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PROGRESS REPORT ON THE COOLED ETH POLARIZED ION SOURCE

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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.

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.

For the investigation of the problems arising in the production of cooled high density atomic hydrogen beams we have built at ETH a test bench for an atomic beam apparatus. The experimental set-up is shown in Fig. 1. The hydrogen molecules are dissociated at room temperature in a

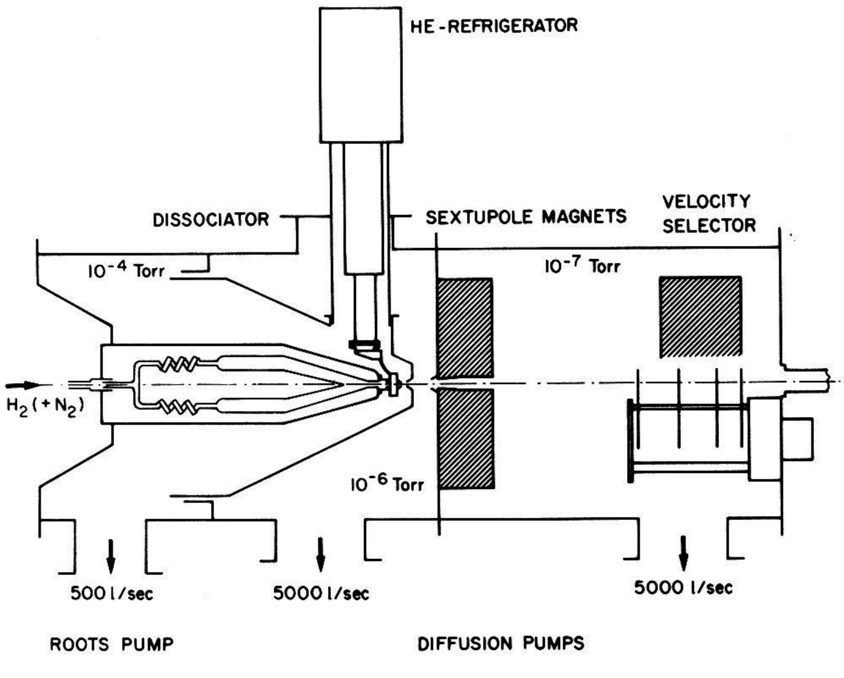

Fig. 1. The ETH experimental arrangement for cooling a high density atomic beam.

Pyrex tube by a 27 MHz rf discharge and the produced atoms are transferred through a short Teflon tubing to a copper accommodator. The accommodator is cooled by a closed cycle ^{4}He-refrigerator. A nozzle, a skimmer and a collimator at the entrance in the magnet chamber form the particle beams. Two sextupole magnets allow to study the effect of the desired atomic states. A velocity selector is used to study the velocity distribution of the produced atomic or molecular beams. These investigations are carried out for judging the efficiency of the cooling, the properties of the beam forming elements and the degree of dissociation obtained in the atomic beam. The measurement of the density of the beam is accomplished by a quadrupole mass spectrometer with a cross beam ion source. The intensity of the beams is measured in a compression tube containing an ionization gauge. The velocity measurements have been tested with molecular hydrogen and deuterium beams as well as with helium beams.

Numerous geometries of the accomodator 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 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.

A typical example for a cooled atomic beam is shown in Fig. 2. The experimentally determined width (FWHM) is about half of the width of the Maxwell distribution. The increase of the most probable velocity compared

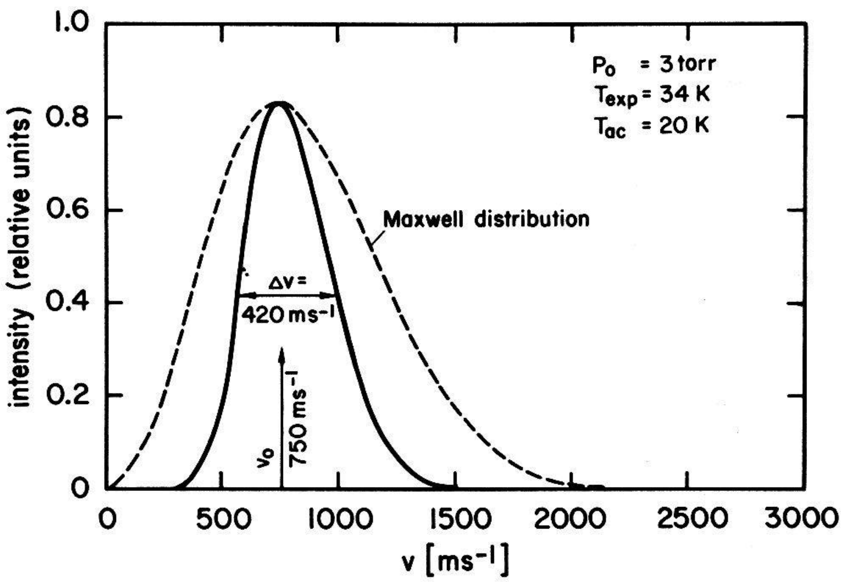

Fig. 2. The velocity distribution of an atomic hydrogen beam measured at the ETH atomic beam apparatus. Temperature of the accommodator 20 K. Pressure in the dissociator p_o=3 torr.

to the accommodator temperature and the decrease of the width arises from the gasdynamical character of the beam forming and expansion of the atomic gas from the accommodator into the vacuum. A more detailed description of this investigation is given in ref. [2, 3 and 4].

