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COOLING HIGH INTENSITY ATOMIC HYDROGEN BEAMS TO LIQUID HELIUM TEMPERATURES*

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Abstract

An atomic hydrogen source, designed to operate in the viscous flow range, has been built at BNL. A unique feature of this source is a miniature gap between a teflon tube which guides the beam and an accommodator which cools it. Across this gap a step-function in temperature, with the teflon temperature exceeding 100°K and the accommodator temperature below 8°K, was successfully maintained. This configuration collimates the beam enough to prevent significant diffusive losses without subjecting it to the temperature range of high recombination. Initial results with an orifice of only one-tenth the dissociator aperture are indicative of particle density in the beam of well above 10^{10} cm^{-3}.

Introduction

Sources of polarized atomic hydrogen beams which are based on magnetic separation employ various forms of beam cooling. The advantage of cooling hydrogen atoms before their exposure to a magnetic field gradient for spin selection has been recognized for quite some time.[1] The force on an atom due to the interaction of its magnetic moment with the magnetic field gradient, is such as to minimize its potential energy which changes by μB at high magnetic fields. However, for an atom to pass through such a magnet, its energy associated with perpendicular motion must be lower than μB. Consequently, an acceptance solid angle $\Delta\Omega$ is roughly determined by

$$\Delta\Omega \approx \mu B/kT \qquad (1)$$

It is obvious from Equation (1) that by lowering the temperature by an order of magnitude, the polarized beam flux should increase by the same factor. Furthermore, for some ionizers, the ionization efficiency increases with density, and if beam cooling can be accomplished with only minimal loss of flux, another factor of $T^{-0.5}$ can be gained in the overall intensity of a charged nuclear spin polarized beam.

At BNL, an experiment to test the possibility of cooling high intensity atomic beams has been constructed (see figure). In this device, an atomic hydrogen beam is produced by a conventional dissociator similar to that of PONI 1.[2] The beam is guided by a teflon section into an accommodator which is cooled by a cryostat to liquid helium temperatures. Hence, the cooling is achieved by collisions with the cold accommodator surface. This apparatus is very similar to other devices[3,4] in which low intensity beams have been successfully cooled to the 5-8°K range. Walraven and Silvera's source[3] achieved an 8°K beam with 2.4×10^{16} atoms/sec. Crampton[4] obtained 4.5×10^{13} polarized atoms/sec at an accommodator temperature of 5.35°K. Our objective is to cool to that temperature range a beam of more than 10^{19} atoms/sec. Another way of comparing beam intensities is the size of the dissociator orifice. In Walraven's source the orifice area was 0.1 mm^2. In our first attempt we started with 0.8 mm^2 and intend eventually reach over 9 mm^2.

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Optimization of Beam Transport and Cooling

Atoms are produced in a dissociator whose nozzle is cooled to liquid nitrogen temperature. The atoms are then guided by a short teflon tube into the accommodator. Being that the teflon is between the 80°K nozzle and the liquid helium temperature accommodator, the 10°K to 70°K temperature range exists in the teflon section. This is a bad temperature range since all materials have a high recombination ratio and the temperature is not low enough for a frozen H_2 coating to be formed. At a low beam flux, the effect of the "bad" temperature range can be minimized by either restricting[3] this range to a small region in the teflon section where very few wall collisions occur; or, by leaving a "large" gap[4] (cm) between the source orifice and the accommodator and since the accommodator diameter is larger than that of the orifice, only a small part of the atomic beam is lost. For a high beam flux, where the flow is viscous, neither solution is acceptable due to the high collisionality of the gas and the large source orifice. The high collisionality makes even a 1 mm region of "bad" temperature unacceptable and the size of the source orifice combined with the high collisionality requires a very large accommodator diameter which is impractical. Our approach is to have a very small gap between the teflon section and the accommodator which is enough to isolate them thermally. The teflon temperature is maintained above 80°K by means of a heater. In this way the beam is not subjected to a temperature range with high recombinations and it is collimated enough to prevent significant diffusive losses.

Physical phenomena in the accommodator are better understood due to extensive studies performed by Crampton and co-workers described in Reference 4, as well as many earlier papers which are cited in References 3 and 4. There are two competing effects which determine the optimum accommodator temperature for a given flux. The lower the temperature, the better the frozen H_2 coating as well as the lower the vapor pressure which minimizes scattering of H° by H_2. However, the surface dwell time of H° increases as the temperature decreases. Thus, to minimize recombination losses, the temperature must be increased. Consequently, there is an optimum temperature, which for a given flux can be determined by adjusting the accommodator temperature. Nevertheless, at a different (higher) flux, the accommodator geometry must also be optimized to ensure enough wall collisions to cool the beam without having excessive recombinations. This optimization is much more difficult to achieve.

