Development of 17T-NMR system for measurement of polarized HD target

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● Introduction of polarized HD target in Osaka

● 17 Tesla portable NMR system
1. Polarized HD target for hadron physics
   From 2007
   Present talk

2. Hyperpolarized 3He for polarized source of MRI
   From 2009
The hadron photoproduction of the $\phi$, $K$, $\eta$, and $\pi^0$ mesons is studied by using linearly polarized photon beams with energies of $E_\gamma = 1.5 \sim 2.9$ GeV at SPring-8 (LEPS). These hadron photoproduction experiments have been carried out with unpolarized target. We plan to carry out hadron photoproduction experiments by using polarized photon beams and the polarized target.

**Objective**
Development of the polarized Hydrogen-Deuteride (HD) target for double-polarization Experiments in LEPS.
HD target is cooled and polarized inside dilution refrigerator for 3 month. NMR measurements are required at various points denoted by ○. Portable NMR measurement system has been developed for handy transportation.
Polarized HD target

HD is heteronuclear diatomic molecule consisted by hydrogen and deuteron

**Polarized method**
We use the statistical method by cooling down and keeping the HD target at 10 mK with 17 Tesla for a few months (Brute-force method).

**Advantage and disadvantage**
Advantage: Dilution factor is good. (the number of H’s / the number of nucleons)
- HD = 1/3(33.3%), NH$_3$ = 3/17(17.6%), C$_4$H$_{10}$O = 10/74(13.5%)
Disadvantage: The HD target needs thin aluminum wires (at most 20% in weight) to improve the cooling power to solid HD.

**Size of Target**
Diameter is 25 mm. Length is 50 mm.

**Relaxation time**
Under the condition of the experiment (T=300 mK and B=1 Tesla), the relaxation time is possible to be longer than several months.
Frozen polarization mechanism

**Initial**
The polarization of HD is produced by the spin-flip with small concentration of ortho-H$_2$ (~0.01%) included in HD at 17 Tesla & T=14 mK

**After 2 or 3 month**
Most of ortho-H$_2$ has converted to para-H$_2$. Polarization degree of HD is kept for about one year at 1 Tesla & T=300 mK
**Frozen polarization mechanism**

**Concentration of ortho-H$_2$**
Decrease with time.
Time constant is 6.5 days

**Relaxation time**
Increase with time. The relaxation time depends on the concentration of ortho-H$_2$

**Polarization**
The Polarization grows with time. Growing rate depends on relaxation time.
When the relaxation time is very short, the polarization reaches Thermal Equilibrium

Initial concentration of o-H$_2$ is important for the polarization degree and relaxation time of HD target. Optimal concentration of ortho-H$_2$ is 0.02%?
Measurement of NMR spectra

NMR signals obtained at 4.2 K as a calibration point (Polarization = 0.024%)

Meas. Environment
- Temperature: 4.2 K
- Magnetic field: 1 Tesla

NMR signals obtained after polarization production.
Polarization: $40.8 \pm 2.3\%$
Relaxation: $112.8 \pm 0.1$ days

