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A HIGH POLARIZATION TARGET FOR INTENSE BEAMS*

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I would like to describe the polarized proton target which is being completed for an experiment in deep inelastic scattering of polarized electrons off polarized protons to be run at SLAC in the near future. The very interesting physics involved in this Yale-SLAC collaboration will be described by Vernon Hughes tomorrow morning.

As this conference seems more oriented to the use rather than the design of polarized targets, I shall give a quick summary of the device and concentrate on the aspects that are important to the use or novel to the design. Details that may be of interest can be handled in later discussions.[1]

The parameters of the target are given in Table I.

Table I SLAC-Yale polarized proton target

Temperature	1°K; Helium 4 system
Field	5 Tesla superconducting solenoid
Capacity	600 milliwatt; 25 cm^3
Material	1, butanol; porphyrexide doped
Polarization	$(\sim 70\%) \times \left(\frac{10 \text{ free protons}}{74 \text{ bound nucleons}}\right) \sim 10\%$
Microwaves	2 mm (140 GHz) backward wave oscillator
NMR	Constant voltage, parallel tank, 200 MHz
Special Features	Polarized parallel to beam $\pm 20^{\circ}$ exit aperture
	Daily target change due to radiation damage (electron beam)

The builders include myself and Dave Coward from the Spectrometer Group at SLAC; Steve St. Lorant from the Cryogenics Group at SLAC; Vernon Hughes, Asher Etkin, Peter Cooper, Satish Dhawan, John Wesley and Percy Yen from Yale. Strong technical support was received from both institutions.

The special feature of polarization parallel to the beam is a consequence of the experiment with longitudinally polarized electrons. This had substantial impact on the design of the magnet and cryostat. The electron beam, with its much higher damage per physics event, dictated more refrigeration,

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rapid and reproducible target changing, and mass production of target material. Our response to all this will be shown in subsequent figures.

Given the desire for high polarization we had an initial choice between a B/T of 5 Tesla/1° and 2.5 Tesla/.5° — each with special problems. We selected the first as indicated for a variety of reasons and so far are happy with that decision.

The magnet, of course, is superconducting and is essentially a solenoid with something better than $\pm$100 ppm uniformity. Cooling is by a "conventional" helium 4 system with offline recovery and reliquefaction. We get about 600 mW of cooling in a 25 cc target volume at about 1.05°K.

This is not the first 5T/1K target but may be the first used in a high energy physics experiment—certainly at an electron machine.

The choice of material at this time is porphyrexide doped butanol. From CERN and DESY data plus preliminary results of our own, we expect a polarization of about 70% times the ratio of polarizable protons to total nucleons of 10/74 or about 10%. To the extent that scattering off neutrons is less than that off protons this ratio is increased. (A coincidence experiment that could distinguish between target protons and neutrons would increase this a factor of about 2.)

We expect to change targets daily and to anneal several times in between. This, among other things, means a lower average polarization.

The NMR system is a constant voltage type with a parallel tank running at about 200 MHz. The measured admittance is proportional to polarization.

Microwave power at 140 GHz is produced by a backward wave oscillator which delivers up to 400 mW to the target cavity.

Helium consumption is about 7 to 8 liquid liters of helium per hour including losses in cooling the magnet dewar.

The beam is expected to be 10^9 electrons per pulse at 180 pps scanning over a 6.5 cm^2 area or about 10^{14} e$^-$/cm^{2}h. This, with the expected damage time of something longer than 10^{15} e$^-$/cm^{2}h, gives our running schedule indicated above. In this regard the target is well matched to the maximum intensity expected from the polarized source. That the peak SLAC electron beam is some 100 times more intense gives a feeling for the mismatch between present targets and electron physics.

Figure 1 gives an idea of the physical layout of the target. Not shown is all the peripheral equipment such as 30 hp of pumps, power supplies for magnet and microwave source, etc. Note that the beam enters along the axis of the cryostat.

