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RECENT DEVELOPMENTS IN THE BNL INTENSE POLARIZED H^- SOURCE PROGRAM*

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ABSTRACT

A program to develop a high intensity polarized H^- ion beam for injection into the AGS is under way at this laboratory. The approach we are following is essentially the polarization and ionization of a very cold and intense atomic hydrogen beam. This paper reports on the magnetic focusing of the cold atomic hydrogen beam we have produced.

INTRODUCTION

One aspect of the BNL program to develop an intense source of polarized H^- is the production of very cold polarized H° beams. The production of cold unpolarized H° beams has been reported[1]. Nuclear polarization of the latter is achieved by a combination of magnetic focusing (the Stern-Gerlach effect), and rf induced transitions. The original plan was to use a superconducting solenoid as the magnetic lens, and beyond it, a set of rf transition units to produce the nuclear polarization. The beam will then be ionized by a ring magnetron ionizer. A review of the entire program was recently given elsewhere[2]. This report deals only with the magnetic focusing of the H° beam.

MAGNETIC FOCUSING

Focusing the neutral hydrogen beam with a superconducting solenoid was not successful at peak beam intensity due, we believe, to intrabeam scattering in the solenoid. This conclusion is based on the observation that focusing decreased with increasing beam density. On the basis of this observation, the H° - H° scattering cross section has been inferred[3] to be $\approx$ 100 Å^2, somewhat higher than values previously reported in the literature.

Modifying the solenoid to give it a more open geometry for improved pumping was not practicable, hence we decided to build a 20 cm long permanent magnet sextupole having a 4 cm bore diameter and a pole-tip field of 7 kG[4]. The individual magnets from which the poles were assembled were made from Nd-Fe and specially coated

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to resist attack by atomic hydrogen. Azimuthally machined slots in the yoke allowed for additional (radial) pumping of the bore.

No significant focusing was observed with this magnet, and our inability to vary the magnetic field was a serious drawback since subsequent simulations showed that the focusing was very sensitive to beam velocity. We have established that the strength of the magnet did not match the velocity spectrum of the beam.

A Two-Magnet System

The permanent magnet has now been reduced to a length of 10 cm. This will be used in conjunction with a conventional electromagnet sextupole which is also 10 cm long, has a 3.6 cm diameter aperture, and is capable of 6.3 kG pole-tip field in d.c. operation (cooling being the limitation) and higher, if it is pulsed. This arrangement is shown in Fig. 1. The permanent magnet will be nearer to the nozzle because its slightly larger bore and pole-tip field give it a larger acceptance. The field of the second magnet will be varied to focus the beam to the detector. The permanent magnet may also be moved axially up to 4 cm, giving us another degree of freedom in optimizing beam focus at the detector.

Simulations

We used computer simulations to determine a suitable configuration of the two magnet system. The simulations involved tracking individual atoms from the nozzle to the detector, which was placed at the position where the ring magnetron ionizer will eventually be located. The Monte Carlo technique was used to launch the atoms. The parameters which were randomly selected are (1) the speed of the atom - according to the measured supersonic velocity distribution, (2) the radial position at the tip of the nozzle - we assumed uniform flux density across the nozzle aperture, (3) the angle of elevation - we assumed a $\cos^5\theta$ distribution but the results are not sensitive to the value of the exponent, and (4) the electron spin state - either 1/2 or -1/2. Azimuthal motion and beam attenuation by scattering were ignored. If the detector was assumed to have a circular aperture, then particles reaching the aperture were weighted with their distance from the axis there. A typical graphical output of the tracking program is shown in Fig. 2. The tracks plotted were also randomly selected and represent 0.025% of 200K starts.

The focusing factor, FF, defined as the ratio

$$\frac{\text{Weighted counts at detector with magnets on}}{\text{Weighted counts at detector with magnets off}}$$

was used as the figure-of-merit to compare the focusing of different sets of operating conditions. In Fig. 3, FF, with typical error bars, is plotted as a function of the pole-tip field of the second magnet. Figure 4 shows FF as a function of velocity for beams assumed to be monochromatic, covering the range of velocities we have measured. We see that with the two-magnet system we should be able to observe focusing over a wide range of beam velocities, by adjusting the field of the variable magnet.