Atomic beam formation.

Basically, we use the same vacuum system as in our previous apparatus. Due to the increase of the relevant cross sections at low temperature, beam formation and scattering are expected to differ from the situation at room temperature. Particularly 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 consideration a small nozzle-skimmer distance (~4 mm) and a short and widely open skimmer ($\alpha=90^{o}$) 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 locations. 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.

The separation magnets.

At ETH we have developed two types of sextupole magnets 10 and 15 cm long, which are designed in a modular technique such that the pole pieces can be changed in a simple way. Computer programs have been developed to analyze a variety of configurations by the acceptance diagram technique and to calculate single trajectories of electron polarized atoms for lens systems of up to four sextupole magnets. In practice, we have in a atomic beam a velocity distribution similar to Fig. 2, but a velocity around 1000 ms^{-1} (roughly 3 times lower than in a room temperature source) was found to be the best compromise for high density and intensity [4].

Intensive computer simulations for optimizing the geometry of the sextupole lens system, using the velocity distribution found from cooled beams and for realistic starting conditions, have been performed in order to obtain a maximum acceptance and transmission of the separation magnets.

The usual method to design a magnet system is the calculation of trajectories in the magnet system. This method makes it difficult to extract global and systematic information on the behaviour of either the whole system, or of a single element, if parameters of the system are changed. We have found that the application of the acceptance diagram technique to atomic beam systems has great advantages in order to match the optical properties of the magnet systems with other elements of a source or target [5]. A typical example of such an acceptance diagram for a two component magnet system is shown in Fig. 3. Here the acceptance diagram of all components of the system has been transferred to the colli-

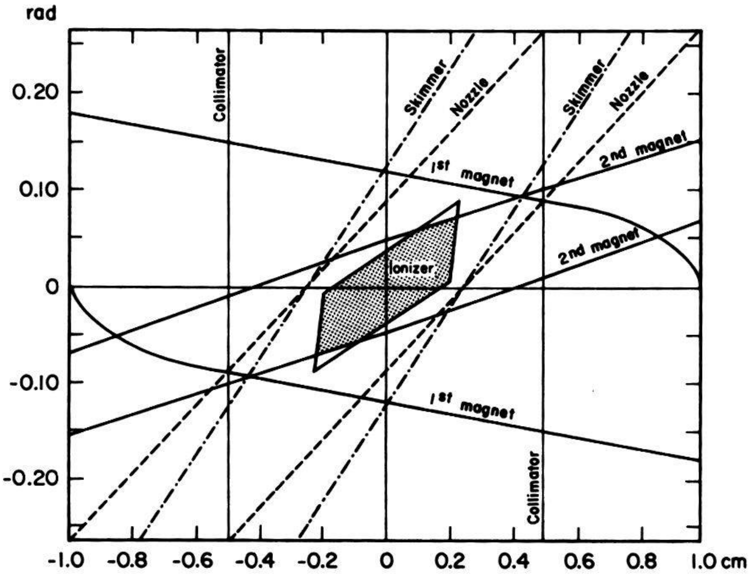

Fig. 3. Acceptance diagram for a two magnet system. For details see ref. 5.

mator position at the entrance of the first magnet, and the area of the overlap region (i.e. the acceptance area) of the whole system is shown. At present the most limiting element of the ETH polarized ion source is the ionizing region.

The present system is characterized by the following features. Two short magnets (10 and 15 cm) are used for achromatic focusing. The apertures of the magnets are large (20 and 30 mm) and a long distance between the two magnets (cf. fig. 1) provides the necessary free space for the rf-transition units in order to produce single state atomic beams. 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. On the test bench good agreement was found between calculated and measured properties of the magnet system.

Results

At ETH, the improvements obtained so far by an atomic beam cooled to a temperature of approximately 35 K and the new design of the separation and focusing sextupole magnet system have resulted in an atomic beam intensity of

$$I_{\vec{H}} = 10^{17} \text{ atoms s}^{-1}$$

with a peak density of

$$n_{\vec{H}} = 2 \cdot 10^{12} \text{ atoms cm}^{-3}$$

at the ionizer entrance.

The cooled atomic beam has recently been installed at the ETH polarized ion source. First experiences show that the atomic beam optic has to be slightly adjusted to get a better overlap with the electron beam in the ionizer. The high efficiency electron bombarding ionizer of ETH reported in ref. [6] has been modified for minimum maintenance on the account of a 30% loss in efficiency. The observed positive ion beam with this modified ionizer is at an energy of 5 keV in dc mode

$$I_{\vec{H}} = 400\ \mu A \quad (\sim 500\ \mu A).$$

After double charge exchange the negative polarized ion beam intensity at 60 keV in dc operation is

$$I_{\vec{H}} = 16\ \mu A \quad (25\ \mu A).$$

The values in the brackets are expected from the original version of the ionizer. These results correspond to a gain by a factor 4 compared with the room temperature source. For operation in a pulsed mode, 3 times higher intensities can be expected.

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