The G_E^n Polarized Target Operation

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1 Introduction

The G_E^n, target consists of four main components, a 5 Tesla superconducting magnet, a 1 Kelvin refrigerator, a microwave system to polarize the target, and a NMR system for measuring the nuclear polarization. The target material used is ammonia in its deuterated and undeuterated form, frozen into small ($\sim$ 3 mm diameter) beads.

The target material is contained in cylindrical target cups (27 mm diameter and 30 mm in length), made out of Kel-F. Two cups holding polarizable material are, together with a carbon dummy target, a small carbon target (10 mm diameter), a 8 mm diameter hole, and an empty target, arranged on top of each other in a target insert. Thereby the different targets can be moved into the beam position.

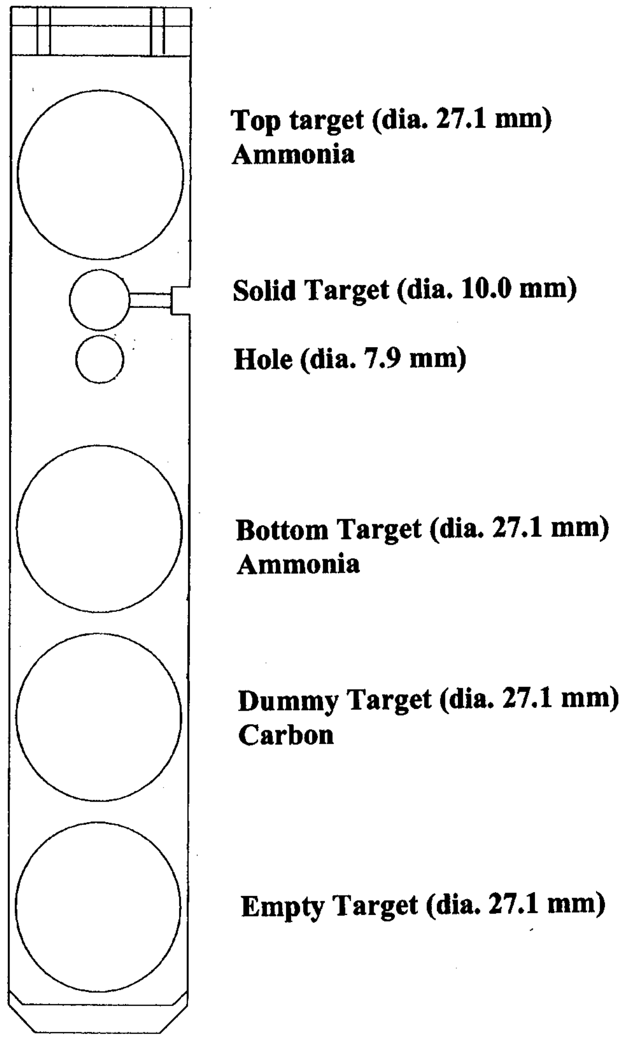

Figure 1: Target

Two NMR coils can be embedded in each target cup, one to measure the deuteron and ^{15}N polarization, the other to measure the proton polarization. The target cups are submersed into a liquid helium bath which is pumped on by large Roots blowers to reduce the temperature to about 1 Kelvin.

The target material contains paramagnetic centers, which are almost fully polarized in the 5 T field and at 1 K. By inducing spin flips of these electrons via irradiation of the target with the electron Larmor frequency, that is about 140 GHz at 5 T, also first-order forbidden transitions, including a simultaneous spin flip of a nucleus, these nuclei can be polarized.

Therefore the task of the target shift is to maintain a low temperature of about 1 Kelvin in a filled target scattering chamber and control the cryogenic supply system. The shift also needs to polarize the target material with microwaves and measure the nuclear polarization continuously with the NMR system. The latter processes might be interrupted by changing the target cups or anneal the target material after longer exposure to the electron beam. Operation beyond that scope will be conducted by members of the UVa target group.

2 Refrigerator Operation

2.1 Cool-Down of the Refrigerator from Stand-By

Stand-by means, that the magnet is cold, the liquid nitrogen (LN) dewar is more than 20% full, the magnet liquid helium (LHe) reservoir is more than 20% full, the jumper transfer line between the magnet LHe reservoir and the separator is inserted, and that there is a separator flow of about 10 standard litres per minute (SLPM). This flow, measured by the flow meter **FI91127**, is kept up by the metal bellows pump on the separator **MP91115** (separator pump) through the electrically regulated separator valve **EV91127**. To cool down the refrigerator and to obtain and maintain LHe in the target chamber follow the steps below.