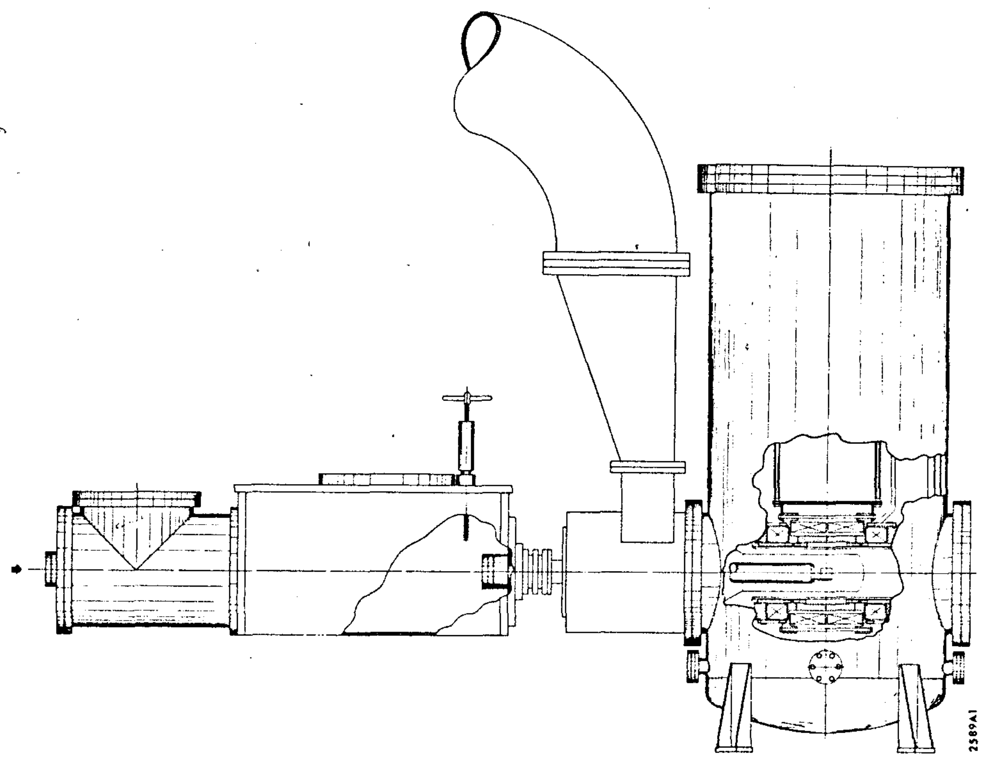


Fig. 1.

The solenoidal superconducting magnet is shown in its 250 liter dewar which also serves as local reservoir for the running cryostat. Refilling during the daily run from an external dewar is still required however.

The extractor is partially described in this view as it allows withdrawal of the tube holding the target, per se, into a vacuum chamber.

The clear aperture can be a 20° half cone angle although we are only using up to 10° in a plane.

The various windows, target walls, NMR loops, cavity walls, which are required in any such target place nontrivial amounts of junk in the beam which makes life more difficult. The butanol comprises about 90% of the total collision length number of .04 and about 60% of the total radiation length number of .08.

In addition, of course, one must face the problem of subtracting the large background from unpolarized nucleons. There are a variety of techniques including the use of 'diet butanol' (a mixture simulating C_4O instead of $C_4H_{10}O$) or using tabulated hydrogen cross sections.

The solenoidal field has some effects on the beam—slightly diverging the transmitted beam and slightly bending the scattered beam. Both effects are small compared to the respective apertures of beam monitor and spectrometer. This also requires us to shield several devices and to be careful with ferromagnetic materials in construction. Not shown are the gas cooled leads for the magnet nor the transfer line details.

In Fig. 2 one gets a better idea of the target extractor. The target is now withdrawn into the vacuum chamber and the cryostat isolated. The insert containing the old material is removed; the new insert is substituted; and the target is returned to the cryostat.

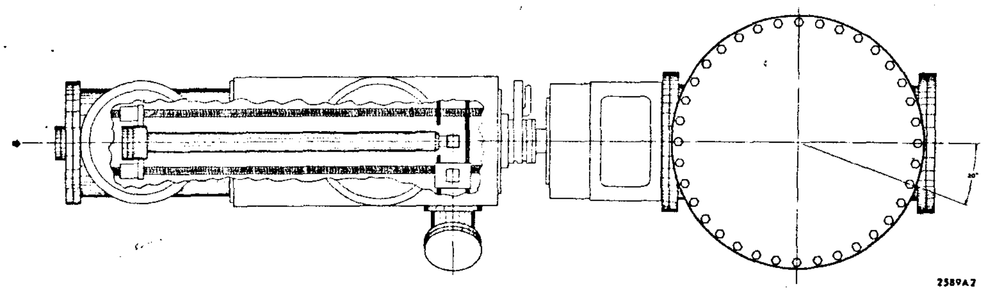


Fig. 2.

The entire procedure should take minutes and be relatively free of contamination and anguish. The extractor has been tested warm, and also cold with the cryostat running.

