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POLARIZED NEGATIVE HYDROGEN SOURCE FOR THE AGS

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POLARIZED NEGATIVE HYDROGEN SOURCE FOR THE AGS*

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1. INTRODUCTION

A collaboration has been formed to create a high energy polarized beam facility at the Brookhaven National Laboratory AGS.[1] Argonne National Laboratory, in collaboration with Yale University, will provide the polarized source as part of its contribution. It must produce polarized H^- since the AGS is converting to H^- injection. Intensity is critical because of the short linac pulse ($\leq$ ½ msec). Our design is based on a source recently built by W. Haeberli at the University of Wisconsin.[2,3] This is the first source that uses the reaction $Cs^0+H^0_\uparrow \rightarrow Cs^+ + H^-_\uparrow$, and it has excellent intensity (1-3 μAmps DC) and polarization (∿90%). Using the improvements described below, the AGS source should produce a much higher intensity (pulsed) and should retain the high polarization of the Wisconsin source. It is scheduled to be operational at BNL by October 1982.

Figure 1 shows a sketch of the planned source. An atomic beam is produced by the dissociator using an RF-induced discharge. The sextupoles select one state of electron spin, $m_j = ½$, by focusing it while defocusing the $m_j = -½$ state. By focusing the $+½$ state, they also increase the atomic beam intensity. The RF transitions transfer the electron spin to the proton. Either proton spin state can be selected. The atomic beam next enters the charge exchange channel where it collides with a 40-keV (or possibly higher energy) neutral cesium beam. A small fraction of the $H^0_\uparrow$ charge exchanges to form $H^-_\uparrow$ which are extracted out of the channel at 20 kV and then bent out of the source by a double-focusing electrostatic mirror. The Cs gun will produce a 40-keV or higher Cs^+ beam which is neutralized with high efficiency (∿90%) in Cs vapor by resonant charge exchange. The neutralized beam passes through a hole in the electrostatic mirror and then enters the charge exchange channel.

The next several sections of this paper will describe, in more detail, the major systems of the source.

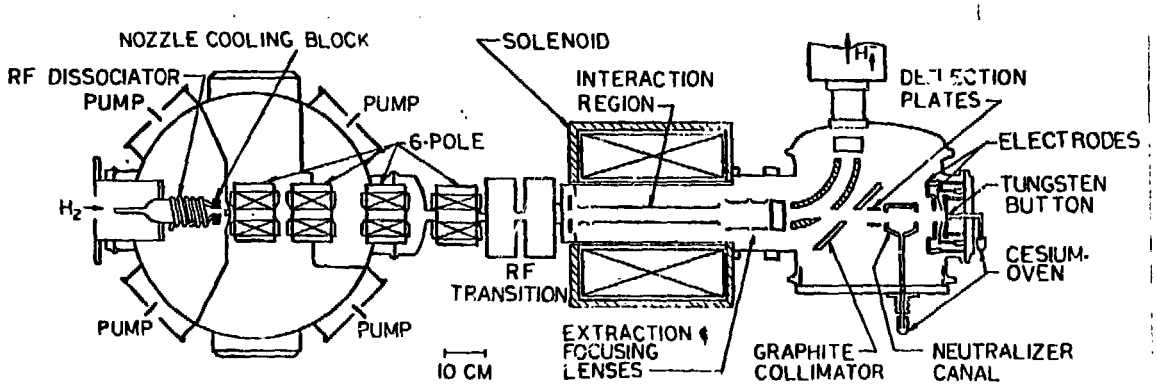

Fig. 1. Drawing of the Present Design of the Source

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2. ATOMIC BEAM STAGE

The atomic beam stage, which includes the dissociator, four sextupoles, the RF transitions, and the associated vacuum system is the newest model manufactured by ANAC, Inc. This stage is the next generation after the ANAC stage that was used during the ZGS polarized program. A factor of two gain in intensity was realized in the ZGS source by pulsing the dissociator RF and gas.[4] This improvement will also be used on the new stage. The pulsing gain is presumably due in part to the reduced gas scattering of the atomic beam. An additional factor of 2½ was gained by cooling the nozzle of the dissociator bottle.[5] Nozzle cooling reduces the velocity and emittance of the atomic beam which, in turn, increases the atomic density in the charge exchange channel. Empirically, the intensity gain varies roughly as $T^{-\frac{1}{2}}$.[5] The nozzle cooling system to be implemented on the new stage will reduce the nozzle temperature from about room temperature to 30° K. The atomic beam speed should be about 10^5 cm/sec.

Based on our experience with the ZGS stage, the new stage should produce about 4×10^{16} atoms/sec into 1 cm^2. With a speed of 10^5 cm/sec, this implies a density, n, of 4×10^{11} atoms/cm^3 in the charge exchange channel.

