CLAS-NOTE 2003-002

Notes about Holding Magnet System for the Hall-B Frozen Spin Polarized Target

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1. Introduction

The principle of the frozen spin target operation is:

1) to polarize the target material optimally at

a high magnetic field B = 2.5 – 5.0 Tesla

and

temperature around T = 300 – 700 mK.

2) to freeze the polarization at

significantly lower temperatures T = 30–70 mK

and

a holding magnetic field B = 0.4-0.8 Tesla.

2. Holding Field

The holding field of the order of 0.5 Tesla in the target area could be produced by

either

1. fringe field of the external Polarizing Magnet

   or

2. "small" internal magnet placed inside the target.

The external Polarizing Magnets are large and have a strong fringe field. Therefore such frozen spin targets cannot be operated in combination with 4π – detector.

Using a small superconducting internal "holding magnet" allows a substantial reduction of the magnetic field affecting the detector components and particle tracking.

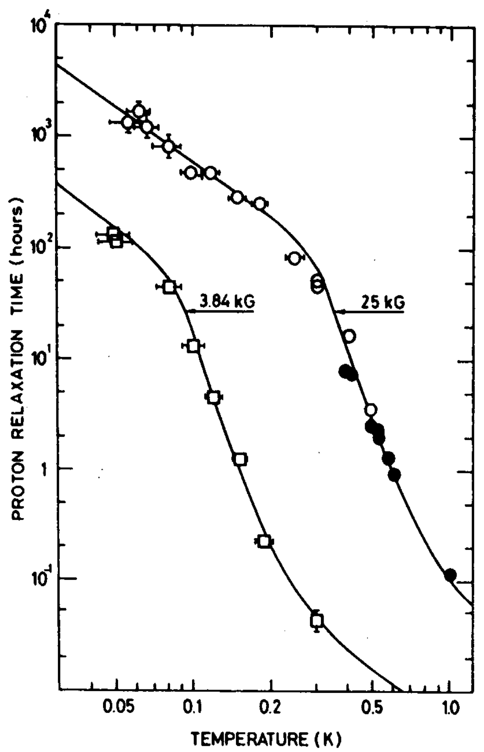
3. W. De Boer and T.O. Niinikoski, 1974

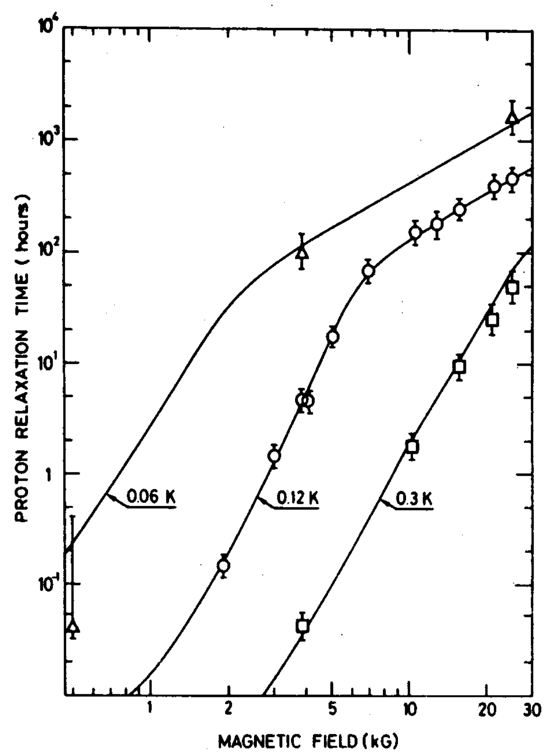
The temperature and magnetic field dependence of the proton spin-lattice relaxation time:

$$T_{1p}^{-1} = [AT_{1e}B^2 \cosh^2(\frac{h\nu_e}{2kT})]^{-1} + (3.96\frac{B^{1.32}}{T^{1.64}})^{-1}, \text{ where}$$

$$AT_{1e} = 0.225\ [B^5 \coth(\frac{h\nu_e}{2kT}) + (6.75 \exp(-\frac{0.5}{T})]^{-1}$$

Below are experimentally measured values.