The target assembly is not too clear in these drawings, but essentially we will have a copper wall box which holds helium and contains a single turn NMR loop. The target material is placed in a glass box which sits in this loop. This assembly then rides into a microwave cavity fixed in the cryostat.

Figure 3 gives more details of the cryostat per se. The second reservoir has been of little value. Isolation of the input helium line, even in the cryostat, has been important. The valve system is becoming straightforward with a precool valve for start up and a fine metering valve for running. Both derive liquid from the magnet dewar.

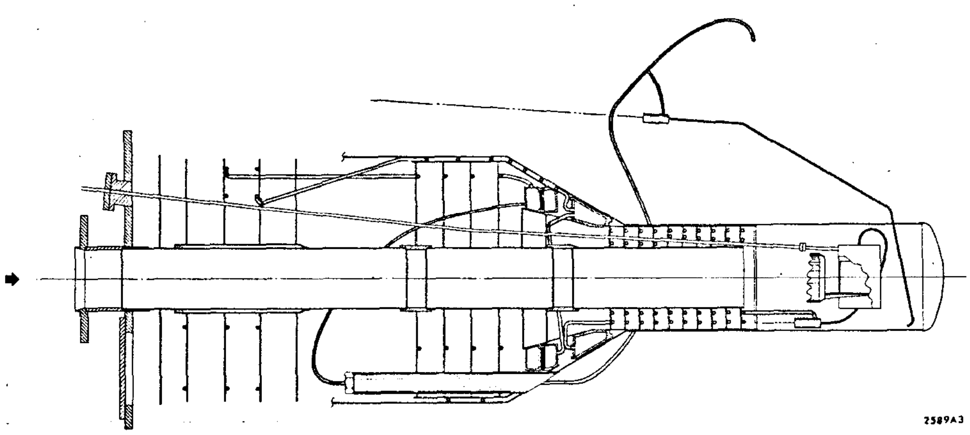


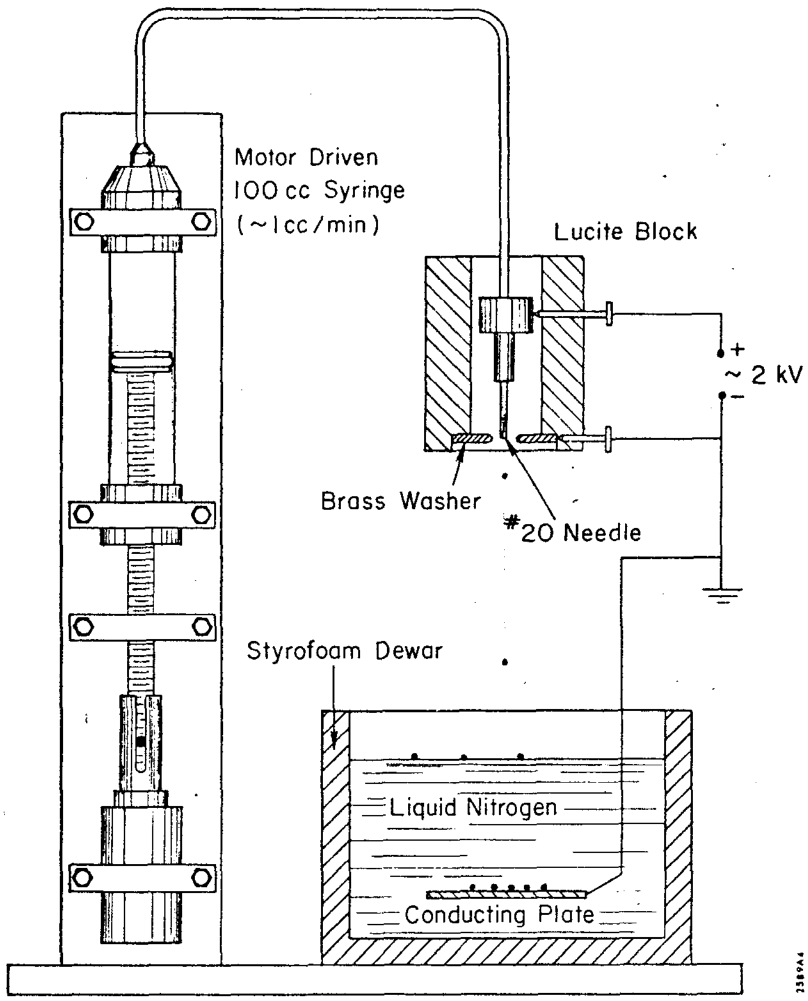
Fig. 3.

