

POSSIBILITY TO OBTAIN A POLARIZED HYDROGEN MOLECULAR TARGET

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It seems the existing Atomic Beam Sources (ABS) have reached a limit of their intensity of about 10^{17} at/sec. In the proposal we discuss a possibility to obtain a flux of polarized ortho-hydrogen molecules with higher intensity by using a separation in inhomogeneous magnetic field. Some aspects of molecular beam formation and separation system are presented. The results of Monte-Carlo simulation of beam formation and separation of molecules are outlined.

1. Introduction

1.1. Limitation of the ABS method

The application of internal polarized gas targets in the storage ring of charged particles has opened a new area of physical experiments, inaccessible earlier in experiments with the beams extracted from the accelerator. The pioneering use of internal polarized deuteron target at the VEPP-3 storage ring in BINP [1] has demonstrated the advantages of this method – easy and fast guidance of the polarization of the target and its direction, possibility to detect interaction particles in coincidence and so on. This method is widely used in many laboratories - HERMES target at the DESY electron storage ring HERA [2], PINTEX target at the IUCF cooler ring [3], ANKE target at COSY [4], JET target at RHIC [5] and others [6]. The major element of all mentioned targets is an Atomic Beam Source (ABS) based on Stern-Gerlach separation of atoms in inhomogeneous magnetic field. Usually permanent sextupole magnets of FeNdB with a magnetic pole-tip field of up to 1.7 T are used as a spin filter and produce an electron-polarized atomic beam. In a Cryogenic ABS superconductive magnets with a pole-tip field up to 4.8 T are used [7]. By using adiabatic radiofrequency transitions between hyperfine levels electron polarization is converted into nuclear polarization. The intensities of the existed ABSs are shown in the Table. These intensities have been achieved at the moderate flow rate of gas through the nozzle. With the increasing flow rate the intensity of the beam remains constant or decreases. There are many factors which define the maxima achievable intensity of the atomic beam from the ABS. We just can mention about the dissociation and recombination atoms in the discharge tube, pumping speed required in the nozzle chamber and

Table. Intensities (at/sec) of the atomic beam being achieved at modern sources

	RHIC	CABS	ANKE
Intensity	$12 \cdot 10^{16}$	$8 \cdot 10^{16}$	$7 \cdot 10^{16}$

down along the beam, problems of beam formation under the expansion into vacuum [8], intra-beam scattering which might be an additional loss mechanism, optimization of the magnet system for a given velocity distribution and others. Not all of these factors are completely understood up to now. Usually an atomic beam is injected into the T-shape storage cell. Not all the atoms from ABS could be injected into the cell. Typical value of the efficiency is about 60-70 %. The modern ABS could provide an internal polarized target with thickness $2.1 \cdot 10^{14}$ nucl/cm² for deuterium and $1.1 \cdot 10^{14}$ nucl/cm² for hydrogen [2].

For new proposed polarized facilities [9] a filtering polarized proton target with much higher thickness is required to get a reasonable polarization time of antiproton beam. It seems that the ABS method has a limit to produce a target with a thickness of about $1 \cdot 10^{15}$ nucl/cm². Even if an ABS with much higher intensity will be created it will be impossible to obtain the needed target. This is due to the inability to inject atomic beam into the tube where the areal density has the same order of magnitude $1 \cdot 10^{15}$ nucl/cm². Just because the cross section for H-H scattering is about $1 \cdot 10^{-14}$ cm².

2. Target of Polarized Molecules

2.1. Magnetic properties of o-H₂

In [10] it was proposed to use molecular hydrogen to obtain a polarized proton target. At normal conditions a hydrogen gas is a mixture of para-hydrogen p-H₂ and ortho-hydrogen o-H₂ in a proportion of 1 : 3. p-H₂ has a

total spin of protons equal zero and even values of quantum rotational number, o-H₂ has total spin equal 1 and odd values of quantum rotational number. At the ground state p-H₂ has no magnetic moment and for o-H₂ the magnetic moment is a sum of spin and orbital moments. Figure 1 shows the energy diagram of o-H₂ versus a magnetic field. For the substates A, B and C magnetic moment in a high magnetic field equals approximately 5μ_n where μ_n is nuclear magneton, μ_n = 0.5 · 10⁻²³ CGS. The first spatial separation of o-H₂ molecules in inhomogeneous magnetic field have been done by Frisch R. and Stern O. [11].

