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DYNAMIC POLARIZATION IN A ^{3}HE/^{4}HE EVAPORATION CRYOSTAT

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ABSTRACT

Studies to improve polarization of the University of Michigan polarized proton target during operation in an intense beam are discussed. Target material, circulating fluid, and cavity configuration were studied and these studies resulted in higher target polarization for a high energy physics experiment.

The University of Michigan group at Brookhaven National Laboratory has been extending measurements of the analyzing power for p-p elastic scattering to high transverse momentum (so far to $P_T^2 = 6.5(GeV/c)^2$). As transverse momentum increases the cross section decreases, so that to make statistically meaningful measurements we must use an intense proton beam(typically $2x10^{10}$/s) and a relatively large target($20\ cm^3$). Since the Bonn Polarized Target Workshop we have worked on the target material, circulating fluid, and target cavity to improve the ability of the target to maintain high proton polarization in an intense beam.

Target Material

In intense beams we use frozen, radiation-doped ammonia as the target material, because chemically-doped materials are radiation damaged by intense beams too quickly to be of practical use. Ammonia, on the other hand, improves under bombardment, as more radicals are formed to act as polarizing centers. In order to irradiate ammonia with doses comparable to those used successfully at Bonn (1), we went to the Bates Linear Accelerator Center. The irradiation arrangement is shown schematically in Fig. 1. The current of the primary 250 MeV electron beam was monitored with a current transformer and beam position and size(about 1½ cm diameter) were monitored with the BeO screens. Showering calculations were not performed and the beam size could only be estimated, so we have only a relative calibration of the total electron flux through the ammonia. Liquid argon was added to the irradiation dewar by hand and allowed to boil away.

Results are shown in Fig. 2; a graph of polarization versus time for samples irradiated with various beam currents and total doses. Results for an earlier sample irradiated with a smaller dose at the National Syncrotron Light Source (NSLS) at Brookhaven are also shown. We attribute the poorer performance of samples irradiated with higher beam currents to heating of the beads by the beam, annealing away some of the polarizing centers that had been formed. Also, we separately irradiated fragments made from ammonia frozen slowly in a dry ice-alcohol bath and fragments made from ammonia frozen quickly in liquid nitrogen. The quickly frozen

