

## Introduction

Polarized targets play a central role in the UNH Nuclear Physics Group's research program. The Slifer Laboratory at UNH uses a Dynamic Nuclear Polarizer to align the spins of nuclei along a magnetic field within the polarizer. The long-term goal of this lab is to develop advances in tensor polarized target technology for the spin-dependent physics program at Jefferson Lab.

Dynamic Nuclear Polarization (DNP) is a well-established method to produce highly polarized targets. The major utility of DNP is that it replaces the difficult problem of polarizing nuclear spins with the more tractable one of polarizing electron spins. The technique requires doping the proton rich target material with paramagnetic impurities to provide unpaired electrons. The sample is then placed in a magnetic field at low temperature in order to polarize the free electron spins.

In the Slifer Lab, I created a chemically doped, frozen proton target. My project used the straight chain isomer of butanol (n-Butanol) as the proton-rich target material. I chemically introduced paramagnetic impurities into the butanol with the stable free radical TEMPO. TEMPO doped butanol is a proton-target candidate that offers a cheaper alternative to the field-standard ammonia  $NH_3$  and deuterium ammonia  $ND_3$  proton targets at the expense of a lower total polarization. Using liquid nitrogen, the TEMPO-Butanol solution is frozen, and stored in cryogenic dewars.

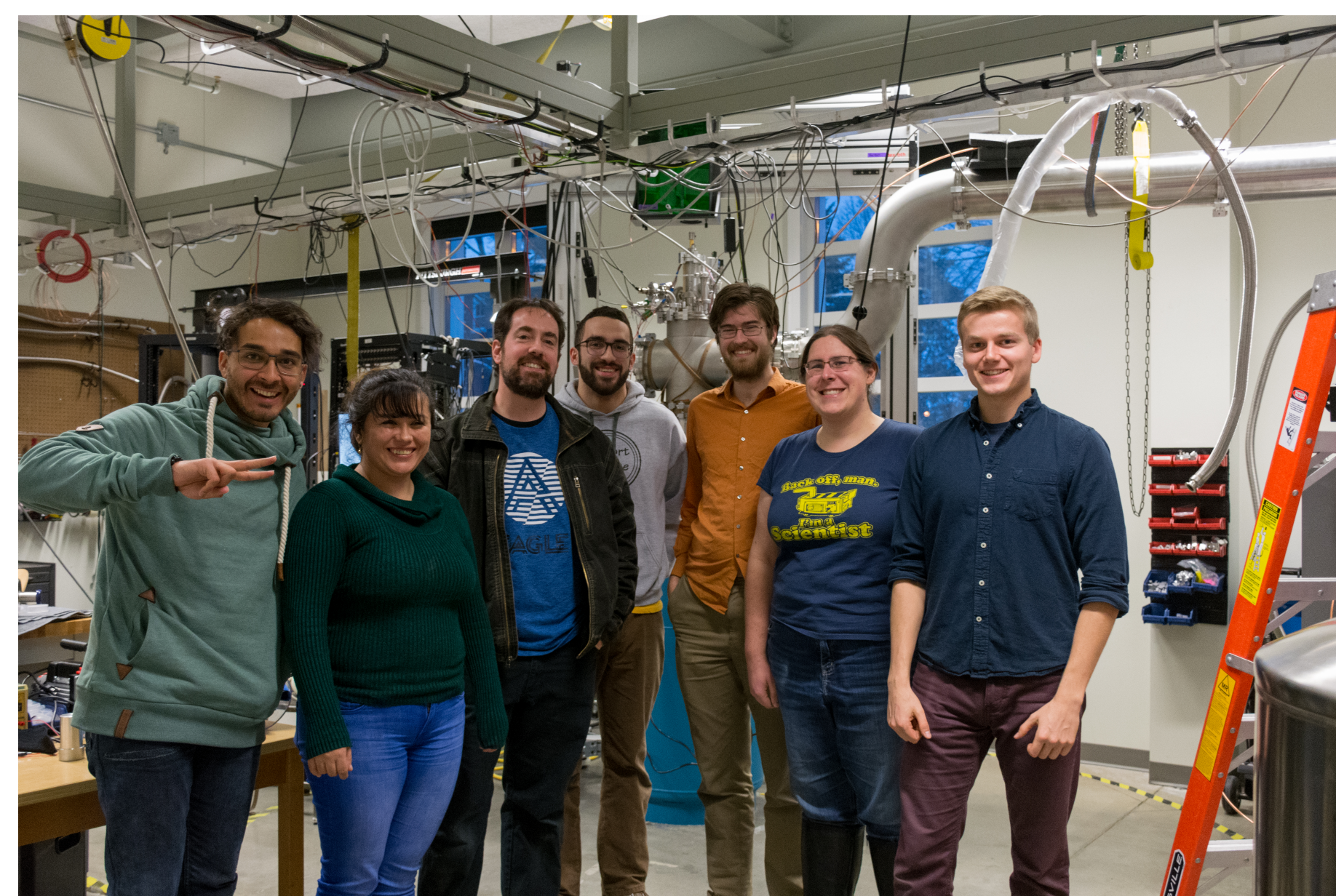


Figure 1: Some members of the University of New Hampshire Nuclear Physics Group during a November 2018 cool-down

## Methods

First I established a freezing process and apparatus. I practiced with regular n-butanol first before I attempted to freeze the TEMPO solution.

