9th International Workshop on Polarized Solid Targets and Techniques

Jaakko Koivuniemi

http://poltarg03.ep1.rub.de/
Monday 27 October

Opening

S. Mango, PSI, *Early target material research with chemical dopants*

J. Ball, Saclay, *Thirty years of research with Lithium compounds in SACLAY*

W. Meyer, Bochum, *Early polarization studies with ammonia targets*

S. Goertz, Bochum, *The dynamic nuclear polarization process*

E. Bunyatova, Dubna, *Free radicals and polarized targets*

J. Ardenkjaer-Larsen, Malmö, *Method for making solutions of molecules with hyperpolarized nuclear spin*

J. Kohlbrecher, PSI, *The dynamics of nuclear spin polarization, investigated by simultaneous NMR and polarized neutron scattering*

H. Stuhrmann, Grenoble, *Polarized neutron scattering from selectively polarized proton domains in catalase*
O. Zimmer, München, *The spin-dependent nd-scattering length - a proposed high-accuracy measurement*

P. Hautle, PSI, *A comparison of NMR concepts for polarization experiments*

G. Court, Liverpool, *The Liverpool NMR-system*

G. Reicherz, Bochum, *Pulsed NMR for the determination of the nuclear polarization*
Fig. 2. A container used for small samples.

New "sexy" instruments

CERN 1964
A BUTANOL POLARIZED PROTON TARGET

S. MANGO*, Ó. RUNÓLFSSON and M. BORGHINI

CERN, Geneva, Switzerland
Received 31 January 1969

Dynamic proton polarizations around 40% have been reproducibly obtained in 5 cm³ samples made of 95% 1-butanol and 5% water mixtures, saturated with the free radical porphyrexide, at temperatures close to 1 K in a magnetic field of 25 kOe.

1. Introduction

In the course of a systematic study of dynamic proton polarization in hydrogen-rich organic substances doped with free radicals, we have given special attention to alcohols CH₃(CH₂)₄OH doped with porphyrexide.*

\[
(CH₂)₂-C\:\:\:\:N\:\:\:O
\]
\[
H\:\:\:\:\:C\:\:\:\:N\:\:\:C=\:\:NH
\]

Ethanol was studied first and it was found that the

<table>
<thead>
<tr>
<th>Table 1</th>
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<tbody>
<tr>
<td><strong>Comparison of lanthanum magnesium nitrate and butanol as target materials.</strong></td>
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<tr>
<td>****</td>
</tr>
<tr>
<td>Max. polarization</td>
</tr>
<tr>
<td>Hydrogen density (g/cm³)</td>
</tr>
<tr>
<td>Total density (g/cm³)</td>
</tr>
<tr>
<td>Bound protons</td>
</tr>
<tr>
<td>Free protons</td>
</tr>
<tr>
<td>Radiation length (cm)</td>
</tr>
<tr>
<td>Acceptable number of min. ionizing beam particles/cm³</td>
</tr>
<tr>
<td>Polarization build-up time (sec)</td>
</tr>
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</table>
Argonne (US) 78 Conference

1978: Abragam: $^6$LiD potentially interesting target material. In contrast with other target materials, linewidth is determined by hyperfine couplings of the F-centres with nearby Li.

$\mu(\text{Li})/\mu(\text{D}) = 4$, same ratio expected between $^7\text{LiH}$ and $^6\text{LiD}$ ESR linewidths and much lower nuclear Spin Temperature.

And $\mu(\text{Li}) = \mu(\text{D})$ and have both spin $l = 1$.

If $^6\text{Li} = ^6\text{D} + ^4\text{He}$, in polarized $^6\text{Li}$, both nuclei have the same polarization $P = P(\text{Li}) = P(\text{D})$. The ratio $r$ of the total number of polarized nucleons to the total number of nucleons is 0.5 which is far higher than for other available materials.

"Highly speculative but amusing. Among other problems, one would have to lay hands on $^6\text{LiD}$ which, if one is not in the thermonuclear business, may prove difficult."

J. Ball / Bad Honnef 00

06/11/2003
1980: Final step of the Abragam group

Aragam, Bouffard, Roinel, Roubaux.

June: "Dynamic nuclear polarization in $^9$LiD"
(J. Phys. A 147, 1980)
Bouffard, Roinel, Roubaux, Abragam.