- Start the mechanical pump set (Alcatel) on the refrigerator pump station. These are the three pumps **MP91144**, **MP91145**, and **MP91146**. The roughing valve **PV91143** has to be open and the electrically regulated ball valve **EV91142** (*throttle valve*) should be opened completely. **(This step will be done by an expert)**
- Open the separator valve **EV91127** to establish a separator flow of about 50 SLPM. That might take a while, so be patient.
- Open the **run valve (EV91120)** 4 turns.
- Monitor the refrigerator ^{4}He pressure **PI91125** and the mainflow (**FI91148**) out of the refrigerator pump station.
- The main flow will go up. If the main flow exceeds about 70 SLPM, close the run valve by 1 turn.
- Gradually close the run valve to 2 turns.
- Monitor the ^{4}He pressure, the separator flow, and the temperature in the separator and the target chamber.
- When LHe starts to enter the target chamber, the ^{4}He pressure and the temperature begin to oscillate. Gradually close the run valve and monitor the LHe level meter in the nose, **LL91112**. When a LHe level of more than 10% is in the target chamber, close the run valve to 1 turn.
- Try to establish a constant nose level at around 75%.
- Put the run valve under PID control at 75%.

- Reduce the separator flow to 20 SLPM by adjusting **EV91127**.
- Place the separator valve under PID control at 20 SLPM flow through **FI91127**.

2.2 Inserting Target Material into the Refrigerator

Once the refrigerator is cooled down to have a constant level of LHe in the target chamber, the target insert carrying the target material can be installed. The following steps describe how to do this, assuming that the target chamber is filled with LHe.

- Close the manual butterfly valves on both sides of the vacuum doughnut.
- Reduce the separator valve, **EV91127**, to achieve a flow of 20 SLPM through flowmeter **FI91127**.
- Close the run valve , **EV91120**, and the bypass valve, **EV91121**.
- Stop the mechanical pumps in the refrigerator pump station and close the main gate valve **PV91141**, the large roots bypass valve **PV91142**, and the annealing valve **PV91143**.
- Before opening the refrigerator and inserting the target material, the refrigerator has to be backfilled with He gas so that air does not enter the refrigerator and freeze. Open the refrigerator backfill valve **MV91128** on the gas panel.
- Wait until the ^{4}He pressure reads above atmospheric pressure, perhaps **1 psi**. Leave the backfill valve open.
- Open carefully the KF-50 blind flange on top of the piston. Wear cryogloves because cold He vapor can rise from the inside of the refrigerator. Also, you can freeze the O-ring, so have a replacement KF-50 O-ring handy.
- Now slowly lower the insert into the refrigerator. When the insert is almost completely inserted, it may boil off remaining LHe from the target chamber. LHe has a very low heat capacity and is therefore boiled off easily.
- About 20 cm before the insert is fully installed, check that the alignment pins have engaged in their slots by rotating the insert 20 degrees in each direction.
- As soon as the insert is in and the flange sealed, stop back filling the refrigerator, start the mechanical pumps in the refrigerator pump station, and open the main gate valve , **PV91141**, and the manual butterfly valves on both sides of the pumpout doughnut.
- Follow the procedures given above on how to cool down the refrigerator from stand-by mode

2.3 Cooling Down the Refrigerator to Below 1 Kelvin

The main step involved in cooling down the refrigerator below 1 Kelvin is to turn on the whole refrigerator pump station. Besides the mechanical pumps it consists of three Roots blowers. In order to turn them on, the inlet pressure of the pumps has to be below a characteristic threshold pressure. These pressures are controlled by the pressure switches **PS91146**, **PS91145**, and **PS91141**. Follow the steps given below.