Meas. environment
- Temperature: 300 mK
- Magnetic field: 1 Tesla

We only observe the NMR signal before and after
## Production results

<table>
<thead>
<tr>
<th>Term</th>
<th>Aging time</th>
<th>Temp.</th>
<th>Magnetic</th>
<th>ortho-H$_2$</th>
<th>Pol.</th>
<th>Relax.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1$^{st}$</td>
<td>2008 Dec – 2009 Jan</td>
<td>53 days</td>
<td>14 mK</td>
<td>17 T</td>
<td>unknown</td>
<td>40%</td>
</tr>
<tr>
<td>2$^{nd}$</td>
<td>Failed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3$^{rd}$</td>
<td>2012 Aug – Sep</td>
<td>53 days</td>
<td>15 mK</td>
<td>17 T</td>
<td>0.06%</td>
<td>30%</td>
</tr>
<tr>
<td>4$^{th}$</td>
<td>2013 Jul – Sep</td>
<td>53 days</td>
<td>18 mK</td>
<td>17 T</td>
<td>0.1%</td>
<td>18%</td>
</tr>
<tr>
<td>5$^{th}$</td>
<td>2014 Feb – Mar</td>
<td>30 days</td>
<td>28 mK</td>
<td>16 T</td>
<td>no meas.</td>
<td>42%</td>
</tr>
<tr>
<td>6$^{th}$</td>
<td>2014 Dec – Mar</td>
<td>53 days</td>
<td>36 mK</td>
<td>17 T</td>
<td>0.2%</td>
<td>45%</td>
</tr>
</tbody>
</table>

*The concentration of ortho-H$_2$ is changed every production test.
*From 2008 to 2012, we were developing the other cryostat, instruments and so on.*
Calculation of polarization growing

This is model equation for polarization growing.

\[ T_1 = \frac{\alpha \beta}{\alpha/\gamma + N_0^2 \exp(-t/\delta)^2}, \quad P(t) = 1 - \exp \left\{ \frac{N_0 \delta}{2 \alpha \beta} (\exp(-t/\delta)^2 - 1) - \frac{t}{\beta \gamma} \right\} \]

- \( N_0 \) : Initial ortho-H2 amount
- \( \alpha \) : Ortho-H2 concentration parameter
- \( \beta \) : Temperature parameter
- \( \gamma \) : \( T_1 \) saturation parameter
- \( \delta \) : Time constant of ortho-para conversion (6.5 day?)

NMR signal is observed before and after the polarization production previously. I want and need the information of polarization growing curve. => Develope the 17 T NMR system and get the parameters of \( \alpha, \beta \) and \( \gamma \).
HD distiller and gas analyzer

Fortunately we have developed the instruments enable us to control the ortho-H₂ concentration with precise of 0.001%

- The gas analysis system enabled us to observe p-H₂, o-H₂, HD, and D₂ separately.
- Components in HD gas enable us to analyze with a high precision of 0.001%
- Distillation term is shorten from 34 days to less than 6 days

Don’t take care to control the initial amount of ortho-H₂
Portable NMR system

Digital modules
- PXI-1036 Chassis
- PXI-8360 Connection card
- PXI-5404 RF generator (100MHz)
- PXI-5142 Digitizer (100MS/s)

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Portable NMR system (PXI-NMR)

- Don’t need to disconnect and connect the cable to port of many device.
- Operation trouble shooting is easy.
- The system enable us to measure NMR signal automatically and to custom the measurement

<table>
<thead>
<tr>
<th>Weight</th>
<th>Size</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1 Kg</td>
<td>W 250  D 200  H 200</td>
<td>$15000</td>
</tr>
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</table>
In order to be able to measure the NMR in 17 Tesla,,

Add these modules

- PXIe-5650 RF generator (1.3GHz)
- PXIe-5162 Digitizer (2.5GS/s)

Add the function

- Frequency sweep method
- Enable the cross coil

- Sweep region is 726.9+-1MHz
- 240 times integration. (For 4 min.)
- Analog circuit is only preamp for NMR signal.
NMR signals from 50 MHz to 100 MHz

Proton NMR signals. No frequency restriction because it does not use Q-meter.
17T-NMR system enable us to obtain a several nuclear NMR resonance. NMR resonance of Hydrogen and Deuteron in HD target is measurable in 17 Tesla.

But we can’t measure Carbon and Aluminum NMR resonance. (We use aluminum wire and PCTFE cell)
HD group in Osaka University have developed polarized HD target.

Production of the target required for a few month.

Helium resource and man power resource will be short in the future.

To reduce or optimize the production term, 17T-NMR measurement system was developed.

17 T NMR measurement with frequency sweep was succeeded.

Polarization growing curve have not been acquired yet.