o)$ in the interaction region. The following sections will describe the source components in more detail and will also describe our investigations into methods of increasing n and $I(Cs^o)$.

Atomic Beam Stage

The atomic beam stage is an ANAC, Inc. Model 2100 Atomic Beam Source. It consists of:

1. A pulsed RF dissociator modified to incorporate nozzle cooling (nozzle cooling increased the beam intensity in the ZGS source by a factor of 2½),[5]

2. Four sextupole magnets (15 cm length each) to produce electron state polarization and to focus the atomic beam into the ionizer, and

3. Two RF transition stages that are exited on alternate AGS pulses to produce the nuclear polarized atoms with polarization reversal on a pulse-by-pulse basis.

Velocity Distribution

In order to maximize the density $n(H^o_{\uparrow})$ in Eq. (1), we have measured the velocity distribution of the H^o atoms produced under RF and gas pulsing and nozzle cooling. Knowledge of the velocity distribution will enable us to optimally place and excite the sextupole magnets.

Velocity distributions under this combination of conditions have not been measured before. Kubischta[6] mentions an unsuccessful attempt. A schematic of the time-of-flight (TOF) method used is shown in Fig. 2a. The measurements were made using the atomic beam stage of the polarized H^+ source of the ZGS. The chopper-to-detector distance was 1.5 m, and rotation speeds between 40 and 90 Hz were used. The chopper had six equally-spaced slits, each 0.05 in. wide. Some of the more interesting features of the experimental setup were:

1. Synchronization of gas and RF pulsing with the rotation of the chopper disk.

2. The time delays in the scope trigger, allowing for selection of any of the gas pulses reaching the detector (quadrupole mass analyzer) from each RF pulse (Fig. 2b). Thus, it was possible to investigate the nature of the velocity distribution at different times during the discharge. Results show significant differences in the most probable velocity for pulses obtained at different times during the discharge.

3. The digitizing oscilloscope (Nicolet Explorer IIIA) interfaced to a Data General Eclipse minicomputer which computed a running average of the signal. The discharge was pulsed at 3 Hz or less, and only one pulse per discharge was analyzed. About 1000 sweeps were averaged during a run, and the result was stored for further analysis. Figure 3 shows a single sweep TOF signal and the average of 1000 sweeps.

Data were obtained at different rotation speeds and for opposite rotations of the chopper. Preliminary analysis of the data indicates that nozzle cooling reduces the most probable H^o atom velocity from

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2.9×10^5 cm/sec (no cooling) to 1.7×10^5 cm/sec (nozzle temperature ~35°K). The width of the distribution decreased from 1.3×10^5 cm/sec to 0.6×10^5 cm/sec.

Beam Transport Studies

The computer codes TRANSPORT and TURTLE have been modified to handle sextupole magnets acting on neutral particles (H atoms in this case) having magnetic moments. Using the most probable velocity and velocity spread results obtained from the velocity and velocity measurements as inputs, it will be possible to find a configuration of sextupole magnets (and magnetic fields) and RF transition units that optimizes the intensity and polarization of the atomic beam at the center of the interaction region.

Commissioning the Atomic Beam Stage

The major modifications to the new atomic beam stage are: (1) redesigning part of the dissociator housing to incorporate the arrangement used in the ZGS source, and (2) installing an efficient system for cooling the nozzle. Special attention is being given to shielding the copper block from the surroundings. The cooling strap between the block and the refrigerator must be flexible enough to allow for about 1.0 in. of axial motion of the dissociator housing.

Cesium Beam

The cesium gun must produce a beam of such quality that, after having been neutralized in the cesium vapor neutralizer, the neutral beam has a waist in the middle of the ionizer. The length of the ionizer (33 cm), the distance from the gun to its center (~70 cm), and the diameter of the atomic beam there (~1 cm), suggests a cesium beam emittance of approximately 8π cm-mrad or less is desired. The pulse length must be at least 500 μsec long in order to match that of the linac.