- To reduce the ^{4}He pressure close the run valve so that it remains open a small amount only. If the pressure does not fall below 12 torr, that might take a while, close the run valve completely.
- **Make sure the bypass valve, EV91121, is fully closed.**
- Open the Balzers bypass valve **PV91142** and open the roughing valve **PV91143** if the later is not already open.
- If the ^{4}He pressure at the pressure switch **PS91146** falls below 12 torr, the Roots blower **(RB) RB1 (MP91143)** can be turned on. If the turn on mode is set to automatic mode, this will happen automagically.
- Close the roughing valve **PV91143** now.
- When the ^{4}He pressure falls below 2 torr at the pressure switch **PS91145**, the Roots blower **RB2 (MP91142)** can be turned on, or will turn on itself if in automatic mode.
- When the ^{4}He pressure is about 1 torr, open the main gate valve **PV91141** and close the Balzers bypass valve. Note, that the opened main gate valve requires the roughing valve and the Balzers bypass valve to be closed. The operation of these valves is disabled then.
- The Balzers Roots blower **RB3** can be turned on, when the ^{4}He pressure has fallen below 1 torr at the pressure switch **PS91141**.
- Now the run valve can be slowly opened to enter LHe into the target chamber. Monitor the ^{4}He pressure.

2.4 Going to Stand-By Mode

- Close the run valve, **EV91120**.
- Shut down the Roots blowers in reverse order, beginning with the Balzers blower **RB3**. Wait about 5 minutes before you turn off **RB2** and then wait another 3 minutes before turning off **RB1** . Leave the mechanical pumps running. You can close the main gate valve , **PV91141**,and open the roughing valve,**PV91143**, instead.

Target Position	Target Material	Diameter	Encoder
1	Top Polarized Target	27 mm	83128
2	Small Carbon Target	10 mm	14474
	Hole	8 mm	
3	Bottom Polarized Target	27 mm	44488
4	Dummy Carbon Target	27 mm	77343
5	Empty	27 mm	7711

Table 1: Target position encoder readings.

- Close the separator valve, **EV91127**, to achive a flow of 5 SLPM through flow meter **FI91127**. The separator valve can then be put under PID control to maintain this flow , if desired.

3 Polarizing the Target

In the following we will assume that the refrigerator is cold with a liquid helium level in the target chamber of about 70% and that the run valve, **EV91120**, is at a setting around 0.5 turn. The separator flow, **FI91127**, should be above 20 SLPM and the main flow around 5 SLPM, depending on the run valve setting.

3.1 Preparation

Increase slightly the main flow by opening the run valve. Make sure that the correct target is in the scattering region of the target chamber and that the NMR is running, with the desired spin species selected. Check, that the microwave switch is connecting the microwave tube to the desired target in the scattering region. Now, the target can be polarized with the microwaves. The table below lists the correct target encoder positions for the different targets.

3.2 Turning on the Microwave Power Supply

The microwaves are generated by an **Extended Interaction Oscillator (EIO)** tube, which is controlled from a power supply in the SOS detector hut. A remote control unit for the EIO PS is installed in the electronics room of Counting House C (CHC). The toggle push button has to be in the **LOCAL** position, indicated by the green LED.

The oscillation of the tube is started and stopped by the toggle push button labeled **TRANSMIT / STANDBY**. Here **TRANSMIT** indicates that the EIO tube is oscillating (generating microwaves).

Several parameters can be monitored on the red LED display. The various parameters can be selected on the left hand side of the supply by the two push buttons below the display. One is scrolling the left column (voltage) , while the other operates the right column of parameters (current).

The status of the supply is indicated on the right hand side of the control unit. The **POWER ON** light has to be always on. Any other LED indicates a problem and inhibits the EIO tube from oscillating. Immediately after turning the power supply on, the **FILAMENT DELAY** LED will light up for about 5 minutes. During this time, the filament voltage is slowly ramped up, keeping its current below 80 mA. After the LED goes off, the EIO tube is operational.

If the control unit is found in a fault mode like **SUMMARY FAULT** or **SYSTEM INTERLOCK**, usually one of the three interlocked control parameters is out of range. In range status is indicated by three green LED's in an interlock status panel, mounted in rack position 2A,on the upper target platform. From left to right, these parameters are **(1)** coolant water temperature below $40°C$, **(2)** an EIO collector temperature below $40°C$, and **(3)** a sufficient coolant water return flow. All three have to be on to enable the operation of the tube. If **SUMMARY FAULT** is indicated alone, often the temperature of the power supply is too high, above 55 degrees Celsius. This could be caused by the breakdown of the additional fan installed in front of the EIO power supply in the SOS hut.

