ATOMIC HYDROGEN FOCUSING MIRROR FOR THE MARK-II ULTRA-COLD POLARIZED JET*

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We are developing a high density ultra-cold jet target of proton-spin-polarized hydrogen atoms to study spin effects in high energy p-p collisions. To obtain a high density jet, we use a 12 Tesla magnetic field with a 1 Tesla cm^{-1} gradient and a 0.3 K temperature; these reduce the beam divergence and energy spread. We will install a parabolic mirror whose surface is coated with a superfluid ^{4}He film to focus the atomic hydrogen and further reduce its beam divergence. Monte-Carlo calculations were done to optimize the mirror shape; a 10 cm long cylindrical mirror was fabricated using electro-forming. We plan to soon install the mirror in Mark-II and test it.

In order to obtain a Mark II Jet[1] beam thickness of 10^{13} protons cm^{-2} in a 1×2 cm^2 interaction region, we plan to increase the transport efficiency from the Jet's rf dissociator to the exit of the separation cell and to increase the focusing efficiency into the interaction region using a special mirror.

Recombination of hydrogen atoms, in the transport line from the rf dissociator to the inlet of the separation cell, increases the probability of collisions between the hydrogen atoms and hydrogen molecules. An increase of the ^{4}He film temperature, due to recombination in the separation cell, increases the ^{4}He gas pressure due to ^{4}He surface evaporation. This increases the probability of collisions between the hydrogen atoms and hydrogen molecules or helium gas, which might lower the transport efficiency. This transport efficiency is discussed by V.G. Luppov in another paper at this symposium. [1]

The focusing in Mark II is done by the sextupole magnetic field gradient of 0.011 T cm^{-2} after the acceleration by the solenoid's 1 T cm^{-1} magnetic field gradient. Figure 1 shows Monte-Carlo calculations for the angular distribution of Mark-II's atomic hydrogen beam. The angular distribution with the

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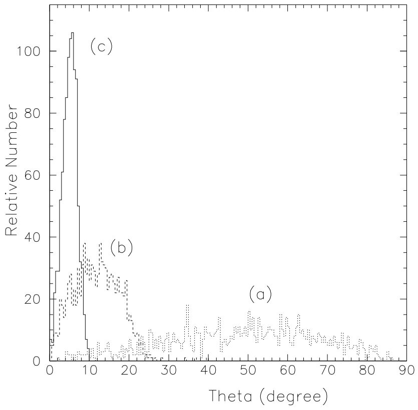

Figure 1: Angular distributions of atomic hydrogen beam from Monte-Carlo calculations for the Mark-II geometry: (a) without the solenoid magnetic field gradient, (b) with the gradient and (c) with both the gradient and the focusing mirror.

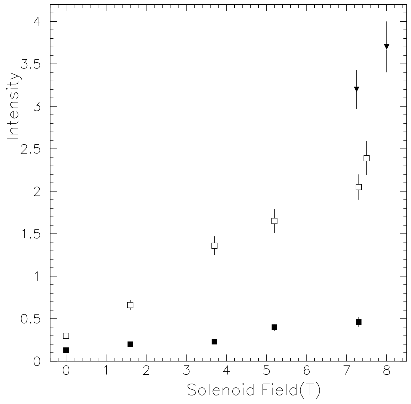

Figure 2: The Prototype Jet's intensity (10^{15} atoms s^{-1}) versus the solenoid field.[3] The solid squares are with no mirror; the empty squares are with the rougher surface four-coned mirror; the solid triangles are with the repolished four-coned mirror.

solenoid's 1 T cm^{-1} field gradient (b) is narrower than the angular distribution without the gradient (a). Using both the mirror and the solenoid gradient gives a much narrower distribution as shown in (c). Unfocused atomic hydrogen is recombined and condensed mostly on the cold surfaces; the increased molecular hydrogen gas pressure increases the probability of collisions with the hydrogen atoms.

The quantum reflection of cold hydrogen atoms on a ^{4}He-film-coated surface was first demonstrated by Berkhout *et al.* [2] They measured more than 80 % specular reflectivity for normal incidence on a hemispherical optical quality concave quartz mirror coated with a 100 mK ^{4}He film.

In the Prototype Jet we used reflection from a copper cylindrical quasi-parabolic (four-coned) mirror whose surface was coated with ^{4}He film; we found that the mirror certainly improved the focusing [3]. As shown in Fig. 2, the intensity was increased by about a factor of 7 using a highly polished four-coned mirror.

In order to optimize the Mark II mirror shape, Monte-Carlo calculations were done using a CERN library program, Poisson, for the Mark-II geometry. A 10 cm long cylindrical mirror shape was optimized for a high beam intensity. The shape is described by $r(z) = \sqrt{2r_0 z + r_0^2}$, where r_0 is the 0.25 cm radius mirror entrance, r is the radial position and z is the axial position. According to the calculations, a mirror with 100 % reflectivity should increase Mark II's focused intensity by about a factor of 3.

A 10 cm long cylindrical copper parabolic mirror was fabricated by Custom Microwave Inc. using electro-forming; its surface roughness is a few μm according to the company. We also constructed a polishing machine in which the rotational motion of a motor is converted into a piston motion by a cam; a polishing head is then attached to this "piston" via a bamboo bar. The stroke of the piston movement is 2.5 cm with a 10 Hz cycle. The mirror can be attached to a lathe and be rotated along its central axis; we may later polish its surface using aluminum oxide powders to reduce the surface roughness to around 0.05 μm.

The mirror should soon be attached to the separation cell in the Mark-II Jet. The surface of the separation cell is covered with a superfluid ^{4}He film whose thickness is a few nm. The mirror surface will also be coated with a superfluid ^{4}He film whose thickness will be monitored by a bolometer. We may install first an unpolished and then a polished mirror to compare the focusing efficiency.

To obtain a higher thermal conductivity between the mirror and separation cell, we may later fuse the mirror with the separation cell.

References

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2. J.J. Berkhout *et al.*, Phys. Rev. Lett. **63**, 1689 (1989).
3. V.G. Luppov *et al.*, Phys. Rev. Lett. **71**, 2405 (1993).