Estimation of beam flux

For a forward H° beam flux density of about 2 x 10^{20} atoms/s/sr^3, the flux into a 4 mm dia. aperture at the detector plane, 70 cm from the nozzle, is 5 x 10^{15} atoms/s when the magnets are off. (The permanent magnet can be "turned off" by lowering it out of the beam.) Since the peak value of FF in Fig. 2 is about 7, the expected flux at the detector is about 3.5 x 10^{16} atoms/s. With a most probable velocity of 575 m/s, the expected beam density at the detector is about 5 x 10^{12} atoms/cm^3, which can be easily detected by the residual gas analyzer detector. This density is about 20 times greater than the density in our present polarized source. However, scattering will probably prevent us from realizing such a dramatic gain.

PLANS

The modifications to the cold beam source to accommodate the two sextupole magnet system are almost complete. We expect to study the beam focusing early in 1990. The next step will then be to couple the ring magnetron ionizer to the source and study the ionization process.

SUMMARY

Focusing our intense, cold atomic hydrogen beam has, thus far, proved elusive due to scattering effects in the superconducting solenoid, and poor optics in the case of the single permanent sextupole magnet. A two sextupole magnet system, one permanent magnet and one variable strength, has been designed and its installation is almost complete. We feel that this approach solves the problems in our previous attempts to focus the beam with a magnetic lens.

ACKNOWLEDGEMENTS

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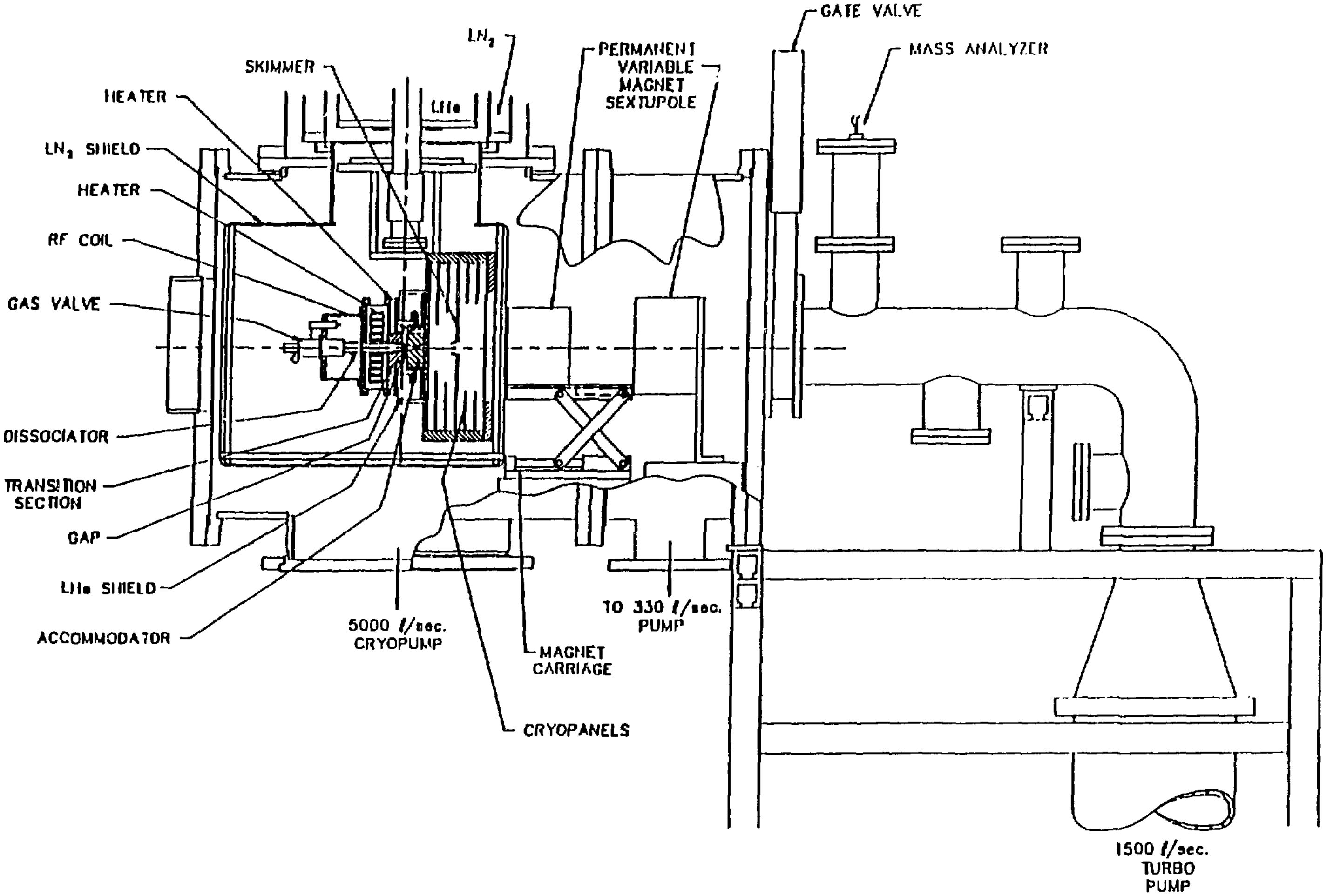
FIGURES