To reset the power supply from the fault, the **TRANSMIT /STANDBY** button has to be toggled. If this does not help, an access is necessary and the power supply has to be power cycled, given that there is no obvious problem which has to be fixed before.

In any case, inform a member of the target group immediately. The phone numbers can be found in the front of the Polarized Target Handbook.

3.3 Adjusting the Microwave Frequency

The microwave frequency is in the range of 140 GHz, the Larmor frequency of electrons in the 5 T magnetic field. This frequency has to be adjusted, depending on the desired direction of the polarization, and on the history of the material. The resonance cavity of the EIO tube is adjustable remotely by means of a small electric motor. The controls for this motor are labeled **bellows** position. Control of the bellows is by a hardware switch or through computer control. Switching the hardware switch to the right increases the microwave frequency, switching it to the left decreases the frequency.

The microwave frequency is continuously read out by a frequency meter located in rack position **3A** on the upper target platform. The value is also displayed on the control computer. The frequency should be monitored when adjusting the **bellows** position. The camera on the upper target platform can be used to monitor the frequency counter in real time. When around the correct frequency, only small changes, may be 20 MHz or so, are advisable.

The power of the generated microwaves is also measured by a meter in rack position **3BR** on the lower target platform.

3.4 Frequency Modulation

The microwave frequency is modulated at the EIO power supply by a triangular wave of about 1 kHz and up to 20 V amplitude. Small adjustments in the amplitude can improve the polarization build-up. The function generator (**hp 33120A**) for the modulation is located above the control unit for the microwave PS in the electronics room rack. The **Amplitude** knob regulates the output voltage. The frequency is set to about 1 kHz, and does not need to be changed. Depending on the position of the **Volts Out** button, the **Amplitude** knob allows the amplitude adjustment up to 2 V Peak to Peak (**P-P**) (button depressed) or from 0 to 20 V P-P (button sticking out). Usually, the modulation should be set below 2 V P-P when polarizing protons and can be set up to 12 V P-P when polarizing deuterons.

3.5 Turning the Microwaves Off

The oscillation of the EIO tube is stopped by pressing the toggle push button **TRANSMIT / STANDBY** into **STANDBY** mode. This will reduce the heat load on the target and the run valve setting may need to be reduced to avoid over filling the tailpiece with LHe.

3.6 Switching Polarized Target

Assume the top deuteron target is under microwave irradiation. We will now change to the bottom proton target position and continue to polarize that target.

- Turn off the microwaves by pressing the toggle push button on the control unit of the microwave PS in the electronics room.
- Stop the NMR on the **PDP** screen by pressing the Pause button. Wait until the next Update counter is disappeared, and the red indicator shows Pause mode.
- Make a Logbook entry, including the last polarization and time.
- Take a look at the target chamber LHe level (nose level).
- Move from the top target position to the bottom target position.
- Switch the active NMR channel on the control computer from **Top Deuteron** to **Bottom Proton**. Check that the settings for gains and number of sweeps are comparable to earlier entries in the Logbook or the Polarization Sheet.

Target	Helicity	Polarizing Frequency	
		Low	High
Deuteron	Positive	141.650	141.600 GHz
Deuteron	Negative	141.860 GHz	141.955 GHz
Proton	Positive	?	141.480 GHz
Proton	Negative	141.760 GHz	141.790 GHz

Table 2: Microwave frequencies for different targets and polarizations.

- Press the Take Data button on the **PDP** screen to start the NMR measurement. Record the polarization of the new target in the Logbook.
- Check the target chamber LHe level.
- Switch the microwave switch from the top position to the bottom position.
- Adjust the run valve to maintain the proper LHe level in the tailpiece, if necessary.
- Turn the microwaves back on by pressing the toggle button on the control unit of the microwave PS. The **Cathode Current** should jump up to around 98 mA.
- Adjust the microwave frequency via the Bellows Position according to the values given in Table 2.
- Lower the frequency modulation by pressing the **Volts Out** button into its depressed position, and turning the **Amplitude** knob clockwise to about the 3 o'clock position. That should be about 1.5 V P-P (**see section 3.4**).
- Adjust the microwave frequency if it drifted. This is not uncommon during the early phase of oscillation.
- Watch the polarization grow, and adjust the microwave frequency to reaach optimal polarization.