$H_0 = 6.5$ T \( R(\text{Li}) = 71\% \)
4.8 T \( 64\% \)
2.5 T \( 40\% \)

At 6.5 T, \( \beta = 825 \text{ K}^1 \).

Building up times range between 20 and 40 hours, not convenient.

"Scaling up 12 mm$^3$ samples to the size currently used in polarized targets would require considerable development work. An important problem that remains concerns the reproducibility of the creation of the F centers. This is believed to depend upon a better control of the sample temperature during irradiation."

J. Ball / Bad Honnef '03
06/1/2003
1970: First dynamic proton polarization in AMMONIA

K. Scheffler (CERN); NIM B2 (1970) 205

"After trying a number of paramagnetic centers such as sodium, porphyrexide, porphyrindine, diphenylpicryl-hydrazil, Ziegler’s radical, di-tert.-butyl-nitroxide, per-chlorotriphenylmethyl and violanthrone, all of which gave low polarization or none at all, we doped the liquefied ammonia with CrV glycerol complexes."

NH₃ with Cr(V) glycerol complexes P = 40% at 1 K and 2.5 T

glycerol or glycerine: C₃H₅(OH)₂ → f = 0.087
Conclusions

After 5 years (1979 – 1984) work on irradiated AMMONIA:
Most practical preparation method: High temperature irradiation

Highlight No. 1:
EMC-results from CERN deep inelastic polarized muon-polarized proton
– 3 ltr NH₃ irradiated in Bonn by Bonn-CERN-Liverpool activities
S. Brown et al., Proc. 4th workshop (Bad Honnef) p. 66
– P = 80 %
Important: high dilution factor
Thermal contact between $(Z)_I$ and $(Z)_S$ if $\omega_1 \gg D$
DNP by the Solid Effect

Nuclear Zeeman
$C_z^I \sim N_I \omega_1^2$

Dipol
$C_S^I \sim N_SD^2$

Zeeman
$C_z^S \sim N_SD^2$

RF
$\alpha$

$T_z^I$

$T_D$

$T_z^S$

$\beta_L$
Signal decays due to relaxation and dilution

- Brain vessels: 23 s / 30 mM
- Lung vessels: 5-15 s / 30 mM
- Coronary artery: 15-20 s / 30 mM
- Heart chambers: 3-4 s / 30 mM
- Aorta: 25 s / 30 mM

Cardiac output: 6 l/min
Injection at 10 ml/s
DNP: a two step process

1. electrons close to electron polarize first
   - time constant: $t_{\text{pol}} < 1 \text{s}$
   - microwave induced direct interaction falls off like $n^6$

2. polarization diffuses to the bulk protons by flip-flop transitions
   - time constant: $t_{\text{diff}} \approx \text{few seconds}$

- paramagnetic centre generates strong local field
- close protons: strongly coupled to the p.c.
  - weakly coupled to the bulk
  - "poorly visible" by cw-NMR
- bulk protons: weakly coupled to the p.c
  - "visible" by cw-NMR

S. Goertz, Bochum, *Highest polarizations in deuterated compounds*

D. Crabb, Charlottesville, *Polarization in Radiation doped D-Butanol and CD2*

T. Wakui, Tokyo, *Proton polarization in naphthalene crystal with a CW Ar-ion laser*

X. Wei, Brookhaven, *New improvements leading to higher polarization frozen spin HD-target at the LEGS facility*

J. P. Dideliez, Orsay, *Static and dynamic polarization of HD*

E. Radtke, Bochum, *Efforts towards a dynamically polarized HD-target*
K. Kondo, Nagoya, *Polarization measurement in the COMPASS polarized target*