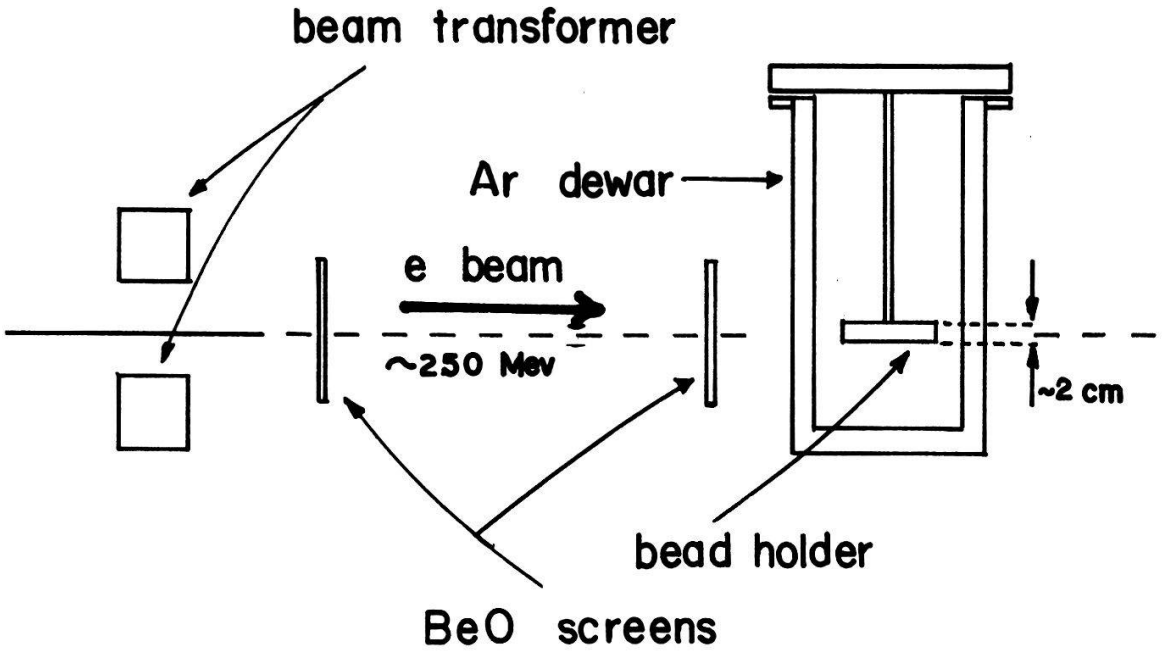

Fig. 1 A schematic diagram of the irradiation arrangement used at the Bates Linear Accelerator Center. Not to scale.

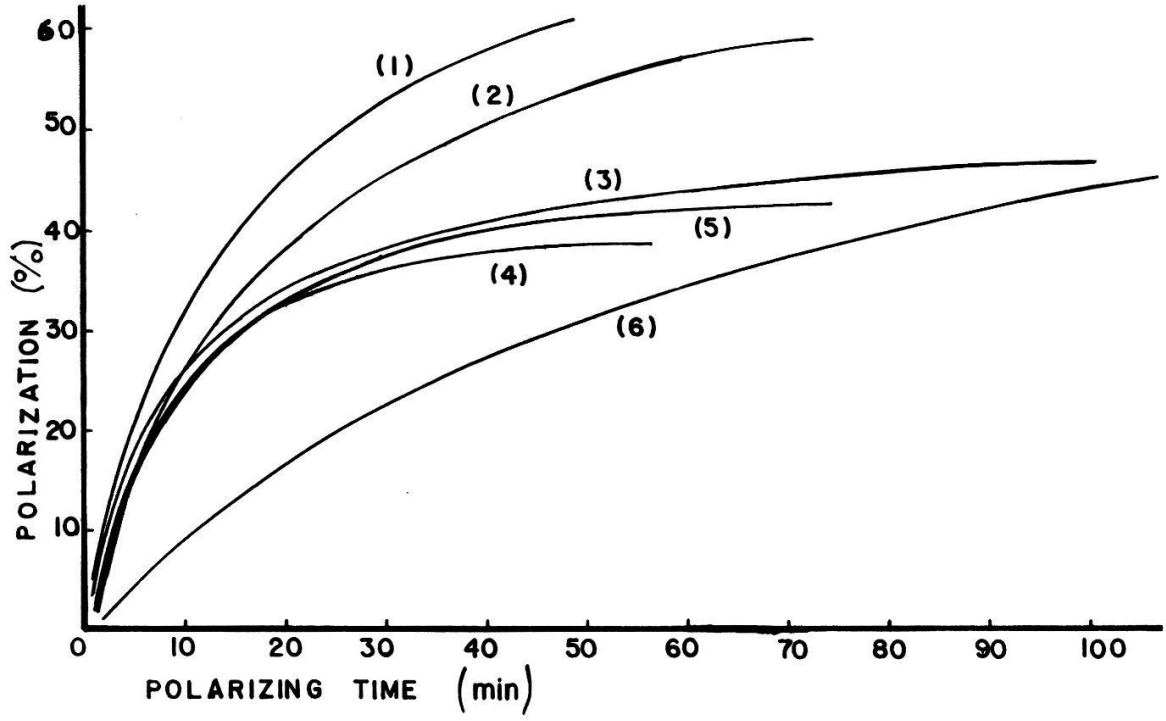

Fig 2. Polarization versus time for various samples of ammonia. (1)-Bates, slow frozen, 1.2×10^{13} e/s, 1×10^{17} total e^-; (2)-Bates, slow, 1.2×10^{13}/s, $.8\times10^{17}$ total; (3)-Bates, 3×10^{13}/s, slow, 1.25×10^{17} total; (4)-Bates, fast, 3×10^{13}/s, 1.25×10^{17} total; (5)-Bates, fast, 5.5×10^{13}/s, 1.26×10^{17} total; (6)-NSLS,slow

ammonia consists of microcrystals whereas the slowly frozen fragments are more nearly monocrystaline and are expected to have higher thermal conductivity. We saw, however, no difference in polarizing time, without beam heating, between slowly and quickly frozen samples.

