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ABSTRACT

In the framework of a collaboration with the University of Lausanne, the University of Michigan and Rockefeller University, a polarized atomic hydrogen beam is being developed at CERN to be used as an internal target at the CERN SPS. A relatively high density beam with more than 90% polarization is produced by Stern-Gerlach separation of the atomic hyperfine states, similar to the atomic beam part of a classical polarized ion source. After a description of the target, the first density measurements are reported.

1. INTRODUCTION

With the exception of the targets at Fermilab^{1,2)} and Serpukhov, gas jets have not yet been used as targets for high energy accelerators, although they offer a number of unique and useful features:

- high luminosity due to multiple traversal;
- efficient use of the accelerated particles;
- parasitic operation; thus no specific allocation of beam time is normally required;
- small and well-defined source size;
- low density, which makes multiple Coulomb scattering negligible and allows detection of recoil protons and other very low energy secondary particles;
- continuous energy variation within the acceleration cycle.

In the case of a polarized atomic beam target, there are several additional advantages:

- low background: the polarized gas target contains pure hydrogen, with a nuclear polarization > 90%, whereas in, for example, a propanediol target, only 10% of the nucleons are free protons which are, on the average, only 60 to 70% polarized;
- small instrumental asymmetries: the target, as it is now conceived, requires only a weak magnetic field (some 10 G) at the target position to define the direction of polarization. This field has a negligible effect on the trajectories of particles with, as a consequence, smaller instrumental asymmetries, and on the spin of the recoil proton, making, for example, "double-scattering" experiments more straightforward;
- low systematic errors: the direction of the proton spin can be flipped much more quickly than in a cryogenic target, where the spin relaxation times are of the order of several minutes. By reversing the spin at, for instance, 1 kHz rate, all slowly varying instrumental asymmetries due, for example, to shifts in beam positions and changes in luminosity will be averaged out to very high precision;

- flexibility: the spin can be easily oriented in any direction with respect to the accelerated beam.

On the other hand, the use of an internal jet target is subject to certain limiting boundary conditions, such as:

- the experimental set-up has to be adapted to the geometry of the ring and the lattice of the machine;
- access to the installation during the run must be restricted;
- the target density and the vacuum system have to be chosen so as to keep the influence on the accelerated or stored beam at an acceptable level.

At CERN, a polarized target facility is being developed which, installed in one of the medium-long straight sections of the SPS, will allow experiments either with protons during the normal acceleration cycle or with stored antiprotons. Alternatively a beam of condensed unpolarized molecular hydrogen may be substituted for the polarized source to provide even larger luminosities.³⁾

2. THE POLARIZED ATOMIC HYDROGEN TARGET

The principle of the polarized atomic hydrogen beam is the same as that used in a ground state polarized proton source. It will be described following the schematic drawing (fig. 1).

Fig. 1 Schematic diagram of the polarized hydrogen jet target

The first step is the dissociation of the molecular hydrogen in an electrodeless discharge. The hydrogen atoms then emerge from a nozzle at thermal speed, a small fraction is selected by a skimmer and enters the first sextupole. As shown in the Breit-Rabi energy level diagram (fig. 2), the hydrogen atom ground state splits up into four hyperfine states in the sextupole field. The force acting on the atoms $F = -\text{grad } \mu|B|$ is purely radial in the field, so that atoms in states 1 and 2 perform stable oscillations around the axis, while atoms in states 3 and 4 are defocussed and eliminated.

The first sextupole is followed by a radio-frequency transition which exchanges the population of states 2 and 4, resulting in a beam of essentially states 1 and 4.

Fig. 2. Energy level diagram of hydrogen atom ground state

In a classical ground state polarized proton source, the beam would now enter the ionizer whose solenoidal field is high enough (~ 1 kG) to give a high nuclear polarization.

For the application as target, it would be inconvenient to require such a high field at the crossing region, especially when fast switching between different spin directions is required, since the coils would cover a too big fraction of the useful aperture. On the other hand, a mixture of states 1 and 4 has only 50% polarization at low magnetic fields.

A second sextupole is therefore added to eliminate the atoms in state 4, and the resulting beam, consisting almost uniquely of atoms in state 1 at the crossing region, has a theoretical polarization of $> 95\%$ even at low fields. Another advantage of this second sextupole is that it has been designed such as to refocus the beam giving a small cross section at the crossing point (see section 4).

3. THE TARGET DESIGN

3.1 The dissociator

A microwave discharge (2.45 GHz) with up to ~ 1 kW power dissociates the molecular hydrogen. The microwave power is coupled to the discharge by a helix surrounding the air cooled discharge vessel. The nozzle can be cooled by water or liquid nitrogen. Lowering the beam temperature increases the target density ideally by $1/T^{3/2}$ since the sextupole acceptance is proportional to $1/T^4$ and the density for a given gas flux is prop. $1/\sqrt{T}$. Calculations with a ray-tracing program⁵⁾ predict a factor of three improvement in target density for our geometry, but this calculation neglects the shorter free path for the slow atoms.