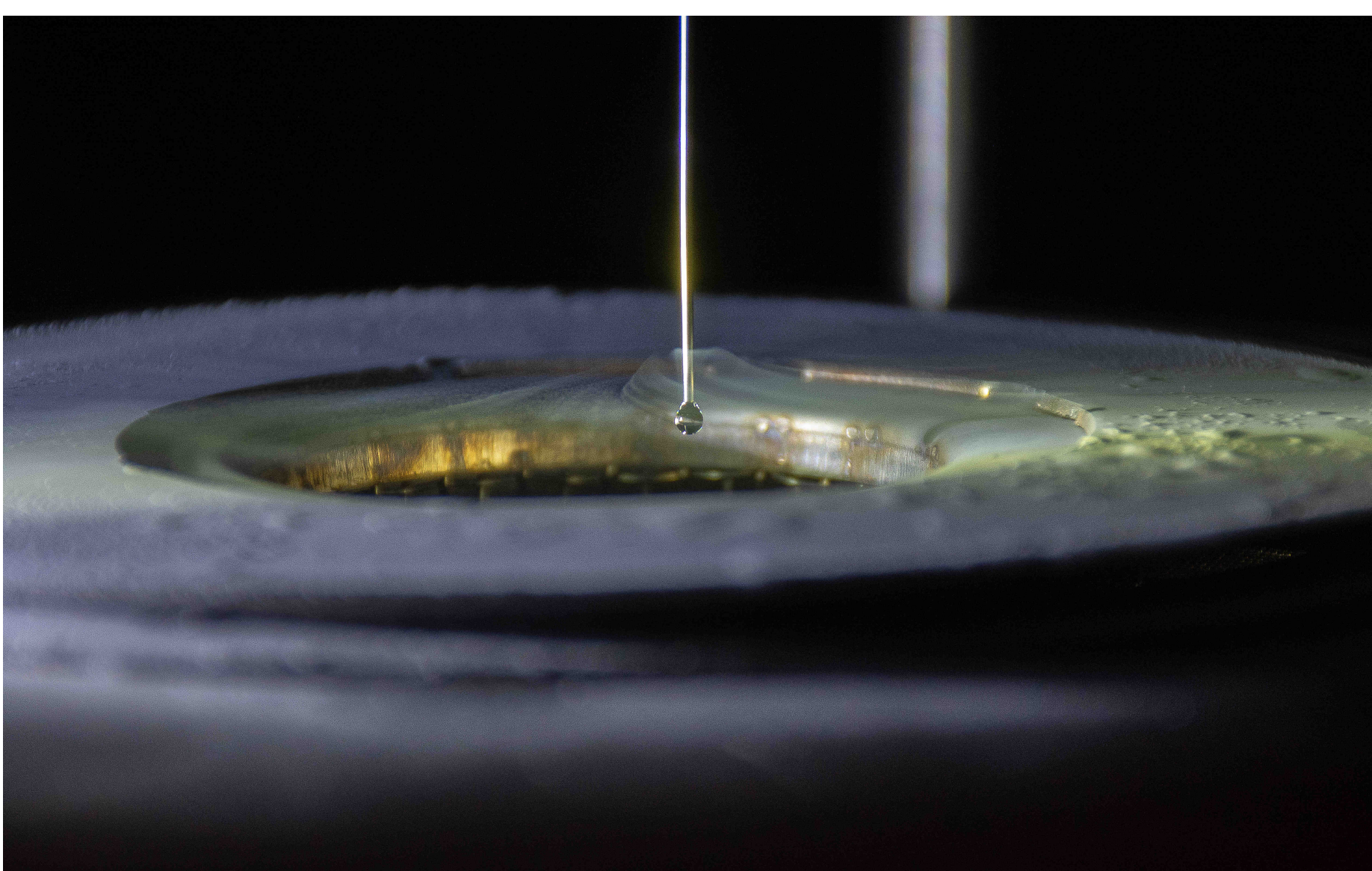


Figure 2: A drop of n-Butanol clings to a needle attached to a burette, suspended over a bath of liquid nitrogen.