The beam energy will be considerably above 40 keV, which is where the cross section for reaction (1) peaks. The reason for this is, since we are using a space charge-limited gun design, the quantity we should maximize is $\sigma V^{3/2}$ rather than σ. The available data for (1) indicate $\sigma V^{3/2}$ is monotonically increasing up to values over 1 MeV. For convenience, however, we have designed a 100 kV gun power supply, although typical operating levels will initially be lower.

To meet the above requirements, we have designed a gridded Pierce-type electrode structure for the Cs^+ ion source. The gun consists of a beam-forming electrode, an intermediate electrode, and a (gridded) extraction electrode. The shapes of the electrodes were determined using the SLAC Electron Gun Program[7] and is illustrated in Fig. 4. The use of a grid enables a high perveance gun to have a low emittance beam, since aberrations arising from the lens-effect of the aperture are greatly reduced. In addition, the grid defines the neutralization plane so that ions emerging from the gun will not be subject to defocusing space charge effects.

Based on the calculations of the SLAC program, the perveance is 0.004 μpervs with an emittance of 4.5π cm-mrad for a 3 cm diameter beam. We expect the emittance to be closer to 9π cm-mrad because of the (small) lens effect of the grid and of thermal effects of the ion emitter.

For the emitter, which is the anode of the gun, we are planning to use a CsO-alumino silicate emitter based on the type developed by R. Feeney.[3] The emitter is a wafer heated to ~1100°C, and ions are extracted from the surface by an electric field. The current density from the 3 cm diameter emitter during a 60 kV extraction pulse is 8 mA/cm², well within the capabilities of the emitter. The amount of Cs ions in the wafer will allow operation for several thousand hours.

The power supply for the Cs^+ gun is shown in Fig. 5. The Cs emitter and beam-forming electrode are maintained at a positive dc high voltage (+ 80 kV max) by the main power supply. The intermediate electrodes will normally be several kilovolts higher than the emitter due to the back biasing supply. The two tubes act as a shunt regulator to drop the intermediate electrode voltage during the beam pulse to the desired level. The time required to reach voltage is 10-20 μsec—small compared to the pulse length of 500-1000 μsec. The regulator circuit will allow programmed grid voltages wh'h will be important in maintaining the proper voltage ratio between the emitter and intermediate electrode in case the main power supply droops during the pulse. The proper ratio is nominally 4:3 for obtaining a waist in the ionization region as determined by the SLAC program. Varying the voltage on the intermediate electrode moves the waist along the axis, and thereby provides a means of focusing the beam.

The power supply for the emitter heater (~500 watts) and a thermocouple readout, as well as the back biasing supply, will be powered by an isolation transformer since they sit at the same high voltage as applied to the emitter.

Interaction Region

The interaction region, where the $H^o_\uparrow$ and Cs^o beams collide, is held at -20 kV potential and has a solenoidal field of ~.15T for maintaining the polarization of the protons. The H^- ions are produced essentially at rest uniformly throughout the length of the interaction region (30 cm), and therefore, the $H^-_\uparrow$ beam has an energy spread equal to the extraction voltage (~1 kV). The extracted $H^-_\uparrow$ beam is accelerated and focused to a waist inside the 90° deflector. Upon leaving the deflector, the beam is transported through a spin rotating solenoid and to the 750 kV preaccelerator (not shown in Fig. 1).

Although the $H^-_\uparrow$ current at the extraction end is low (~20 μA), the energy is also low (0-1 kV), and radial space charge forces are considerable, especially for those ions created near the extraction end. The radial forces can be reduced by the proper potential gradients within the beam and radially external to it. (The problem is similar to space charge limited emission of a planar diode except that the ions are created within a long cylinder rather than from a surface.) Theoretically, the potential should vary as the square of the distance to overcome the radial forces. However, the resultant final energy and energy spread in the beam would be much too high (~8 keV), so we have chosen to use a small constant gradient over the first half and a large constant gradient over the remainder. The electrode structure allows a variety of gradients. The final energy of the H^- beam after extraction to ground potential is 20 keV with an energy spread of ± 500 eV.