4. Relaxation time vs Temperature
Holding field

Previous plots show that

1. relaxation time is strong function of temperature and field

2. after "critical point" $T = 100\ mK$ and $B = 0.5\ Tesla$, relaxation time is changing rapidly

3. depending on cooling power of the dilution refrigerator, for a chosen relaxation time, we have to keep a proper combination of temperature and holding magnetic field which means

   for photon experiments we can afford to work at lower temperatures $T = 50\ mK$ (cooling power problem) and decreased holding field down to $B = 0.3\ Tesla$

   in opposite to that

   for electron experiments we have to work at higher temperatures $T = 200\ mK$ (?) which enforces us to use holding field up to $B = 1.0\ Tesla$ (?)

5. Typical cooling power vs temperature /Mainz,GDH, 1999/

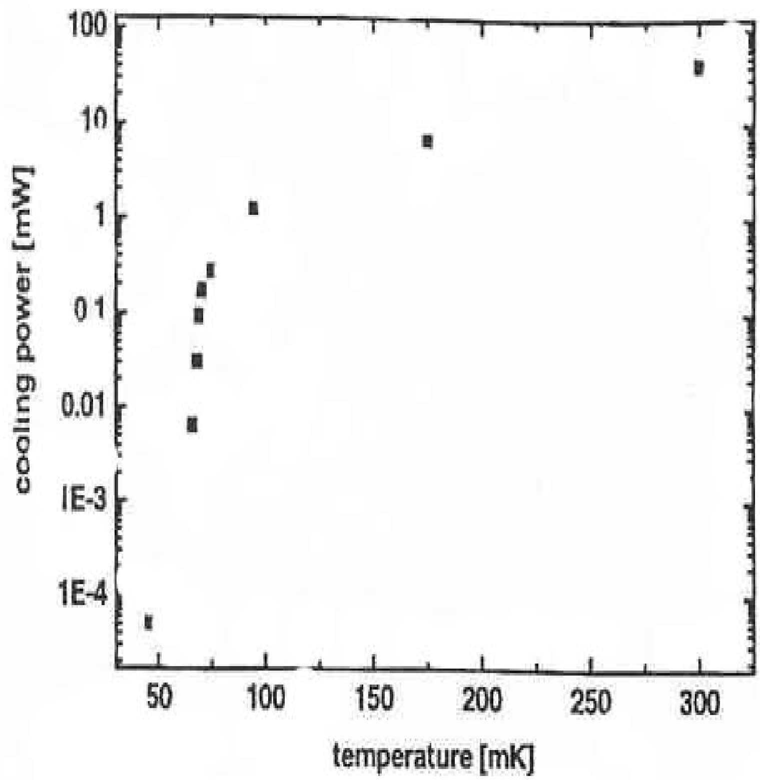


Fig. 3. Cooling power of the refrigerator.

After 100 mK, cooling power drops down pretty fast. In the frozen spin mode the refrigerator is usually operated at 50-60 mK with a cooling power of a few micro-watts.

6. Bonn, 1998 experimental setup

Polarized target in combination with a full $4\pi - detector$.
experiment $- \eta - photoproduction$
material $- butanol$

multi-filament $NbTi$–wire, diam $D = 100mkm$
current $I = 7A$ (current density $J = 900A/mm^2$)
at $T = 4.2K$ with the critical field $B = 1.0\ Tesla$.

Operating temperature $T < 1.3K$
winding numbers $N = 5000$ (4 $layers$)
current $I = 9.48A$ (current density $J = 1207A/mm^2$)

Results

Polarizing field $B = 2.5\ Tesla$
Max proton polarization achieved $P = 85\%$
Average proton polarization $P = 71.6\%$

Holding Mode $B = 0.38\ Tesla$ and $T = 57.4\ mK$

The longest proton relaxation time achieved

$$t = 245 hours$$

7. GDH sum rule experiment. Mainz

Polarized target in combination with a full $4pi-detector$.

multi-filament $NbTi$–wire, diam $D = 100mkm$
$Four$ layers of 1050 $turns$ each.
operational temperature – below $1.2K$
max achieved current $I = 12A$ ($B = 0.48$ $Tesla$)

material **ammonia** and **butanol** (protons)