The nozzle diameter is 3.5 mm, and its distance from the skimmer at the sextupole entrance can be varied between 2 and 10 cm.

3.2 The sextupoles

The aperture profile of the sextupoles has been optimized using the above-mentioned ray tracing program (see table 1). With poles made of cobalt-iron alloy we achieve a poletip field of about 10 kG. The yoke is generously ported to provide a good conductance for the unused gas to be pumped from the beam region.

The distance between the two magnets is 10 cm; the distance between exit of sextupole 2 and the crossing region 6 cm.

3.3 The RF-transition

The RF-transition uses the adiabatic passage method⁶⁾ and is similar to the design described by Glavish.⁷⁾

Fig. 3. Target facility in the SPS tunnel

Table 1. Dimensions (in cm) of the sextupoles

	first section			second section		
	length	entry ϕ	exit ϕ	length	entry ϕ	exit ϕ
sextupole 1	15	0.8	2.0	10	2.0	2.0
sextupole 2	10	2.0	2.0	15	2.0	0.8

3.4 The vacuum system

The vacuum system has been designed with its future use in the SPS tunnel in view. The atomic beam generation part is pumped by six turbomolecular pumps, each with 2900 l/s for hydrogen, backed by Roots and rotary pumps. As shown in fig. 3 there are four differential pumping stages to achieve the pressure gradient between dissociator region ($\sim 10^{-3}$ mbar) and accelerator tubes (some 10^{-8} mbar).

The beam dump is a cryopump of the refrigerator type consisting of a cylinder at 14°K with several surfaces covered with charcoal. The backstreaming gas is smaller than 10^{-3} of the incoming beam. The capacity of 20 bar·l of hydrogen is expected to be sufficient for an uninterrupted operation of 6 weeks without regeneration.

The region around the accelerator beam is pumped by a large Titanium sublimation pump, which should keep the pressure rise due to the presence of our target at a few 10^{-8} mbar.

4. EXPECTED PERFORMANCE AND FIRST MEASUREMENTS

Although the method has been used for more than 20 years, densities which have been achieved in polarized atomic beams are not very well known. From published flux measurements one can deduce densities between $3 \cdot 10^{10}$ atoms/cm³ and $3 \cdot 10^{11}$ atoms/cm³. An absolute measurement⁸⁾ gave $2 \cdot 10^{11}$ atoms/cm³.

Based on these data and taking into account a certain number of improvements, the target beam is expected to have an approximately Gaussian density distribution with a diameter (4σ) of 8 mm and a density between 10^{12} atoms/cm³ (room temperature nozzle) and $3 \cdot 10^{12}$ atoms/cm³ (nozzle cooled with liquid nitrogen).

Fig. 4. Atomic beam profile

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The complete system has been assembled in the laboratory and debugged. The first profile measured with a compression gauge is shown in fig. 4. The gas input to the dissociator was 1.6 mbar l/s, the dissociation degree higher than 60%, the nozzle was cooled with water. Assuming an atomic velocity of 2700 m/s, the measured flux with the RF-transition switched on corresponds to a density of about 10^{11} atoms/cm³. Nothing in these early measurements suggests that the design goal cannot be achieved after further work.

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REFERENCES

- 1) V. Bartenov et al., Adv. in Cryogen. Eng. 18 (1973) 460.
- 2) P. Mantsch, F. Turkot, Fermilab Report TM 586 (1975).
- 3) J. Antille et al., Proposal for the study of e^+e^- , γ , and hyperon production in $p\bar{p}$ reactions at $\sqrt{s} = 22.5$ GeV using an internal jet target at the SPS, SPSC/80-63.
- 4) R. Keller, L. Dick and M. Fidecaro, Helv. Phys. Acta Suppl. VI, 48 (1960).
W. Haeberli, Annu. Rev. Nuclear Science 17, 373 (1967).
H.F. Glavish, Proc. Internat. Symp. on Polarization Phenomena in Nuclear Reactions, Madison, 1970 (eds. W. Haeberli and H.H. Barschall) (Univ. of Wisconsin Press, Madison, 1977).
- 5) Written by H.F. Glavish and D.G. Mavis, Stanford.
- 6) A. Abragam and J.M. Winter, Phys. Rev. Letters 1 (1958) 373.
- 7) H.F. Glavish, in: Polarization phenomena in nuclear reactions, H.H. Barshall and W. Haeberli editors, Univ. of Wisconsin Press, Madison, 1971.
- 8) D.G. Mavis et al., Proc. Conf. on High-Energy Physics with Polarized Beams and Targets, Argonne, 1976 (ed. M.L. Marshak) (Argonne National Laboratory, Argonne, 1976), p. 517.