## Methods

Then, with the help of previous research papers [2] [3], I developed procedures for mixing TEMPO with n-butanol in the Slifer Lab chemistry room.

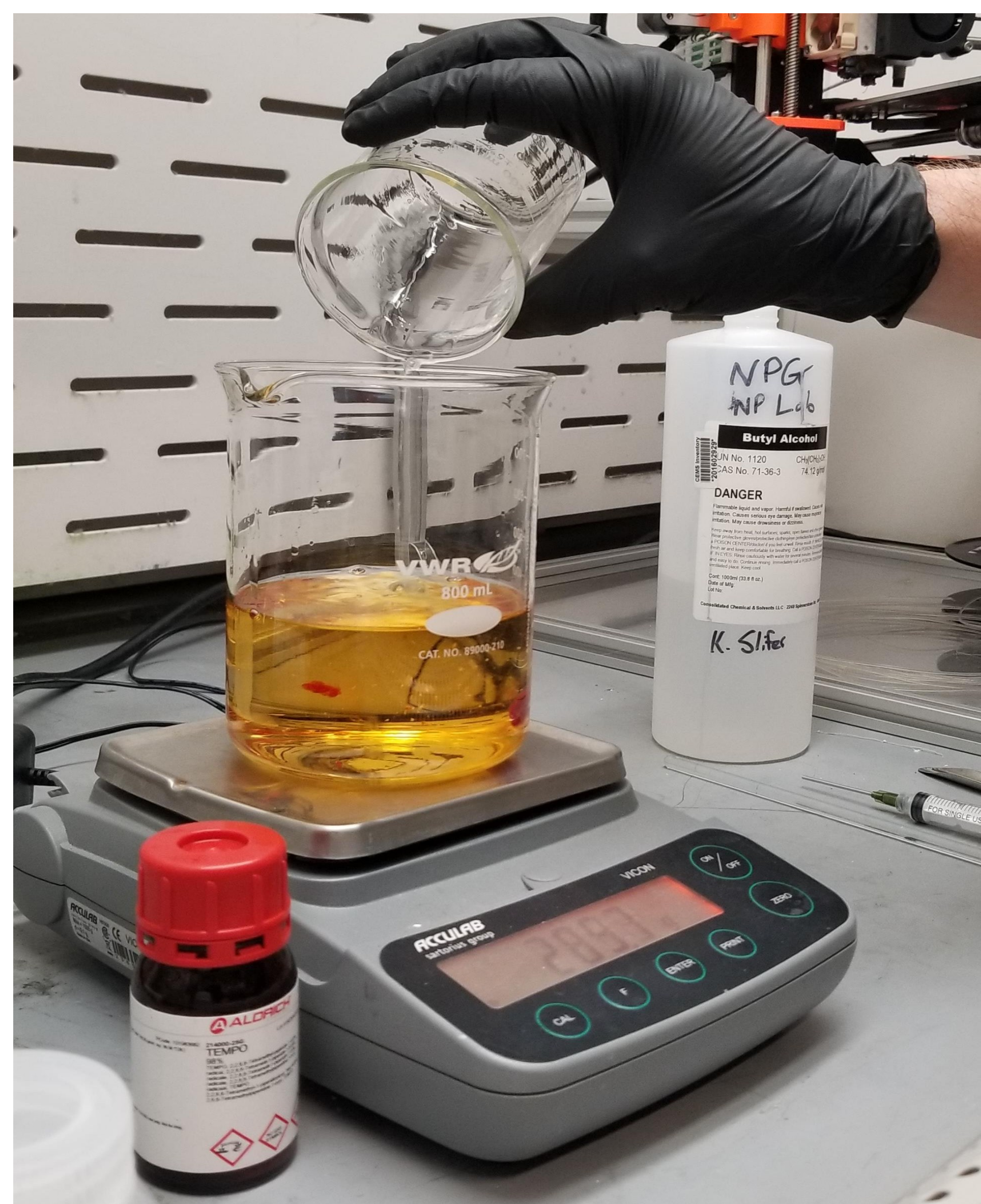


Figure 3: Massing the first batch of TEMPO doped n-butanol. The concentration of TEMPO:Butanol by mass is 1:200

Next, I froze the TEMPO n-butanol solution and prepared the sample for storage.



Figure 4: Frozen TEMPO doped n-butanol in storage vial. Prepared for long-term storage. This is the sample of n-butanol that the polarization data was measured from. See figure 5 for this sample's polarization measurements.

## Important Result

The UNH-NPG successfully polarized a frozen proton target I created on campus!