In the frozen spin mode of
Holding Field $B = 0.42$ $Tesla$ and $T =$ 50-60 mK
the relaxation time

$$t = 200hours.$$

8. Ch.Bradtke, H.Dutz, et al, Bonn,1998

GDH sum rule experiment.
Polarized target in combination with a full 4$pi-detector$.
coil temperature $T = 1.2K$
material $- \ butanol$

The relaxation time using different frozen spin modes

$t = 120hours$, $T = 70mK, B = 0.42Tesla$

$t = 200hours$, $T = 55mK, B = 0.42Tesla$

$t = 1500hours$, $T = 55mK, B = 0.70Tesla$

9. Other Groups

Prague, Czeck

material − $propanediol$
target dimensions − $D = 20mm, L = 60mm$
Polarizing Mode $T = 0.3 - 0.8K, B = 2.7T$
Holding Mode $T = 18 - 25mK, B = 0.4T$

Relaxation time $T = 250hours$

Protvino, Russia

material − $pentanol$
target dimensions − $D = 20mm, L = 100mm$
Polarizing Mode $T = 0.3 - 0.8K, B = 2.08T$
Holding Mode $T = 18 - 25mK, B = 0.4T$

Relaxation time $T = 300hours$

Dubna, Russia

material − $propanediol$
target dimensions − $D = 20mm, L = 200mm$
Polarizing Mode $T = 0.3 - 0.8K, B = 2.7T$
Holding Mode $T = 50 - 60mK, B = 2.7T$

Relaxation time $T = 400hours$

10. JLAB Holding Solenoid(Prototype)

Assuming that the target cell has

diam $D = 15mm$ and $L = 25mm$

Mike Seely has made a prototype of the holding solenoid with parameters

1. diam D = 40 mm
2. length L = 220 mm
3. thickness δ = 0.24 mm
4. diam of wire d = 0.112 mm
5. max current I = 12.7 Amps
6. turns N = 1800 turns per layer
7. layers n = 2 layers
8. field map has not been measured yet.

Using such parameters, TOSCA(OPERA) simulation gives us a magnetic field on the center of a solenoid

