Test Bench Studies and Simulations of Atomic Beam Sources

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Abstract. Two new test bench studies have deepened the understanding of polarized gas targets and the atomic beam sources (ABS) that fill them. The attenuation coefficient for beam loss due to rest gas scattering has been measured over a range of beam velocities. The total scattering cross sections can be extracted from these measurements for the first time.

Low conductance injection tubes have the potential to increase the thickness of storage cell targets. Injection tubes with internal fins were characterized, and the beam loss at the tube exit was larger than expected. Beam simulations agree with the measured intensity loss only when the atoms' trajectories have a non-zero azimuthal velocity component.

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INTRODUCTION

The combination of internal polarized gaseous targets and high energy storage rings is a powerful tool in the study of the spin structure of the nucleon. Examples include the HERMES experiment[1], the beam polarimeter of the RHIC spin physics program[2], and the proposed antiproton polarizer for the PAX experiment[3]. However, the low target thickness is one of the obstacles that future experiments must overcome. The SpinLab laboratory at the Università di Ferrara focuses on the combination of test bench measurements and beam simulations to both understand the limits of existing targets and test new ideas for overcoming these limits. Two of the latest results are presented here. In the spirit of understanding existing targets, a study of beam attenuation due to collisions with rest gas molecules was undertaken. In the spirit of testing new ideas, low conductance injection tubes were characterized, and their potential to increase the thickness of the storage cell target for the proposed PAX experiment was evaluated.

BEAM ATTENUATION STUDIES

Rest gas attenuation (RGA) inside the ABS may be a limiting factor in existing and/or future targets. The relevant physical quantity is the total scattering cross section σ_{tot} for collisions of beam particles with rest gas particles, yet previous studies of RGA losses reported only the attenuation coefficient of the beam, referred to as A herein, for different nozzle temperatures. A depends not only on σ_{tot}, but also on the beam's velocity distribution, which varies from one ABS to another due to different nozzle temperatures

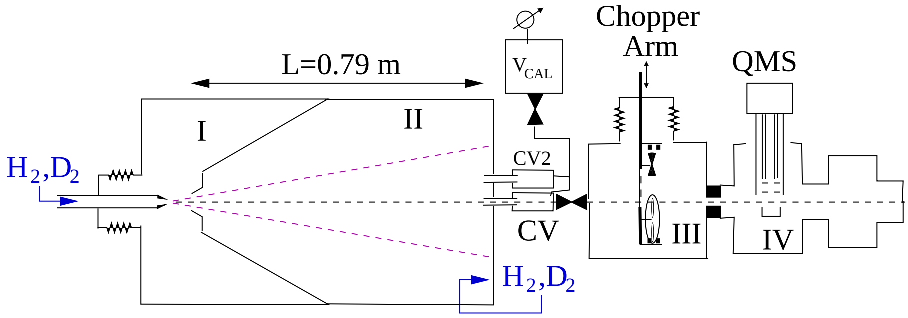

FIGURE 1. The experimental setup for the RGA measurements.

and geometries. At SpinLab, the attenuation coefficient A of hydrogen and deuterium beams, both atomic and molecular, was measured for several different beam velocity distributions. For each measurement of A, the beam's velocity distribution was directly measured with a time of flight apparatus.

Fig. 1 shows the experimental setup for the RGA measurements, using one of the two ABSs available at SpinLab. After dissociation, the beam is collimated by the skimmer that separates chambers I and II and continues to the Quadrapole Mass Spectrometer (QMS), where only 0.005% of the initial flux is collected. For these measurements, the rest gas pressure in chamber II was changed by adding gas through a side inlet. Chamber III contains two beam choppers. The first alternaltely blocks and passes the beam, allowing background subtraction of the QMS signal offline. The second is a solid disk with a 2 mm wide radial slit. The sliver of beam that passes the slit expands spacially along the beam axis due to the different velocities of the atoms: the faster atoms arrive at the QMS before the slower ones. A time analysis of the resulting QMS signal reveals the beam's velocity distribution.

The dependence of the background-subtracted QMS signal S on the pressure P in chamber II is given by Beer's law

$$\ln(S) = \ln(S_0) - A \cdot P \cdot L/k_B T \tag{1}$$

where S_0 is the beam signal in the QMS for null pressure (no attenuation) in chamber II, $L = 0.79$ m is the length of chamber II, T is the temperature of the rest gas and k_B is Boltzmann's constant. The constant A was measured for a particular nozzle geometry and temperature by varying the pressure in chamber II in small steps until the QMS signal was 67% or less of its original value.

The collection of measurements for a molecular hydrogen beam is shown on the left in fig. 2 for different operating conditions (nozzle diameter, discharge ON or OFF). The mean beam velocity was varied by changing the nozzle temperature. Similar measurements were performed for atomic hydrogen beams, atomic deuterium beams and molecular deuterium beams[5].