Acknowledgments

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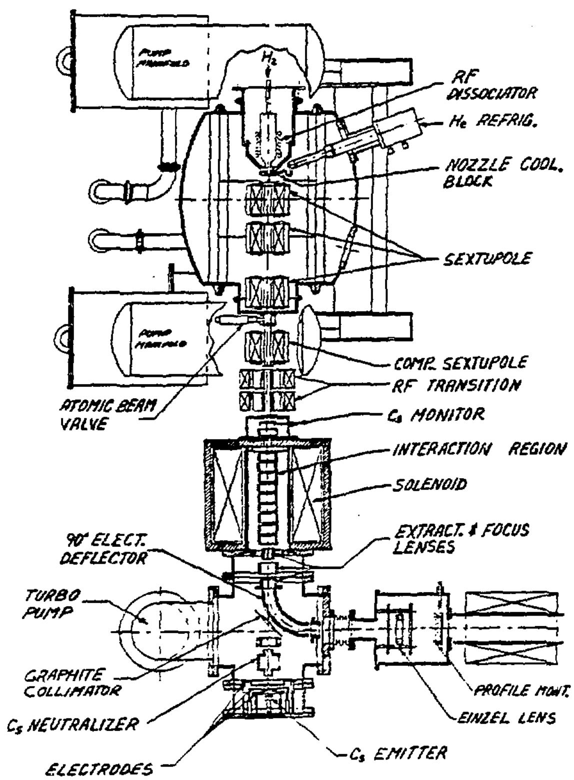

Fig. 1. The AGS Polarized Negative Ion Source Under Development by Argonne National Laboratory and Yale University

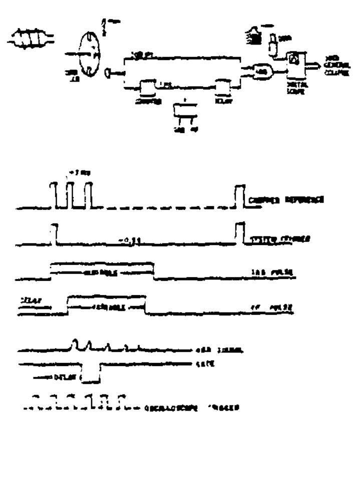

Fig. 2. Time-of-Flight Experimental Arrangement. See Text.

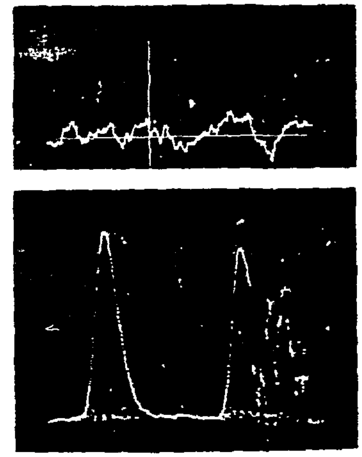

Fig. 3. Signal Averaging of the Time-of-Flight Signal. Top: One Pulse. Bottom: Average of 1000 Pulses.

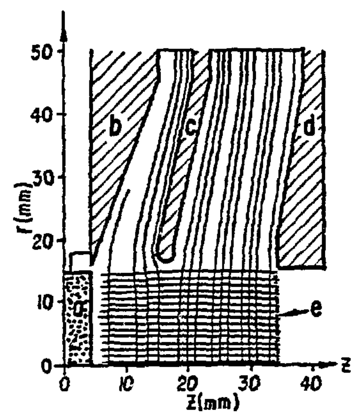

Fig. 4. Electrode Structure for the Cs^+ Gun: (a) Cs^+ Ion Emitter; (b) Beam Forming Electrode; (c) Intermediate Electrode; (d) Final or Ground Electrode; (e) Grid.

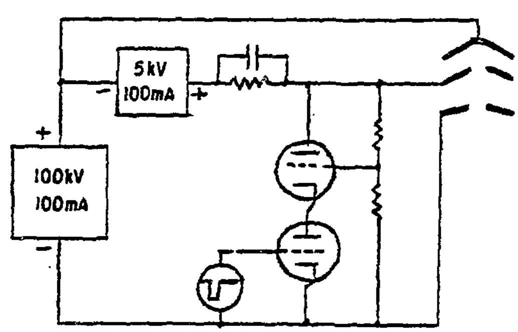

Fig. 5. Schematic of the Cs^+ Gun Power Supply