3. THE CESIUM GUN

The Wisconsin source uses a heated, porous tungsten plug as the anode for the Cs^+.[2,3] While this is an excellent choice for a DC gun, it is poor for a pulsed source. Such guns operate only when the proper Cs coating (less than an atomic monolayer) is kept on the anode surface.[6,7] Maintaining that layer is a delicate balance between the diffusion of Cs to the plug surface and the evaporation of Cs^+ off the surface. We believe that it would be difficult to maintain that balance in a pulsed gun. While pulsing is not required, it is clearly attractive from a maintenance and reliability point of view. Other possible gun types are:

1. Hot plate coated by a pulsed Cs^o vapor jet,[6]
2. Penning discharge, and
3. "Zeolite" button impregnated with Cs^o.[8]

Whatever type we select, it will use a (space-charge limited) Pierce geometry in order to minimize emittance and maximize stability. We are tentatively planning on a gun voltage of 40 kV. However, it is not clear what the optimum voltage is. Because we will use a space-charge limited design, the optimum voltage is not where the charge exchange cross section, $\sigma(V)$, peaks, but where $\sigma(V)V^{3/2}$ peaks. The available data[9,10] suggest 100 kV may be a better choice than 40 kV.

All the techniques we are looking at should be able to produce 2 mA/cm^2 of anode surface. Using an emitting surface of 3 cm^2 (approximately the Wisconsin case) leads to 6 mA of Cs^+. The problem is to transport this beam into the charge exchange channel. Because of the neutralizer, all beam matching into the charge exchange channel must be done either by the gun or between the gun and neutralizer. The atomic beam is about 1 cm in diameter and the charge exchange channel is about 30 cm long, which implies the Cs^o beam emittance must be less than 8.3π mrad-cm in both planes. It may not be practical to achieve ideal matching conditions as the distance from the gun to the center of the charge exchange channel is about 60 cm. In this case, the Cs^o emittance may have to be better than the above number. We are looking at using additional focusing between the gun and the neutralizer. However, electrostatic focusing

destroys the beam space charge neutralization and magnetic focusing is cumbersome for the cesium energies we are considering. Our hope is to have the beam adequately matched by the gun itself. The biggest possible gains (and biggest possible losses) in our program are to be found in the gun design, and we are looking at it carefully.

4. NEUTRALIZATION

Neutralization of the Cs^+ beam is by resonant charge exchange in a cesium vapor. The cross section is $\gtrsim 10^{-14}$ cm^2 below 100 kV,[11] which means that vapor densities of 10^{14}/cm^3 over a few centimeters will provide nearly complete neutralization. Such a density can be produced by a vacuum spark-induced cesium vapor jet developed at LBL.[12] This technique has the advantage of being pulsed, which will reduce the cesium contamination. We are planning to test such a vapor jet.

5. CHARGE EXCHANGE CHANNEL AND ELECTROSTATIC INFLECTOR

These units are being procured from ANAC. The charge exchange channel has several requirements. It must provide a solenoidal magnetic field of about 2 kG to maintain the polarization and a weak electric field (<1 V/cm) to extract the $H^-_\uparrow$. The charge exchange channel must be at about 20 kV to accelerate the extracted $H^-_\uparrow$ beam. The inflector extracts the beam out of the source. Since the entire source will sit at 750 kV, the 20 kV beam line leads to the preaccelerator high voltage column. The inflector must have a hole in it to allow the Cs^o beam into the charge exchange channel.

The existing cross section data for the charge exchange reaction are not consistent.[9,10] Below, we will use a conservative number of 3×10^{-16} cm^2, which is from Reference 9 at 100 kV.

6. INTENSITY

The source current is given by the expression $I(H^-_\uparrow) = \sigma\, n\, L\, I(Cs^o)$, where σ = charge exchange cross section in cm^2, n = number of $H^o_\uparrow$ atoms per cm^3, and L = length of charge exchange channel in cm. Using $\sigma = 3 \times 10^{-16}$ cm^2, $n = 4 \times 10^{11}$/cm^3, L = 30 cm, and $I(Cs^o)$ = 6 mA (this is a "neutral current") gives $I(H^-_\uparrow)$ = 22 μamp. This current implies 4×10^{10} ppp extracted at high energy from the AGS for a ½ msec linac pulse and for an overall efficiency of 60%.

It is interesting to speculate on what may be the ultimate performance of a cesium charge exchange source. The cesium gun is the obvious place to look for large increases in intensity. The Heavy Ion Fusion group at ANL has a Penning discharge source built by Hughes Research Laboratory that produces 100 mA of singly-charged Xenon with a satisfactory normalized emittance.[13] A similar cesium source would be easy to make. Therefore, it seems reasonable to consider beam intensities an order of magnitude higher than the 6 mA used in the calculation above.

It is not likely that the atomic density, n, can be increased by a large amount. However, increasing the atomic beam diameter while maintaining the density would allow large increases in the cesium beam emittance, hence current.

Another possibility is to produce multiple beams or essentially multiple polarized sources. The emittance of each beam can be made small by charge exchange in a weak field as described by Glavish.[14] While this scheme lacks elegance, it does have some features. A single, multi-hole source could provide all the cesium beams. The sextupoles could be rare-earth permanent magnets and the charge exchange solenoids are simple because of the weak field.

It is not unreasonable to expect a combined factor of four gain from among the above schemes. This, and the factor of ten gain in cesium current, would lead to over 10^{12} ppp. The AGS linac pulse length can be increased to 3 msec,[15] which leads to about 10^{13} ppp! Therefore, intense development of the cesium charge exchange source, combined with straightforward improvements to the AGS linac, has the possibility of providing polarized intensities comparable to unpolarized intensities at the AGS.

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