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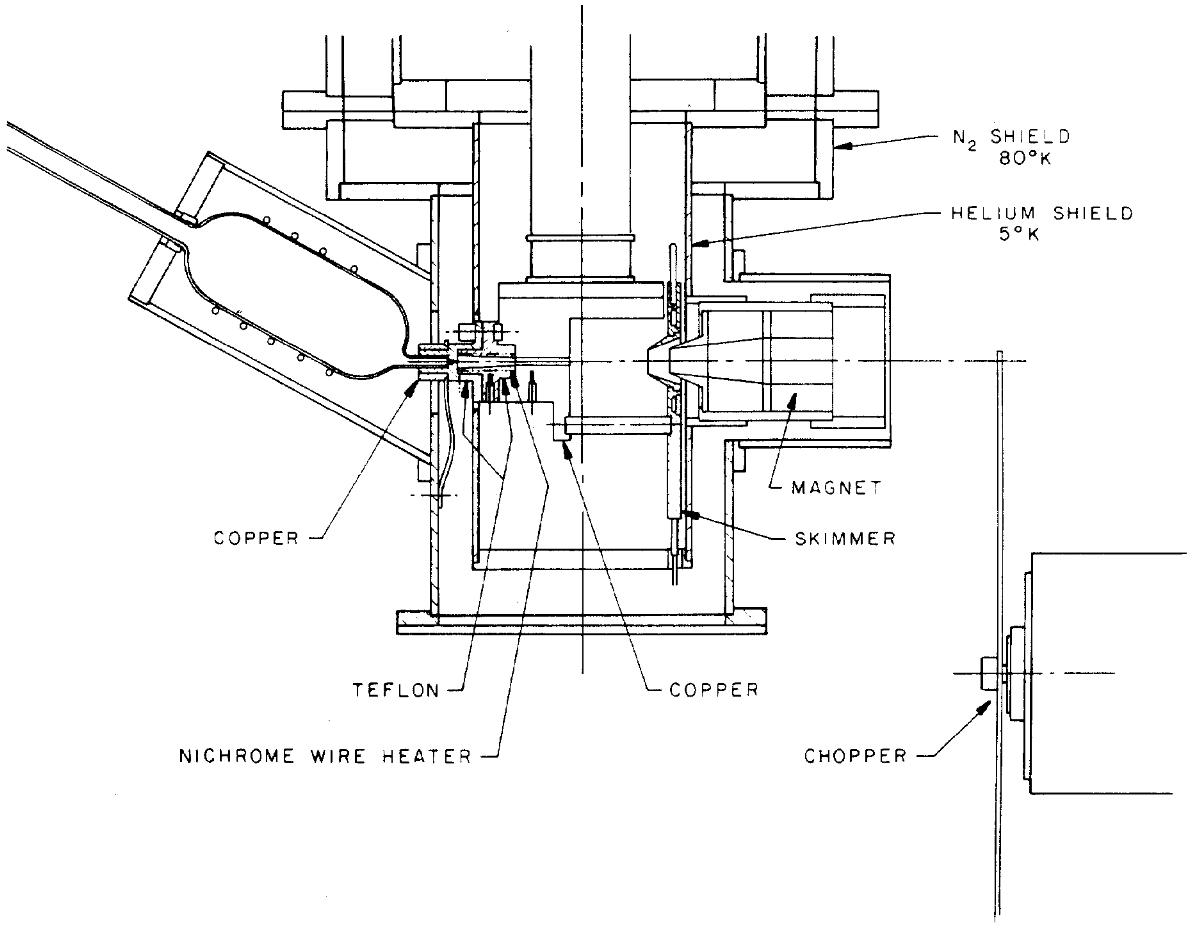

Figure 1 - Schematic of the cold atomic source.

Initial Results

With an orifice of 0.8 mm^2 initial experiments have been performed. The various components seem to work well. At the foot of the cryostat, a temperature as low as 3.8°K was maintained without thermal loading (i.e., no atomic beam) and as low as 4.1°K with the dissociator on. Also, across the gap, a step function in temperature was successfully maintained. The teflon section was kept above 100°K while the accommodator temperature (as measured at the foot of the cryostat) was varied between 4°K and 8°K. A UTI C100 RGA was placed in the chamber at a distance of 39 cm downstream from the accommodator exit to measure the density of the cooled atomic beam. Based on the calibration of this RGA against a calibrated ion gauge (done by the AGS Vacuum Group) for H_2 and based on the relative sensitivity of the RGA to H_2 and H_o, the density of the cooled atomic beam was determined to be 9.1×10^{10} cm^{-3}, when the accommodator temperature was about 6°K. The significance of this result is that the orifice area is an order of magnitude smaller than that of the dissociator aperture.

Experiments are in progress to determine the optimum accommodator temperature. The procedure is to monitor the RGA signal as a function of the accommodator temperature. The range explored was 300°K to 56°K and 5°K to 4.7°K. Unfortunately, due to arcing, the dissociator power supply was operated at 65% of capacity during measurements at the lower temperatures. Nevertheless, the peak RGA signal was observed at an accommodator temperature of 5°K. The 5°K to 56°K has yet to be explored. Also, the cooling will be measured via the beam velocity which will be measured by the time-of-flight method.

References

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