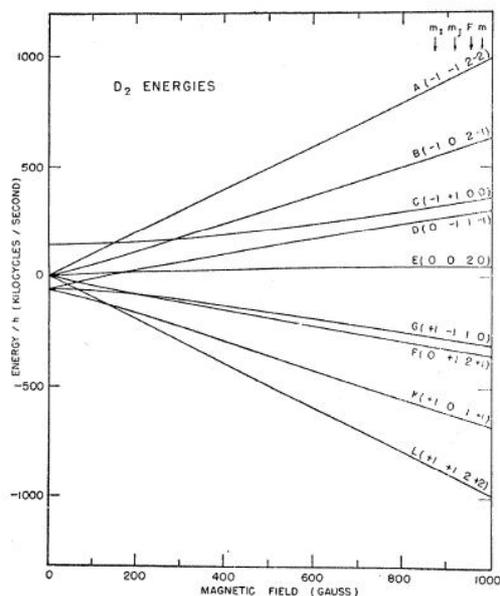


Figure1. Energy diagram of o-H₂ versus the magnetic field.

2.2. Separating magnet

We propose to use axisymmetric multipole superconductive magnet to get a spatial separation of the molecules with different projections of full moment. In an ideal axisymmetric multipole magnet the magnetic field distribution is given by

$$B=B_0 \cdot (r/r_{\text{mag}})^{N/2-1}, \quad (1)$$

where r_{mag} is an aperture radius of the magnet, N – number of poles. For the estimates let us set N=32, the entrance radius of the magnet r_{mag1} = 10 cm, the exit radius of the magnet r_{mag2} = 9 cm, length of the magnet L_{mag} = 200 cm and the magnetic poletip field B₀ = 4 T. Having some experience in construction and operation of superconducting magnet we suppose that such a magnet might be manufactured [7]. In such a magnet the magnetic field and its gradient are large only near

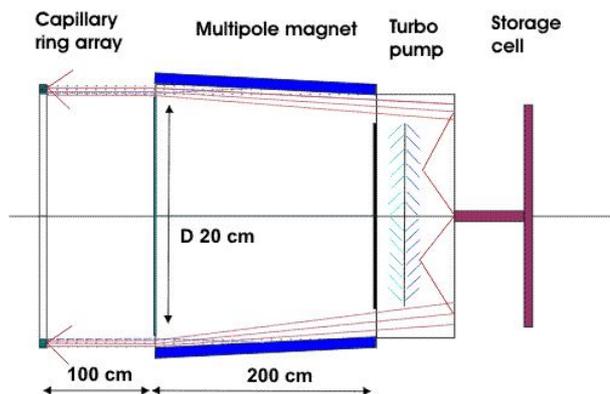


Figure 2. Schematic view of the source of polarized molecules.

the poletips. Therefore a ring aperture near the poletips can be used for a spatial separation of the substates. For our estimation we set an average radius of the ring aperture 9.5 cm and width of the ring 0.5 cm. A schematic view of the source of polarized molecules is presented in Figure 2.

