# Polarized Proton Target System in G2p Experiment

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## 1 Introduction

The polarized proton target used in g2p experiment is from UVa target group, it has beem used for many experiments before like SANE, RSS, Gen in Hall C, E143,E155,E155x in SLAC. The material NH3 is chosen because of its high polarization resistance against radiation damage. The basic principle for polarization is dynamic nuclear polarization(DNP), i.e., using low temperature down to 1K and 140GHz microwave to pump the polarization into a high level up to 94%. The 5.1T superconducting magnet used for polarization is built in oxford, the nuclear magnetic resonance(NMR) is used for measuring the polarization of the target and the thermal equilibrium(TE) polarization is used for calibrated it.

The target cool down is token for testing the polarization in UVa at the end of January by using several proton target such as NH3, LiH, LiD, butanol, propanediol, and for NH3 the polarization reached to -92.7% in the microwave frequency of 140.5MHz; and reached to 94.3% in the frequency of 140.20MHz.

## 2 Polarization Mechanisms

### 2.1 Thermal Equilibrium Polarization

A zeeman splitting because of the high magnetic field will cause a number of 2I+1 sublevels which the proton's spin is I=1/2 and will cause 2 sublevels, the population of these two sublevels can be calculated by Boltzmann law:

$$N_1 = N_2 e^{(\frac{-\Delta E}{k_B T})} \tag{1}$$

Here $N_1$and $N_2$ are the population of two sublevels, T is the temperature of the environment, $k_B$ is the Boltzman constant, $\Delta E$ is the energy difference of two sublevels in the magnetic field of B. As defined polarization by $P(\frac{1}{2}) = \frac{N_{\frac{1}{2}} - N_{-\frac{1}{2}}}{N_{\frac{1}{2}} + N_{-\frac{1}{2}}}$, one can calculate the thermal equilibrium polarization as:

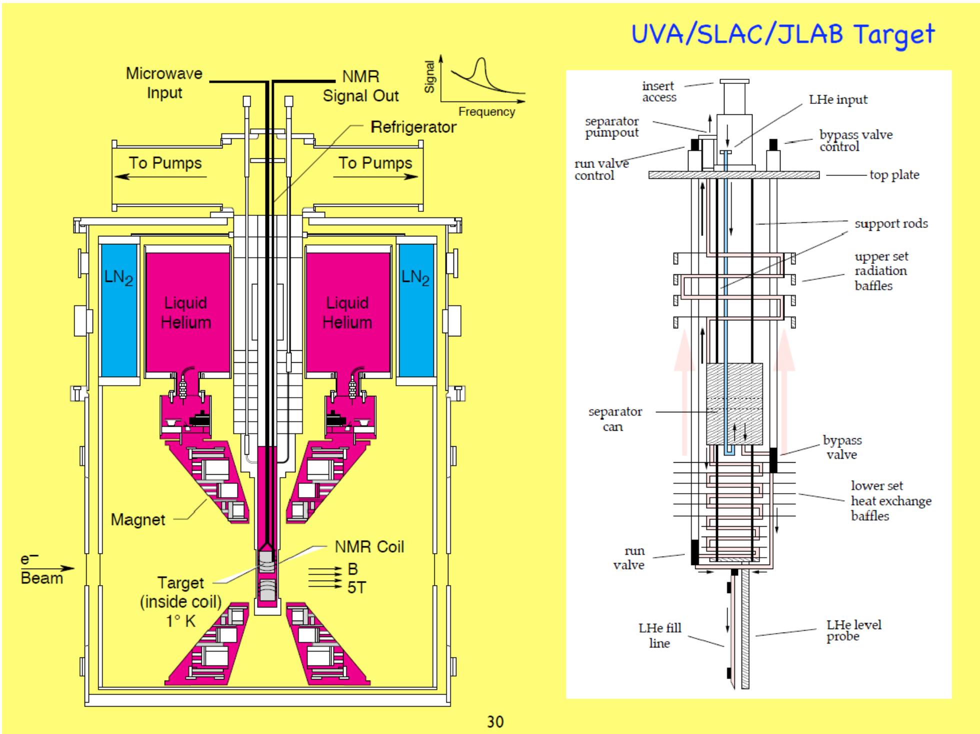


Figure 1: Polarized target system used in g2p

$$P(\frac{1}{2}) = tanh(\frac{\mu B}{k_B T}) \tag{2}$$

which is only the function of magnetic field B and temperature of T. The proton's thermal polarization is about 0.5% at 5 tesla and 1 K. It is used for calibrating the NMR measurement.