Circulating Fluid - $^3He/^4He$ Ratio

Under bombardment by an intense beam our target maintains substantially higher polarization when a mixture of ^3He and ^4He is used as the circulating fluid instead of pure ^3He. We believe that the ^4He improves the thermal contact between the bead surface and the ^3He which does the actual cooling. The mechanism is not understood in detail so we tried to optimize target polarization by varying the ratio of ^3He to ^4He, X, in the circulating fluid. Beam was not availble for the tests so we used microwaves to heat the beads. The preferred method was to polarize the sample and then move the microwave frequency away from resonance and for various levels of microwave power watch the polarization decay. The decay time then indicates the bead temperature.

Target performance was most satisfactory with a mixture with 60% ^3He (X= .6), but there was no large qualitative change between X = .4 and X = .7. With less than 40% ^3He the target did not cool to a low enough temperature for high polarization, and with more than 70% ^3He the target could not maintain high polarization for high heat loads, as with pure ^3He.

Target Cavity

The target cavity consists of a cylinder 4.1 cm long and 2.9 cm in diameter, with the beam going down the axis. Polarization is measured using two NMR "coils", the "small coil" being a tube down the cylinder axis and the "large coil" a coil of tubing near the cylinder walls and coaxial with the cylinder. In the past the circulating fluid entered at the bottom of the cavity and vapor was pumped away through a slot at the top. With intense beams we have observed that the polarization measured by the small coil is hurt more by the beam than that by the large coil, because of the higher beam flux along the axis. These observations led us to try introducing the fluid at the middle of the cavity, through holes in the small coil, or alternatively at the top of the cavity. Again, initial measurements were made using microwaves to heat the beads instead of beam.

As might be expected, the top inlet worked very poorly, probably because the fluid was pumped away quicky, cooling the beads near the top but not those further down. Target operation with the inlet at the middle, with only spatially uniform microwave heating, was essentially the same as with the inlet at the bottom.

Results

The studies described were made without beam, but success of failure is determined by operation in an intense beam, and may be judged by the summary in Table 1. Shown are typical average target polarizations for two experimental runs, in the spring of 1984 with NSLS ammonia and in the spring of 1985, after most of these studies, with Bates ammonia. For both experiments the proton beam had a full width at half maximum of 1.1 cm and an intensity of about 2×10^{10} protons/s. We attribute the improved polarization at the small coil compared to the large to the change of inlet position from bottom to middle. The ratio of ^3He to ^4He in the circulating fluid did not change substantially between runs, so we believe that the

Target Polarization	Spring 1984	Spring 1985
Large Coil	48%	56%
Small Coil	42%	54%
Average	45%	55%

Table I. Average target polarizations for two experimental runs.

rest of the increase in average polarization is due to the improved ammonia. Harder to quantify but also important to the success of the experiment was the reduction in polarizing time. We usually reverse the polarization direction of the target about every four hours, to control systematic errors, and a reduction in polarizing time allows more useful data to be collected during a given running period.

We hope to continue our studies to further improve the target material and cryogenics, and so, ultimately, improve the quality of the data taken using the University of Michigan polarized proton target.

We would like to thank the Bates Linear Accelerator Center for helping us to irradiate the ammonia and F.Z. Khiari, Y. Gialas, and R. Raylman for assistance in preparing and irradiating the ammonia. This work was supported by the United States Department of Energy.

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Reference

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Secretary's report, Session (D), B. van den Brandt:

S. Mango : You compared the results of polarization measurements in 1984 and 1985, giving different figures. Were these measurements done on the same samples?

Answer : No, they were not.

W. Meyer : Did you investigate the influence of the diameter of the beads as you announced in Bad Honnef?

Answer : We did not have the time, unfortunately.

W. Wenckebach: Which $^3He/^4He$ concentration did you indicate in your talk?

Answer : The molar ration $^3He/(^3He+^4He)$ in the gas storage tanks before starting the experiment.