Thorough cooling of the beads is most important to maintaining polarization in the presence of heating by beam and microwaves (typically 250-300 mW). Small diameter (less than 2 mm) beads have been a favored configuration for alcohol targets. In small quantities on infrequent occasions, producing the beads by dropping from a syringe onto liquid nitrogen works well. It tends to be a slow process because the drops must be made one at a time or in separated areas of the liquid or they coalesce before freezing. For daily changes, this is a problem.

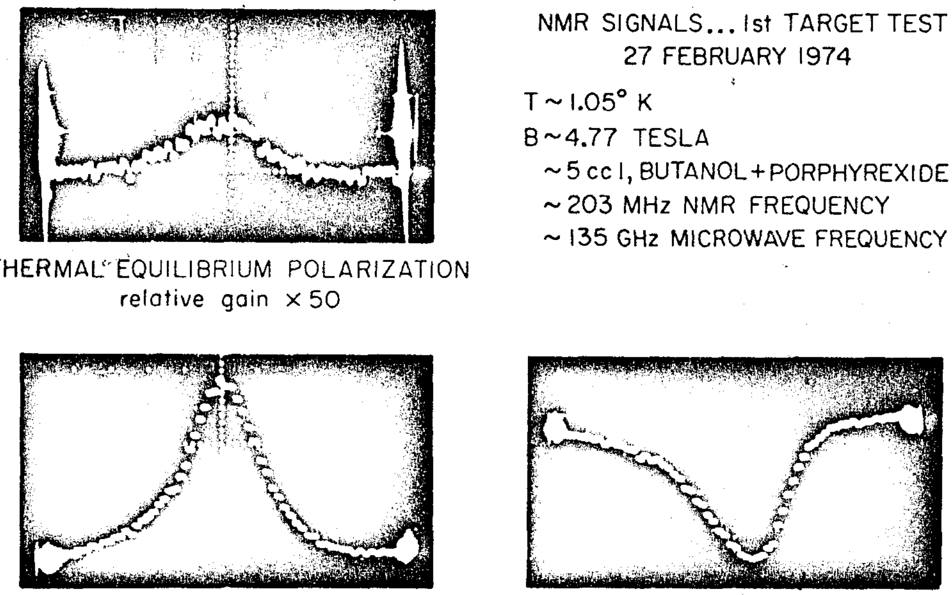
In trying to find ways to speed up this process and to automate it some, I found a technique which kills two birds with one stone.

As shown on Fig. 4, we use a motorized syringe to feed liquid to a needle at a desired rate. If a potential is placed on this needle the electric field increases the volume force on the liquid thereby giving smaller drops for a given needle than gravity alone. The size of the drops is variable with the potential down to about 1 mm. Most importantly, however, the drops retain the charge and repel each other dramatically on an open surface. The prototype illustrated here allows a production rate of about 1 cc/min, and is easily paralleled.[2]

Fig. 4.



In February, we polarized for the first time obtaining the rough data in Fig. 5. The enhancement, T_1, and T_2 are all consistent with data from other labs. We are hedging this statement because we did not have the NMR system completely debugged at the time; we were using a considerably smaller sample and the target assembly was quite different from the expected final design.[3]



NMR SIGNALS... 1st TARGET TEST
27 FEBRUARY 1974

T ~ 1.05° K
B ~ 4.77 TESLA
~ 5 cc I, BUTANOL + PORPHYREXIDE
~ 203 MHz NMR FREQUENCY
~ 135 GHz MICROWAVE FREQUENCY

THERMAL EQUILIBRIUM POLARIZATION
relative gain × 50

POSITIVE ENHANCED POLARIZATION
relative gain × 1

NEGATIVE ENHANCED POLARIZATION
relative gain × 1

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Fig. 5.

We have a fair amount of confidence in the target at this point and a great deal of work ahead in converting it from a laboratory curiosity with a half dozen handmaidens to a remotely located working target on the floor of the SLAC end station.

REFERENCES

1. Details on the target design will be submitted for publication in the near future.
2. Although the charge repulsion feature is unique, this is the Nth reinvention of a device to produce small drops by electric fields. See, for example, Raghupathy and Sample, Rev. Sci. Instr. 41, 645 (1970) and references therein.
3. Since the above talk we have run again with a full sized target in final design obtaining polarizations of $+66 \pm 5\%$ and $-70 \pm 5\%$.