2557 Gauss (0.26 Tesla)

11. Relaxation time vs Holding field /Mainz,GDH, 1999/

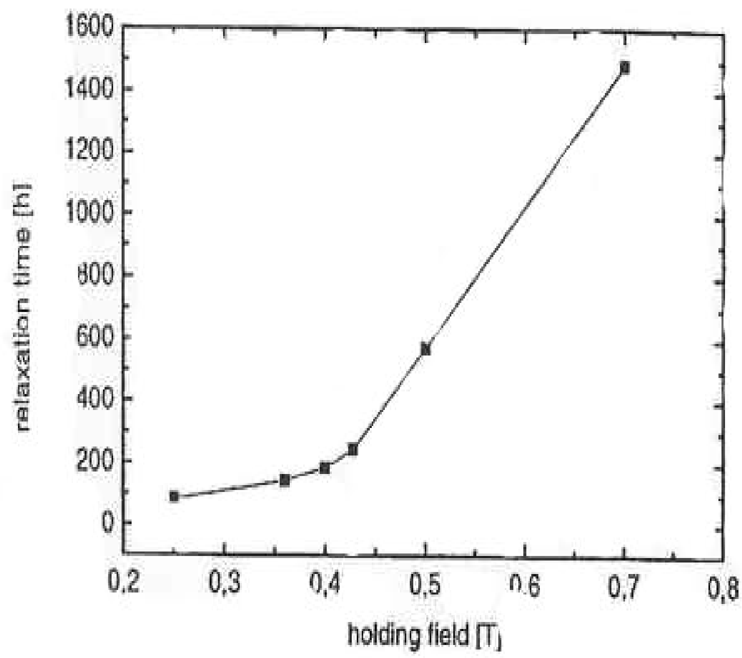


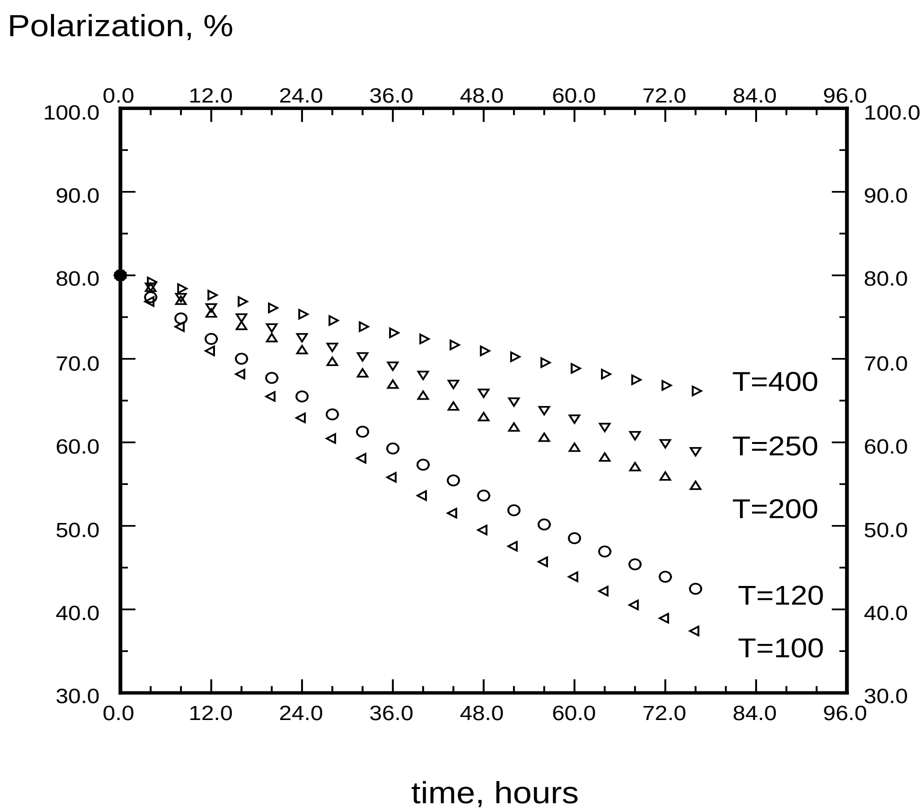
Fig. 11. Relaxation time of butanol at 60 mK.

Using this picture, we can estimate a relaxation time.
Realizing Frozen Spin Mode
$T = 60\ mK$ and B = 0.25 Tesla

we can expect a relaxation time

$$t < \mathbf{100}\ hours$$

12. Polarization drop with different relaxation time



13. Work cycle with different relaxation time

Lets assume that we start from
$P = 80\%$
and polarization drop should not be less then
$P = 75\%$
Using previous picture, we can estimate a work cycle, the period after which we have to stop a run and polarize target back to maximal value.

Having target setup with relaxation time T_{rel}, we can expect a work cycle T_{work}

$$T_{rel} = 100\ hours,\ T_{work} = 4\ hours$$
$$T_{rel} = 120\ hours,\ T_{work} = 8\ hours$$
$$T_{rel} = 200\ hours,\ T_{work} = 12\ hours$$
$$T_{rel} = 250\ hours,\ T_{work} = 16\ hours$$
$$T_{rel} = 400\ hours,\ T_{work} = 28\ hours$$

14. Needed Holding Field

For reasonable conditions:

Work cycle $T_{work} = 12 - 16\ hours$
Frozen Mode at T = 50 - 60 mK,

we need Holding Magnet with field

$$\mathbf{B = 0.5\ Tesla}$$

(maybe even more ?)

Which means that we need to double an amount of layers and overall wall thickness becomes

$$\delta = 0.5\ mm$$

15. Conclusions

1. Photon experiments are supposed to work in $T =$ 50–60 mK mode. For the reasonable work cycle $T_{work} = 12 - 16\ hours$ we need Holding Magnet with field

   B = 0.5 Tesla

2. Electron experiments need more cooling power and might be run at higher temperatures $T = 100 -$ 150 mK (?). In this case we need Holding Magnet with field

   B = 0.7 Tesla or even more(?)

3. To satisfy both electron and photon experiments we have to consider the "universal design" of Holding Magnet with field

   B = 0.7 Tesla

16. Acknowledgments

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17. References

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