W. Heeringa : Did you use a film burner for the superfluid ^4He film?

Answer : No, we did not.

E. Schilling : Did the beam heat the NMR pick-up coil?

Answer : No, it did not. The coil was made of very thin CuNi wire, so it would not have influenced the measurement anyway.

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CONSTRUCTION AND PRELIMINARY TESTS OF A SUBCOOLED He^4 POLARIZED PROTON TARGET**

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ABSTRACT

The construction and first tests of a subcooled He^4 polarized target are reported. Such a target might be useful for experiments in high intensity beams and neutron beams, and for optical experiments. Polarization comparable to He^3 evaporation-type targets was obtained. Design and operational difficulties are discussed.

1. Introduction

The idea of the subcooled He^4 target has been around for a long time[1]. The target material is immersed in a high thermal conductivity He^4 bath, which is in good thermal contact with a heat sink (for example, a He^3 evaporation refrigerator or a dilution refrigerator), via a large surface-area heat exchanger. Improved target polarization is expected in high intensity beams because of the superior thermal properties of the pure He^4 bath.

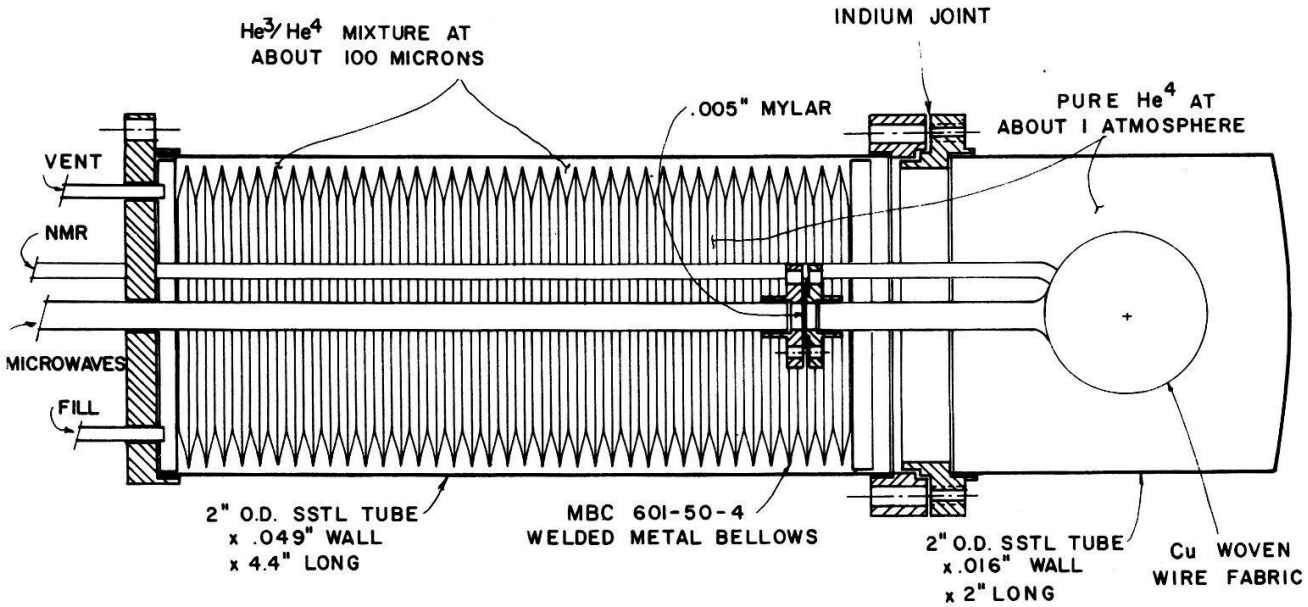

Figure 1. Cold End of the Subcooled Target

**Work performed under the auspices of the U.S. Department of Energy

The advent of ammonia[2] as a radiation-doped target material has prompted renewed interest[3,4] in this scheme. The actual implementation has brought into focus some of the practical difficulties associated with the design and operation of this kind of target.