4 Magnet Operation

The 5 Tesla superconducting magnet is operated from the Intelligent Power Supply (**IPS**) rack, located on rack D on the lower target platform. The rack houses, besides the power supply, the level meters for the liquid nitrogen in the shield and the liquid helium in the magnet coil dewar, and a second power supply for the correction coils (**shim coil**).

Current Range	Rate
0-60A	1.2 A/min
60 A -72A	0.6 A/min
72 A - 78A	0.3 A/min

Table 3: Energizing the magnet in training mode.

4.1 Energizing the Magnet from the Power Supply

Initially, the magnet IPS should be in HOLD status. The actual current setpoint can be checked by pressing the SETPOINT button. By holding this button and pressing (and holding) either LOWER or RAISE button, the setpoint can be changed. Make sure that the PS is in HOLD during this time. The rate of current change can be checked by pressing the SET RATE button and changed as described above. After a warm-up or quench, the magnet has to be energized in the so-called training mode. This means a slower energization rate than under the usual circumstances.

To energize the magnet:

- Set the **SETPOINT to 60** and the **SET RATE to 1.2** to begin with.

  To connect the magnet PS to the magnet, the superconducting switch, connecting the two terminals of the superconducting coil inside the LHe dewar, has to be heated up. Thereby, the connection warms up and becomes resistive, making the leads to the PS and the PS itself a path with lower impedance.

1. Heat the main coil superconducting switch by pressing the SWITCH HEATER button. Both LED's have to light up, one indicating, that the switch is activated and the other, that a current is flowing through the leads of the switch heater, usually set to about 100 mA.
2. Turn on the shim power supply and verify that it is in current output mode and generating Zero Amps.
3. Turn on the Shim Switch heater power supply. Put it in local mode by pressing the red button to the left of the display until the LED above it lights.
4. Activate the Shim Switch heater by throwing the switch to the far right of the unit. Verify that 0.100 amps are flowing. Adjust with knob if necessary.
5. If both the main coil switch heater AND the shim coil switch heater have been on for more than 30 seconds, press the **TO SETPOINT** button to start the energization of the magnet.
6. After the current setpoint is reached, the **HOLD** button has to be pressed. **No change of either setpoint or setrate should be made while the PS is not in HOLD mode.**

7. Adjust the setpoint to 72A, and the set rate to 0.6 A/min. Hit **To Setpoint**
8. When the current reach 72 A, again put the magnet in hold mode. Adjust the setrate to 0.3A/min and the setpoint to the desired full-field value, normally around 77.3A. Check the logbook for the exact value.
9. Once the magnet reaches the full-field current, put the supply in hold mode. Wait 30 seconds to allow the output voltage to stablize and then turn off the main coil switch heater by pressing the **Switch Heater** button on the supply.
10. Wait 30 seconds after turning off the main coil switch heater and then ramp the magnet leads down by pressing the **GOTO ZERO** button.
11. Adjust the current in the shim coils to 0.78A by pressing the increase current button on the shim supply.
12. Turn off the shim coil switch heater by throwing the switch on the right of the heater power supply.
13. Wait 30 seconds for the switch to open and then ramp the shim leads to zero by adjusting the current output on the shim supply.

Name		Phone Number					Email
Last	First	Jlab	Page	Cell	Home	Inst	
Spokespersons							
Day	Donal	269-5255	989-9248		249-2951 804-296-2494	804-924-6566	dbd@virginia.edu
Warren	Glen	269-5797	888-4124		877-0069		gwarren@jlab.org
Zeier	Marko	269-5255	820-5695		851-5591		zeier@jlab.org
Target							
Crabb	Don	269-5555			804-979-3177	804-924-6790	dgc3q@virginia.edu
McKee	Paul	269-5191		679-8032 804-466-2423	804-974-1431 249-7832	804-924-7337	pmm3w@virginia.edu
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Meekins	Dave	269-5434	872-2442				meekins @jlab.org
Seely	Mikell	269-5036	881-1194				mseely@jlab.org
Vulcan	bill	269-5235	888-5451				Vulcan@jlab.org

Table 4: Phone List. All the local numbers the area code are 757 .