The attenuation coefficient A is a complicated combination of the beam's velocity distribution and the total scattering cross section σ_{tot}, which depends on the relative

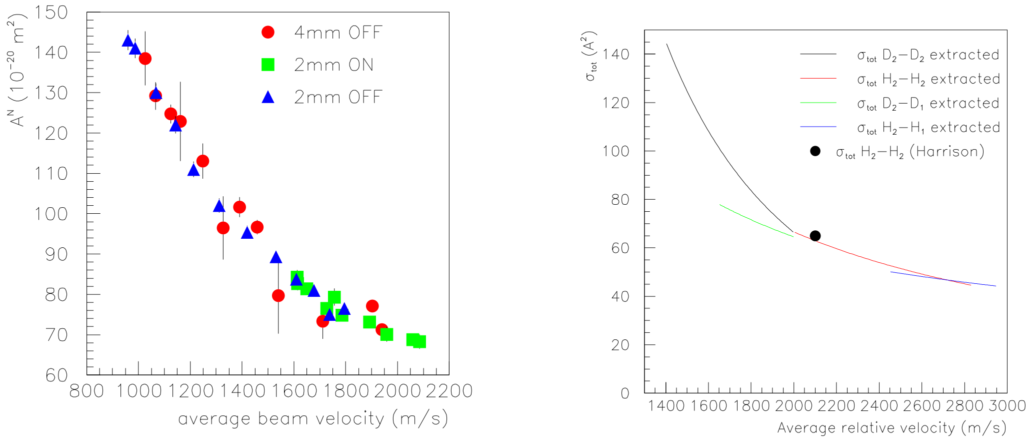

FIGURE 2. The set of A measurements for a molecular hydrogen beam (left) and preliminary determinations of σ_{tot} for the four processes studied (right).

velocity of the colliding particles.[1] Assuming a functional form for σ_{tot}, the values of the function's parameters which best agree with the measured values of A can be obtained from a simple χ^2 minimization. The right panel of figure 2 shows very preliminary results of these fits, illustrating the coverage of our data.

LOW CONDUCTANCE INJECTION TUBES

The geometry of a typical storage cell target is shown in the left panel of fig. 3. Atoms from the ABS enter the center of the cell through the injection tube, then either diffuse out one end of the beam tube or diffuse back out the injection tube. The target thickness t is given by

$$t = IL/C_{tot} \quad \text{where} \quad C_{tot} = C_{beam} + C_{inj} \tag{2}$$

where I is the intensity of the incoming ABS beam, L is the half length of the beam tube and C_{tot} is the total cell conductance. Adding radial fins to a traditional cylindrical injection tube ideally does not obstruct the incoming ABS beam but does impede the diffusion of atoms back out the injection tube, increasing the target thickness.

If the incoming atoms from the ABS have a non-zero azimuthal velocity, they may collide with the radial fins, reducing the intensity I in eqn. 2. Our test bench measurements quantified both I and C_{inj} for tubes with 0,5,10, and 12 fins[6]. A general parameterization of both I and C_{inj} in terms of the tube geometry was obtained and the calculated change in target thickness for the proposed PAX experiment is shown in the right panel of fig. 3. No improvement is foreseen for the PAX target despite the 50% reduction in

[1] The mathematical expression for A and its derivation can be found in references [4] and [5].

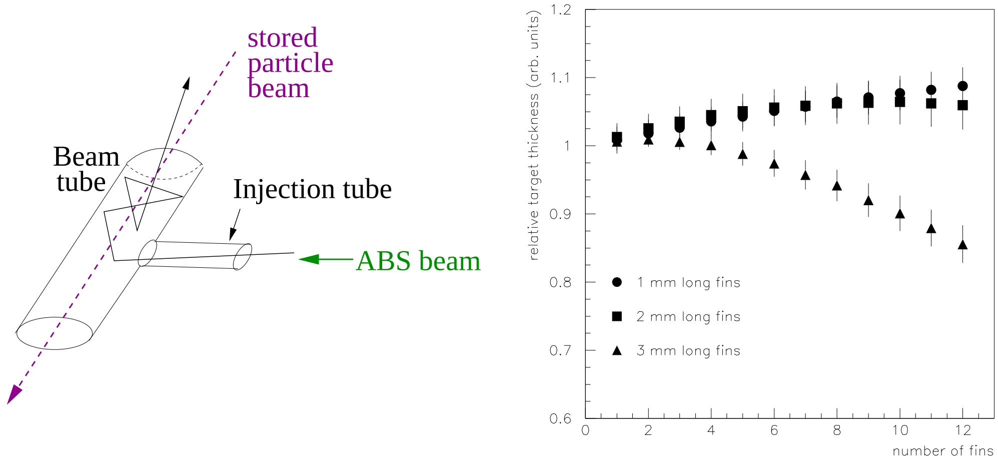

FIGURE 3. A typical storage cell (left) and the predicted thickness for the PAX experiment as a function of the injection tube geometry (right).

the conductance of the injection tube, which could not compensate the large intensity loss of the ABS beam. Beam simulations reproduce the measured beam intensity losses only when the beam atoms have a non-zero azimuthal velocity component.

CONCLUSIONS

A parameterization of the total scattering cross section can be extracted from SpinLab's RGA data for the first time. This cross section is needed to calculate RGA losses for other sources and is a fundamental input for simulations of the beam formation process using the Direct Simulation Monte Carlo (DSMC) method. Low conductance injection tubes cannot increase the target thickness for the PAX storage cell target. This result is very sensitive to both the ABS beam characteristics and the storage cell geometry, therefore finned injection tubes may be useful in different experimental setups. The measurement of the beam's azimuthal velocity improves ABS sextupole tracking calculations because it discriminates among the various starting generators used to model the beam.

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