J. Koivuniemi, Helsinki, *NMR lineshapes in highly polarized $^6\text{LiD}$ at 2.5 T*

Y. Kisselev, Dubna, *Nuclear Local Fields in LiD polarized target material*

N. Doshita, Nagoya, *Performance of the COMPASS polarized target dilution refrigerator*

S. Neliba, Praha, *Weight measurements of the COMPASS large double-cell target volume*

F. Gautheron, Bielefeld, *Cryogenic control system of the large COMPASS polarized target*
Tuesday 28 October

B. van den Brandt, PSI, *DNP with deuterated TEMPO and oxo-TEMPO*

P. Hautle, PSI, *EPR and DNP of alcohol water mixtures with nitroxyl radicals*

J. Heckmann, Bochum, *High field-/low temperature EPR-spectroscopy*

M. Iio, Miyazaki, *Development of polarized target for nuclear fusion experiments*
### Maximum polarization

<table>
<thead>
<tr>
<th></th>
<th>+ pol. (%)</th>
<th>- pol. (%)</th>
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</thead>
<tbody>
<tr>
<td>2001 upstream average</td>
<td>54.18</td>
<td>-</td>
</tr>
<tr>
<td>2001 downstream average</td>
<td>-</td>
<td>-47.40</td>
</tr>
<tr>
<td>2002 upstream average</td>
<td>55.49</td>
<td>-52.72</td>
</tr>
<tr>
<td>2002 downstream average</td>
<td>56.89</td>
<td>-47.47</td>
</tr>
<tr>
<td>2003 upstream average</td>
<td>58.81</td>
<td>-50.67</td>
</tr>
<tr>
<td>2003 downstream average</td>
<td>54.07</td>
<td>-48.95</td>
</tr>
</tbody>
</table>

Polarized Solid Targets, 28 Oct. 2003

Kaori Kondo, Nagoya Univ.
Jaakko Koivuniemi

D pol = -40.8 %

signal

B = 2.506 T

$D_{pol} = -40.8\%$

signal

$M_2 = 1.8\ kHz^2, -37.0\%$

$M_2 = 2.7\ kHz^2$

$M_4 = 34.8\ kHz^4, -38.9\%$

$M_4 = 34.8\ kHz^4$

$B = 2.506\ T$
4. For the first time we have measured D, 6Li and 7Li local fields in crystalline LiD material and have compared with the theory elaborated for monocrystal. In Gauss approximation we have:
Norihiro Doshita

Optimization of $^3$He flow for DNP

$^3$He flow rate [mmol/sec] vs. MC Temperature [mK]

- Near 350mW microwave power at the beginning of DNP
- ~50mW microwave power at close to 50% polarisation

Measured by TTH4
### Upstream | Downstream
---|---
m = 172.1 ± 2.5 g | 178.1 ± 2.5 g
V = 413 ± 5 cm³ | 416 ± 5 cm³
PF = 0.508 ± 0.027 | 0.522 ± 0.027

2003
<table>
<thead>
<tr>
<th></th>
<th>mass [amu]</th>
<th>up [mol]</th>
<th>down [mol]</th>
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<tbody>
<tr>
<td>H</td>
<td>1.00794</td>
<td>0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>D</td>
<td>2.0140</td>
<td>21.23</td>
<td>21.97</td>
</tr>
<tr>
<td>$^3$He</td>
<td>3.0169</td>
<td>0.7 ± 0.2</td>
<td>0.7 ± 0.2</td>
</tr>
<tr>
<td>$^4$He</td>
<td>4.0026</td>
<td>6.8 ± 0.3</td>
<td>6.6 ± 0.3</td>
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<tr>
<td>$^6$Li</td>
<td>6.0151</td>
<td>20.44</td>
<td>21.15</td>
</tr>
<tr>
<td>$^7$Li</td>
<td>7.0160</td>
<td>0.90</td>
<td>0.93</td>
</tr>
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</table>
Cryogenic control system of the large COMPASS polarized target

the monitoring of the temperature measured in the upstream and in the downstream cell

Online Temperatures
Cryogenic control system of the large COMPASS polarized target
Wednesday 29 October

T. Uesaka, Tokyo, CNS polarized proton target

C. Djalali, Columbia, Studies of dipole magnets for transversal holding magnetic field for the Jlab Hall-B Frozen Spin Polarized Target

Y. Usov, Dubna, Frozen spin solid targets development at the laboratory of nuclear problems

Chr. Rohlof, Bonn, Effective densities of the polarized targets for the GDH-experiment at ELSA

P. McKee, Charlottesville, Radiation damage and recovery in ammonia targets

H. Dutz, Bonn, Highlights of the polarized solid target instrumentations

Closing remarks
• ELSA target longer than MAMI target
  \(\rightarrow\) Filling factors differ
• Influence of NMR wire inside?
• Distribution of \(f(x, y)\)?
  \(\rightarrow\) Convolution with beam profile
  \(\Rightarrow\) Numerical Calculation