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8.5 A Low Temperature Atomic Beam for the ETH Polarized Hydrogen Ion Source

P.A. Schmelzbach, D. Singy, W.Z. Zhang+ and W. Grüebler

Institut für Mittelenergiephysik, Eidg. Techn. Hochschule
CH-8093 Zürich, Switzerland
+ Shanghai Institute of Nuclear Research
P.O. Box 8204, Shanghai, China

The atomic beam method has proven to be a very powerful technique for the production of polarized hydrogen ions and the prospects for future improvement are very promising[1)]. A significant increase of the beam intensity is expected from the redesign of the atomic beam stage in order to take full advantage of the use of low velocity atoms which allow larger acceptance of the magnet system and higher ionization efficiency. We present here some results obtained during the development of a cooled atomic beam for the ETH polarized hydrogen ion source.

Magnet design. The acceptance of a sextupole magnet shows a T^{-1} dependence which suggests, together with a $T^{-\frac{1}{2}}$ variation of the ionization efficiency, a very large increase of the ionic output, if the velocity of the atoms is decreased. However, the acceptance of the sextupole magnet is not a reliable criteria in a practical source, since other elements can reduce the usable phase space. We have used the acceptance diagram technique to investigate the properties of the whole system (diaphragms, magnets, drift spaces, ioniser)[2)]. The geometry of the existing ionizer set an upper limit to the acceptance of the system. The beam transport has to be designed accordingly. A typical configuration which also provides the necessary free space for the rf-transition units is shown in fig. 1. Two magnets are needed for achromatic focusing. The system is characterized by the shortness of the magnets (10 and 15 cm), large apertures (20 and 30 mm) and a large distance between the two magnets. The maximum fields on the pole tips are 1 Tesla and 0.7 Tesla. The whole atomic beam apparatus can be moved easily in order to change the distance between the second magnet and the ionizer. The efficiency of the beam transportation, defined as the ratio of the mean atomic density in the ionizer to the density at the skimmer, is calculated at a velocity of about 1000 m/s to be one order of magnitude larger than in our room temperature source. The calculations have been performed with measured velocity distributions. On a test bench good agreement was found between calculated and measured properties of the magnet system. For these investigations a quadrupole mass spectrometer was used. Its location corresponded to the center of the ionizer in the polarized ion source.

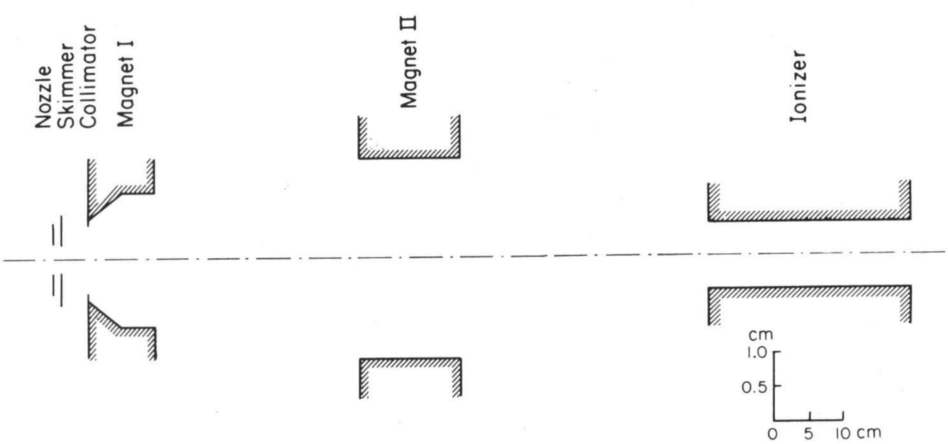

Fig. 1 Atomic beam transport system for the ETH polarized ion source.

Cooling of the atomic beam. The atoms generated in a room temperature dissociator are transported through a Pyrex and Teflon tubing to a copper accommodator, of which the end forms the nozzle. Cooling is provided by a closed-cycle He Refrigerator. Numerous geometries of the accommodator have been investigated, the goal being to simultaneously optimize thermal accommodation, recombination and beam formation. Good results are obtained with a conical channel 20 mm long having an exit aperture of 3 mm diameter.

The nature of the accommodator surface is a crucial point to avoid recombination of the atoms. The material of the accommodator, however, is not of primary importance. Oxydized or unoxydized Cu, Al, Teflon coating on these materials show the same behaviour at low temperatures, leading us to the conclusion that under practical conditions of gas and vacuum cleanness the role of frozen or adsorbed species dominates. We found that doping the gas with a small amount of N_2 allows to create and maintain a good recombination inhibiting surface at about 35 K. The H-atoms generated this way have a velocity around 1000 m/s, roughly 3 times lower than in a room temperature source. With our arrangement beam cooling down to 20 K is feasible, however, at the cost of an increased recombination and a less good optical matching to our geometrical requirements.

Beam formation. Basically, we use the same vacuum system as in our previous apparatus . Due to the increase of the relevant cross sections a low temperature, beam formation and scattering are expected to differ from the situation at room temperature. Particularily the nozzle-skimmer geometry has to be reconsidered. The beam formation occurs in a regime between opaque mode and free jet expansion. In contradiction to supersonic beam design considerations a small nozzle-skimmer distance (~ 4 mm) and a short and widely open skimmer ($\alpha = 90^0$) give the best results, the diameters of the nozzle and skimmer being 3 and 4 mm respectively. Measurements of the velocity distributions show a strong flux dependence of shape and most probable velocity. The distributions are quite narrow, but also characterized by a deficiency in low velocity particles. Currently, the maximum beam is observed at a gas flow of 30-40 cc/min, i.e. about 4 times smaller than at room temperature. At higher fluxes, an increasing mismatch is observed between beam properties and acceptance of the present beam transportation system.

The performance of the vacuum system has been checked by varying the residual gas pressure or adding a 3500 l/s diffusion pump at several location. The limitations of the routinely used vacuum system introduce a loss of 20-30% in the first stage (nozzle chamber) and of 10% in the second stage (skimmer-collimator chamber). Attenuation of the beam as a function of various distances has been investigated also. No evidence of skimmer interference at small nozzle-skimmer distances has been observed. Apparently, only the conditions at distances smaller than 1-1.5 nozzle diameters are relevant to the beam characteristics.

Ion beam intensity. Beams of more than 10^{17} atoms/s have been observed at the exit of the atomic beam apparatus. For some applications of atomic beams this intensity could even be further increased. However, since in a polarized ion source using a cooled beam the usable phase space is limited by the geometry of the ionization volume, this number alone is of little use to judge the performances of the whole system or to compare different devices. During the development of the apparatus we have used relative density measurements at the ionizer location as a criteria for the optimization.

Now the cooled atomic beam apparatus is installed at the ETH polarized ion source. So far, an increase in ion beam intensity by a factor of 4 has been observed. First experiences show that the atomic beam optic has to be slightly adjusted to get a better overlapp with the electron beam in the ionizer. Further work is needed to efficiently form a cooled atomic beam at higher gas flow. The source will than produce very intense DC beams of more than 1 mA positive or 50 µA negative polarized hydrogen ions.

References

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