## 2.2 Dynamic Nuclear Polarization

In G2p experiment, DNP is used for polarizing the NH3 target. The energy splitting between two electron sublevels $m_e = \frac{1}{2}$ and $m_e = -\frac{1}{2}$ is about 140 GHz at 5T, and the energy splitting between two proton sublevels $m_p = \frac{1}{2}$ and $m_p = -\frac{1}{2}$ is about 200MHz at 5T. Thanks for the granular control of the microwave technology, we can obtain any frequency we want use in microwave section acculately by using the cavity. The "positive" polarization from the state of $e_{-\frac{1}{2}}p_{-\frac{1}{2}}$ to $e_{\frac{1}{2}}p_{\frac{1}{2}}$ need 140.2 GHz microwave and the "negative" polarization from the state of $e_{-\frac{1}{2}}p_{\frac{1}{2}}$ to $e_{\frac{1}{2}}p_{-\frac{1}{2}}$ need 140.5GHz.

# 3 Target material

There are many requirements used for choise the material, the polarization that can be obtained, the dilution factor (ratio of free polarizable nucleons to the total), the build-up time of polarization, the simplicity for the preparation and handling, the radiation damage resistance[1]. For example, butanol has less polarized background than ammonia and higher dilution factor than propanediol, ammonia and propanedial can achieve higher polarization.

In order to let the material cooling averagely, it will be processed granularity and equal size into ~1mm beeds. The rapid freezing process is used for create a glassy state in order to achieve the hypodispersion of paramagnetic radicals. In order to get more paramagnetic radicals, the irradiation proicess is necessary. For the g2p experiment, the high temperature irradiation at ~80K will be done in NIST at a short time away in the future.

The most important things that can reduce the polarization is radiation damage. The radication can produce additional radicals that the Larmor frequency of it is different as the material, as the increasing of these radicals, the relax time of nucleon will be shortened and the polarization of it will be reduced. The ammonia is chosen because of its high resistance of radiation damage and low temperature(~77K) for annealing to recover. Even so, the target material need to change for many times in the g2p experiment.

# 4 Devices used in cool down and g2p experiment

The target cool down for testing the polarization of ammonia has been token at the end of January, many of devices such as several electronics also will be moved to jlab for g2p experiment.

## 4.1 Microwave

The microwave generator used in cool down contains a microwave chamber(EIO tube) used for generate the microwave of 1W, a motor and motor control used for change the lenth of chamber in order to change the frequency of microwave, a water cooling system, high voltage and power supply, and a power meter used for measureing the frequency, waveguide used for leading the microwave to target insert. It can be changed smoothly near 140GHz[2].

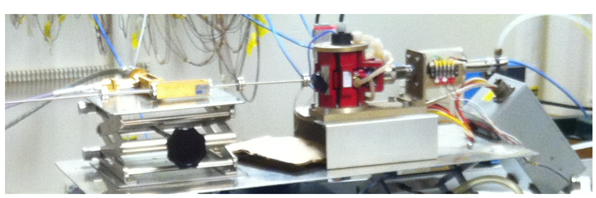

Figure 2: Microwave system used in cool down

In g2p experiment, there will be a interlock for the motor control so that the frequency can be stabled in a special number.

## 4.2 Target insert

The target insert used in cool down contains two chambers, each have the microwave tube in the upstream of it and have the NMR coil in it, also there has the temperature sensors. In order not to affect the beam colliding the target the NMR coil will be designed out of the chamber or at the edge of the wall in the g2p experiment. The target insert used in g2p experiment is still in designing, there will have four to six cell , two is for NH3, one is empty, one is for cross, one is for carbon or Ta or CH2 used for optics.