2. Construction

The subcooled target is a modification of a dilution insert[5] built for the Michigan PPT. The still, final heat exchanger, and mixing chamber were replaced by the assembly shown in Figure 1. The bellows[6] is made from butt-welded, .05mm thick, type 347 stainless steel sheets. The surface area of the bellows is 4300 cm^2, which is ten times the surface area of 10 cm^3 of 1.5 mm diameter target beads. The enclosed volume is 0.3 liters. The Indium joint is of a design[7] which has been found reliable under thermal cycling. Twice the usual number of brass screws were used in the joint, which was made after bead loading. A heavy and precise-fitting copper ring was clamped to the joint during tightening to help keep the Indium warm enough to flow properly. The 2.5 cm diameter x 4.0 cm long bead holder was made from fine copper mesh. The vent and fill lines are about 2 mm diameter, and each line promptly executes a 5 cm diameter loop after exiting the enclosed volume. A multi-tube manifold uniformly distributes the incoming mixture along the length of the outer bellows region.

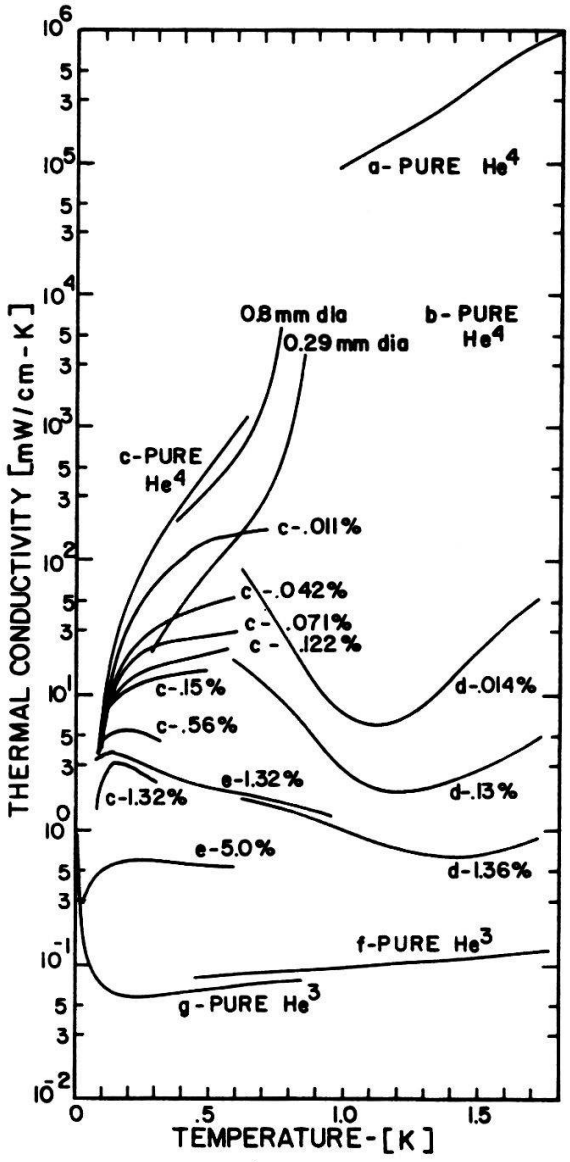

Figure 2
Thermal Conductivity of Mixtures
letters refer to ref[8]

3. Results

The Michigan PPT is situated in a heavily-used extracted beamline of the Brookhaven AGS, and is only infrequently available for development work. A two week period was available in late November of 1985, interspersed with tests of the conventional He^3/He^4 evaporation insert. During that test period we made the following observations:

a. Fill time - The time required to condense pure He^4 into the bellows was about 4 hours. Condensation was accomplished by bleeding He^4 gas into the bellows volume while cooling the surrounding surface with an evaporating He^3/He^4 mixture. Provision for direct liquid He^4 filling from the supply dewar is built into the insert, which would

probably greatly reduce the fill time. This method was not attempted during our test period.

b. Capillary blockages - The bellows fill line was connected to dewar boiloff or a bottle of He^4 gas, and the vent line to a manometer. At the observed condensation rates, the expected pressure drop through the capillaries is about 1 torr. The measured pressure drop was often as high as 2 bar. Repeated observation over the course of the two weeks convinced us that these were not solid blockages (caused, for instance, by frozen impurities). The dynamic behavior of these pressure drops was complicated, and is presently not understood.