2.3. Source of molecules

We will assume that the source of molecules is a ring aperture with an average radius 9.5 cm and width of the ring 0.5 cm placed at the 100 cm distance from the magnet entrance, see Figure 2. The aperture of the source is filled by capillaries with a diameter of 0.1 μm and length of 10 μm. For the same total flux under a free molecular flow such a capillary has provide an intensity forty time higher then orifice at a distance of 100 cm in a circle of 2 cm diameter. Regular microporous membrane with pores of 0.3 μm in diameter and 30 μm thickness providing a geometrical transparency of about 70 % could be fabricated by the method of deep X-ray lithography [12]. The total area of the source is about 30 cm². Assuming geometrical transparency of 50 % this area should contain 2 · 10¹¹ capillaries. If we set a flux through a single capillary 1 · 10¹⁰ mol/sec the density of the molecules before a capillary should be in the range of 1 · 10¹⁸ mol/cm³. Assuming the temperature of the gas 20 K we get a pressure in the source P_s = 2 Torr and a mean free path of molecules about 10⁻⁴ cm. A total flux through the ring aperture will be equal 2 · 10²¹ mol/sec. Further we assume a free molecular flow through the capillaries. For this case Monte-Carlo simulation gives a density distribution of the molecules at the entrance of the magnet shown in Figure 3. Zero position on the Figure 3 corresponds the axis of the capillary.

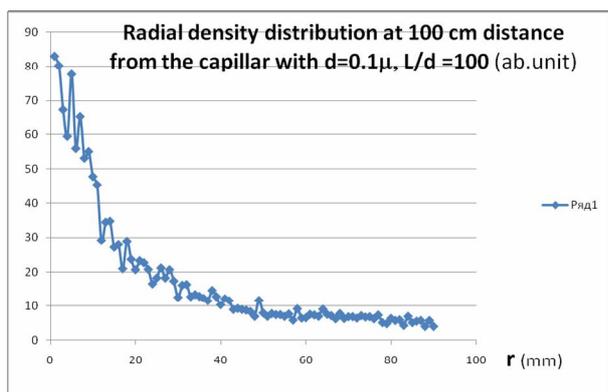


Figure 3 Radial density distribution in molecular beam at 100 cm distance from the capillary source.

2.4. Result of Monte Carlo simulation

For further simulation we will assume a Maxwellian velocity distribution of molecules. Monte-carlo simulation has shown that the fraction of molecules from a single capillary that reach the entrance aperture of the magnet and focus to its axis has a value of $2.3 \cdot 10^{-3}$. Molecules with opposite sign of the magnetic moment hit the inner surface of the magnet and pumped out. Only small amount of the molecules with zero magnetic moment reach the exit of the magnet. The spatial distribution of the molecules at the exit of the magnet is shown in Figure 4. If the receiving aperture will be a ring of 3 cm width almost all of focused molecules will be accepted by this aperture. A molecular flow from the capillary source consists of 1/4 of p-H₂ molecules and of 3/4 of o-H₂ molecules one third of which will be focused. Therefore the estimated fraction of the focusing molecules is about $0.6 \cdot 10^{-3}$ of the total flux or $1 \cdot 10^{18}$ mol/sec for the whole system. These polarized molecules are collected by turbopump and transported into the storage cell.

Preservation of nuclei polarization in a molecule during the transportation remains an open question. Only limited information on nuclear polarization of hydrogen molecules from recombination of polarized atoms is available [13]. A pumping system with high pumping speed needed to realize free molecular flow between the source of molecules and separating magnet is a serious problem also.

Acknowledgments

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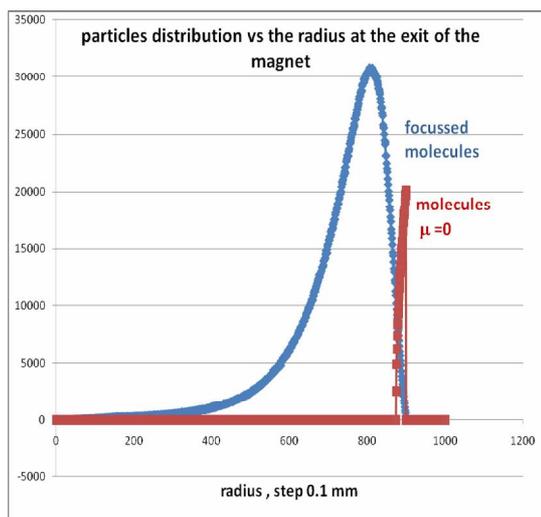


Figure 4. Spatial distribution of molecules at the exit of the separation magnet from a single capillary.

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