## 4.3 Magnet

Since the magnet used in g2p experiment is still in Oxford when the target cool down taking, the solid magnet is used for cool down, it is a 5T superconductor magnet, cooled in 4K by using liquid He4 fridge. The magnet used in g2p experiment can be seen in Figure 1, the signed field is 5.1T, it contains two coils with empty in the middle, so that the beam can be injected from either front or side for different config such as transfersity and longitudinally.

## 4.4 Refrigerator

The refrigerator used in UVa keeps the temperature in magnet to 4K and in target cell to 1K. It is similar used in g2p experiment, since the refrigerator used in UVa is too small and the refrigerator used in SANE experiment is not working, a new refrigerator is canabalized and tested in UVa.

As it is seen in the right side of Figure 1, there have eight temperature sensors used for monitoring the temperature changes. The LN is used for shielding the LHe. In order to cool down the target cell to 1K, a large capacity roots pumps is also used.

## 4.5 Q meter

The Q-meter is used for measuring the polarization of target in NMR system and the circuit of it is shown in Figure 3. As the polarized mucleons given, the target material will have a susceptibility like:

$$x(\omega) = x'(\omega) - ix"(\omega) \tag{3}$$

in an RF field that the frequency of $\omega$. The polarization of target can be characterized as:

$$P = K \int_0^\infty x"(\omega) d\omega \tag{4}$$

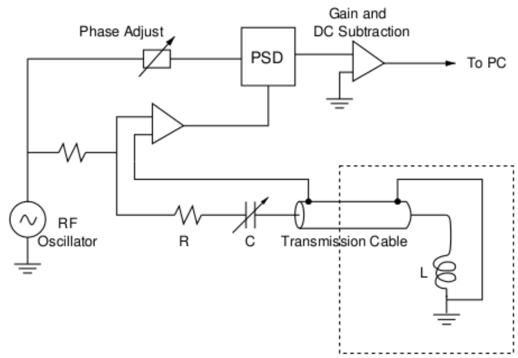


Figure 3: The circuit of Q meter[3]

which K is a constant related to the nucleus's property[4]. As it has a inductance $L_0$ in the NMR coil itself, the inductance of it will be changed by the target material as:

$$L(\omega) = L_0(1 + 4\pi\eta x(\omega)) \tag{5}$$

where the $\eta$ is a filling factor of coil. For proton, the number of $x(\omega)$ is 0 in all frequency except in the near of the larmor resonance frequency $\omega_0$. This will cause a peak in the output.

Because the TE polarization is about 0.5% and the polarization of the NH3 can be reached as 94%, the linear of the Q-meter system is strictly, i.e. the output need to keep linear in broad polarization in order to let the TE calibration reliable. A method that can enhance its linearity is to use the real part of the Q-meter output voltage by tuning the phase, detailed of it can be found in the Court's paper[4].

### 4.6 Control and Operating system

Many of the electronics have the GPIB port to connect to the computer, we can control them and see the count of the sensors from Labview interface such as the superconductor magnet, the Q meter output, several sensors and electronics used for monitoring the devices such as the temperature sensors, the pumping flow sensors, the level of LHe and LN. Also in order not to overheat caused the electronics damaged, the water cooling system is used.

## References

[1] W. Meyer D. G. Crabb. Solid polarized targets for nuclear and particle physics experiments. *Annu. Rev. Nucl. Part. Sci.*, 47:67–109, 1997.

[2] D.B. Day D.G. Crabb. The virginia/basel/slac polarized target: operation and performance during experiment e143 at slac. *Nuclear Instruments and Methods in Physics Research A*, 356:9–19, 1995.

[3] C.D.Keith. A polarized target for the clas detector. *Nuclear Instruments and Methods in Physics Research A*, 501:327–339, 2003.

[4] G.R. Court, D.W. Gifford, P. Harrison, W.G. Heyes, and M.A. Houlden. A high precision q-meter for the measurement of proton polarization in polarised targets. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 324(3):433 – 440, 1993.