Fig. 1 Section through the cold source showing the two sextupole magnets. Some cryopanels were removed to move the dissociator and accommodator forward.

Fig. 2 A randomly selected fraction of the large number of atom tracks used in the computer simulations. The first of the two target planes to the right corresponds to the detector.

Fig. 3 Focusing factor, FF, versus the magnetic field of the variable magnet. The values of the parameters in the velocity distribution were: $V_d = 565$ m/s, $T_b = 0.35$ K.

Fig. 4 Focusing factor versus monochromatic beam velocity for three values of the magnetic field of the variable sextupole magnet.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LN$_2$
PERMANENT VARIABLE MAGNET SEXTUPOLE
MASS ANALYZER
SKIMMER
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LHe
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HEATER
RF COIL
GAS VALVE
DISSOCIATOR
TRANSITION SECTION
GAP
LHe SHIELD
ACCOMMODATOR
5000 ℓ/sec. CRYOPUMP
TO 330 ℓ/sec. PUMP
MAGNET CARRIAGE
CRYOPANELS
1500 ℓ/sec. TURBO PUMP

Figure 1

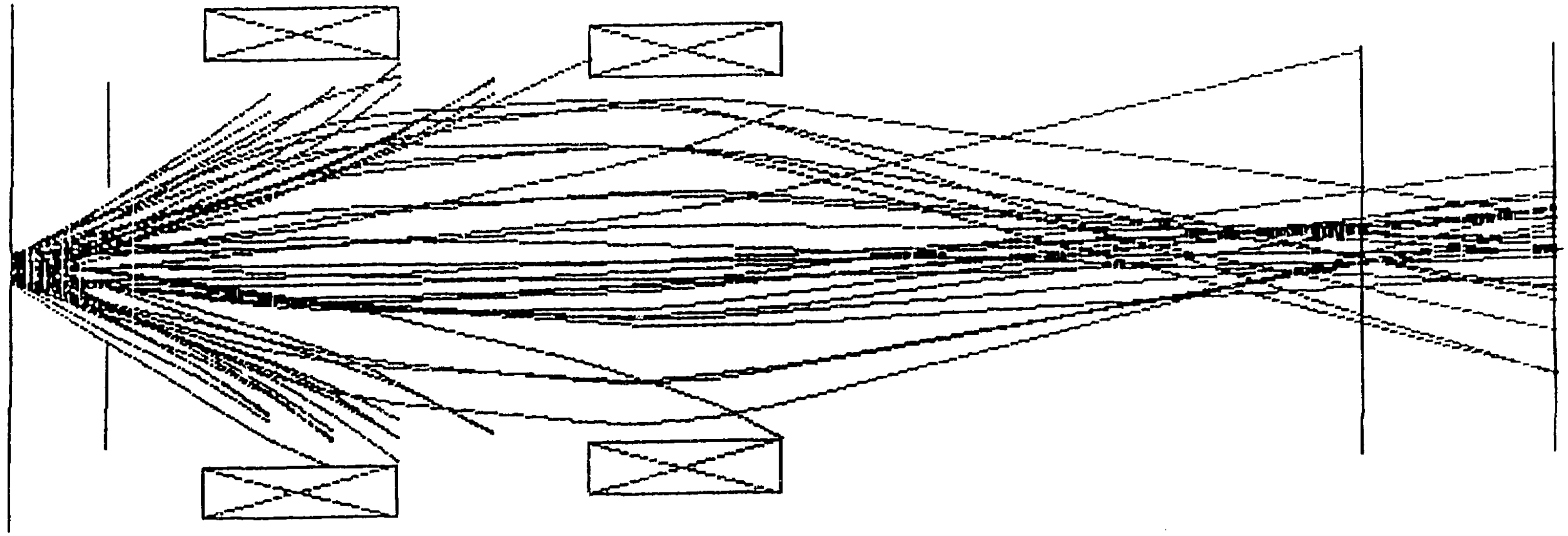

Figure 2

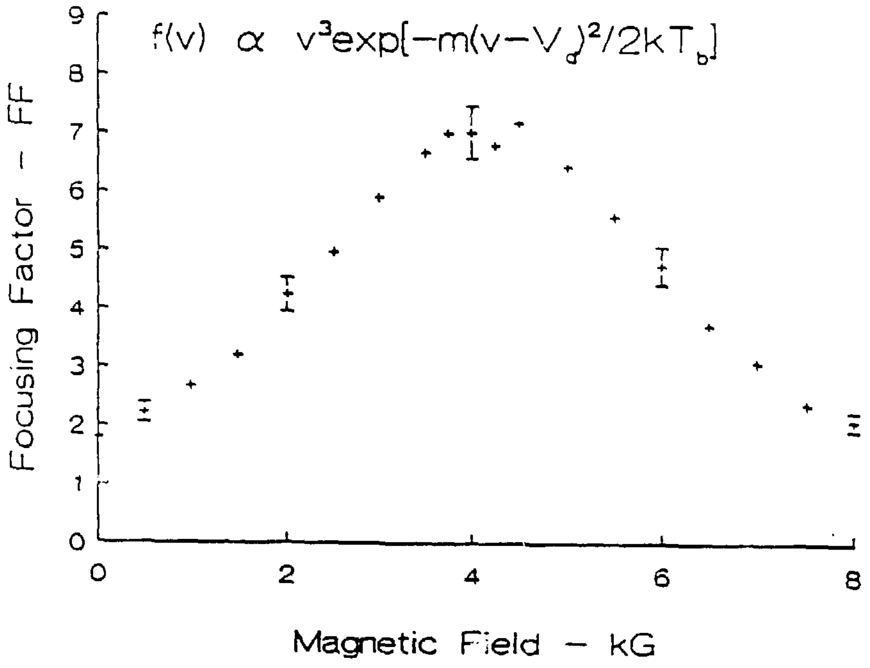

Figure 3

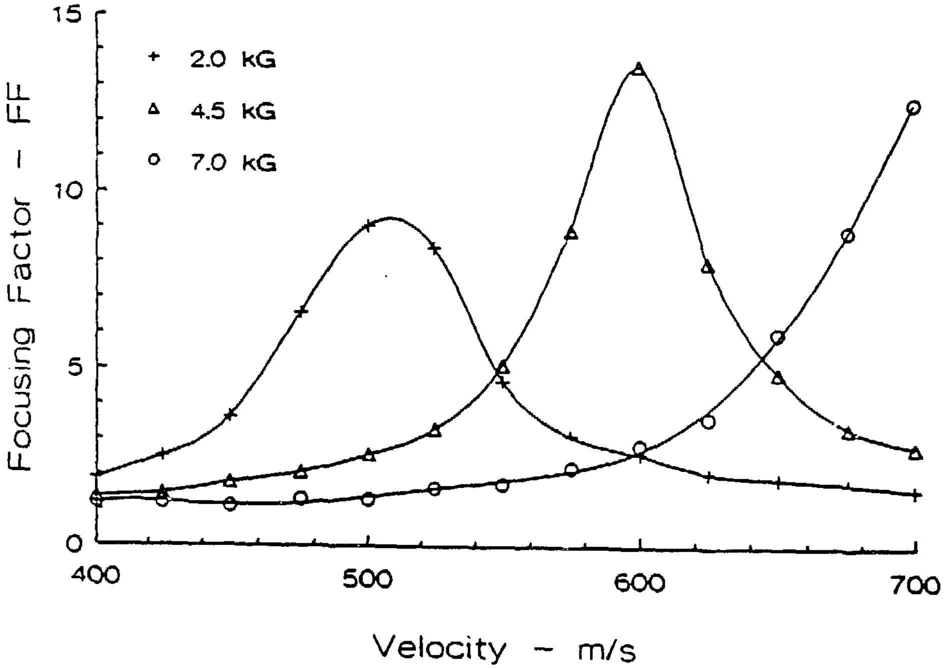

Figure 4