c. Heat leak - With the bellows evacuated, the minimum temperature was 0.48K, as measured by a calibrated Germanium resistor. With the bellows almost full (as determined by the volume of gas condensed) the minimum temperature was 0.6K, with large and frequent temperature and pressure surges. The manometer indicated a pressure of about 5 torr. No attempt was made to extrapolate the pressure within the bellows by correcting for temperature effects, capillary size, the presence of superfluid film, or the erratic blockages mentioned in part b above. The high temperature can be attributed to the presence of the pure He^4 in the fill and vent capillaries, which probably conducted about 100 mW to the cold end. Smaller diameter and longer (more coils) capillary which is better thermally anchored at intermediate stages would reduce this heat leak.

d. Vacuum leak - During cooldown the bellows was pumped on by a leak detector while the He^3/He^4 refrigerant was condensed into the space surrounding the bellows. A small but consistent cold leak of about 5×10^{-7} std cm^3/sec was seen when liquid (probably superfluid) was present. The thermal conductivity of He^4 below 1K (see Figure 2) is very sensitive to impurities, and in the presence of He^3 is limited by scattering of the thermal excitations (phonons and rotons) from the He^3 atoms. Our leak detector was not sensitive to He3, so we don't know the relative magnitudes of the flows of the two isotopes passing through the leak, but He^3 leaking at the measured He^4 rate would halve the pure-He^4 thermal conductivity in a few hours.

e. Under these conditions a polarization of 50% was attained, using old ethanediol beads which could be polarized to about 60% with the conventional He^3/He^4 evaporation insert.

4. Discussion

Utilizing our existing hardware required that we combine both the pure He^4 bath and the He^3/He^4 refrigerator into an insert that fit into our He^4 cryostat. Most of the difficulties encountered in our testing could be eliminated in a more simple design. Such a design is not difficult to imagine, particularly in a vertical refrigerator.

Two distinct modes of operation might be considered for subcooled targets in intense beams; with a 2.5 Tesla field or a 5 Tesla field. In a 2.5 T field the subcooled target must compete with the He^3/He^4 evaporation target and the dilution refrigerator. Theoretical understanding of high flux heat transfer in the mixing chamber of a dilution refrigerator is complex and perhaps limited, andno experimental data exists in the 10^{10} incident particles/cm^2sec and up range of interest, so this comparison will

not be made here.

The rationale of the subcooled insert at 2.5 T and 0.5 K rests on two assumptions. The first is that the thermal resistance at the bead-fluid interface will be smaller in the subcooled He^4 bath than in the saturated He^3/He^4 mixture. The subcooling (supression of vapor by the high pressure) might make a difference, but there is doubt that there will be a significant difference. The second assumption is that the heat can more easily escape through the interbead openings when the beads are immersed in the subcooled bath. Data gathered using the He^3/He^4 evaporator[9] indicates that the minimum bead diameter for crushed ammonia fragments is limited to about 1.5 mm, probably by pressure drop through the interbead openings[10]. If this pressure drop is the dominant thermal resistance, the subcooled approach might offer a significant improvement. However, there is some evidence to the contrary. During the bead cooling studies reported in these proceedings[11], several variations in geometry were tried, including pumping on the small NMR 'coil' (a perforated 2 mm CuNi tube running along the center of the cavity). This geometry did not perform well.

In a 5 Tesla field the dominant factor is microwave power, which varies at least as fast as the fifth power of magnetic field. This huge heat load at 5 T dictates that pure He^4 must be the cooling fluid. The subcooled target then competes only with the He^4 evaporation target in this mode. From Figure 2 we see that the thermal conductivity of He^4 starts dropping sharply around 0.8 K, so we might take this as a approximate minimum practical operating temperature. The SLAC data[12] claims about 70% polarization in a beam of 3×10^{11} e/sec[13], and also that polarization is inversely proportional to the first power of temperature in this region, which suggests that the subcooled target might deliver around 85% at best under these circumstances. Additionally, suppression of vapor by the high pressure might make possible higher beam intensities.

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