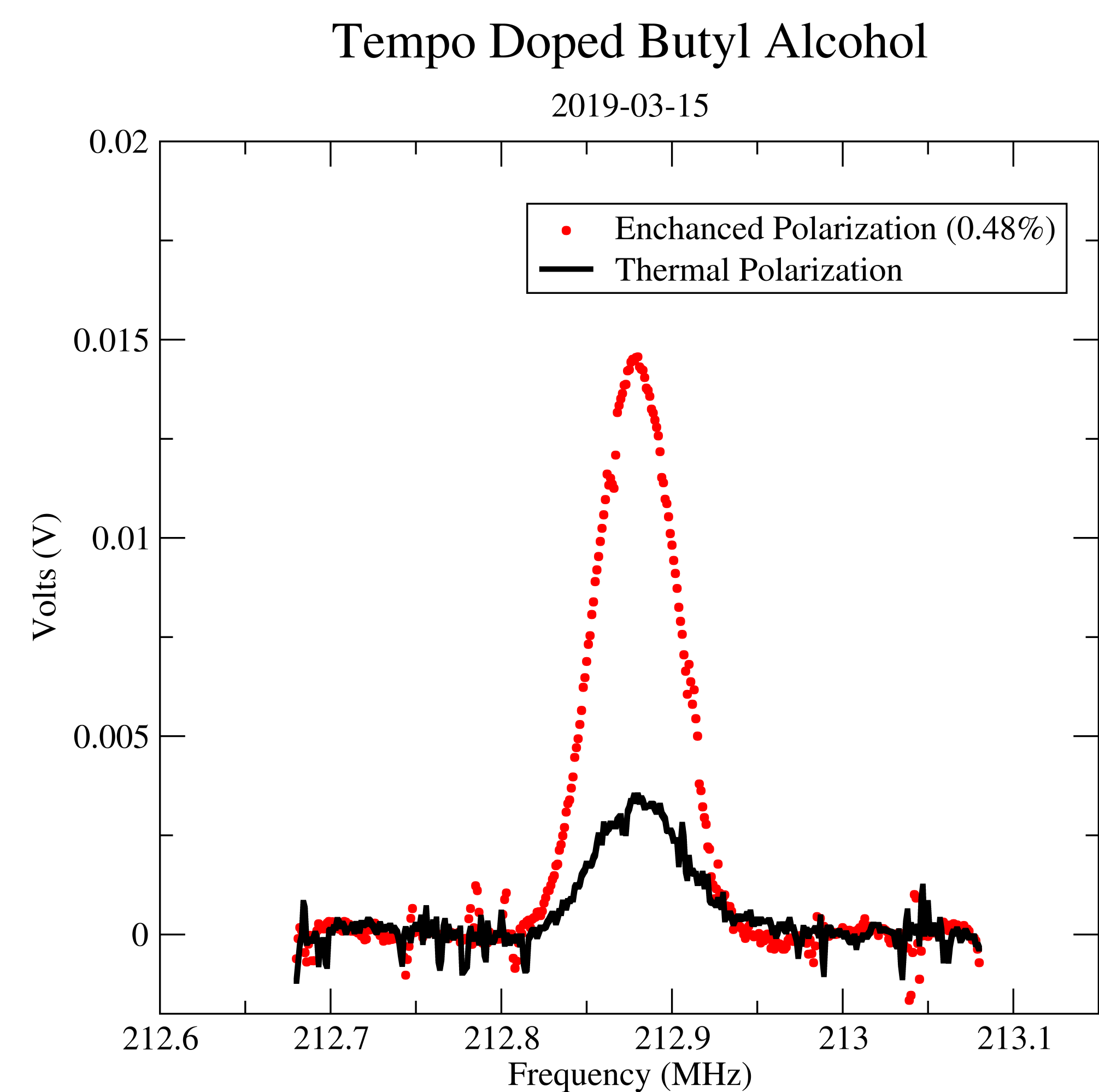


Figure 5: The area under the red curve is the enhanced polarization signal of the sample of n-butanol. The black line is the signal of the thermal polarization

## Target Polarization

When any material rests in thermal equilibrium in a magnetic field, that material's thermal polarization can be modeled by the function:

$$Polarization = \tanh\left(\frac{\mu_p * \vec{B}}{k * T}\right)$$

This quantity is calculable if the Temperature (T) and the magnetic field (B) are known. Constants  $\mu$ , and k are the magnetic moment of the proton, and the Boltzmann constant. The Slifer laboratory uses this function in tandem with the Thermal Polarization data above. Using the thermal polarization measurements, polarization per unit area (underneath the black curve) can be obtained by numerical integration. Once this polarization constant has been found, the polarization is enhanced by microwave radiation and a decrease in temperature that results in the red curve.

**The UNH-NPG measured an enhanced polarization of 0.48%.** TEMPO doped n-butanol has a theoretical maximum polarization of ~80%.

## Dynamic Nuclear Polarization

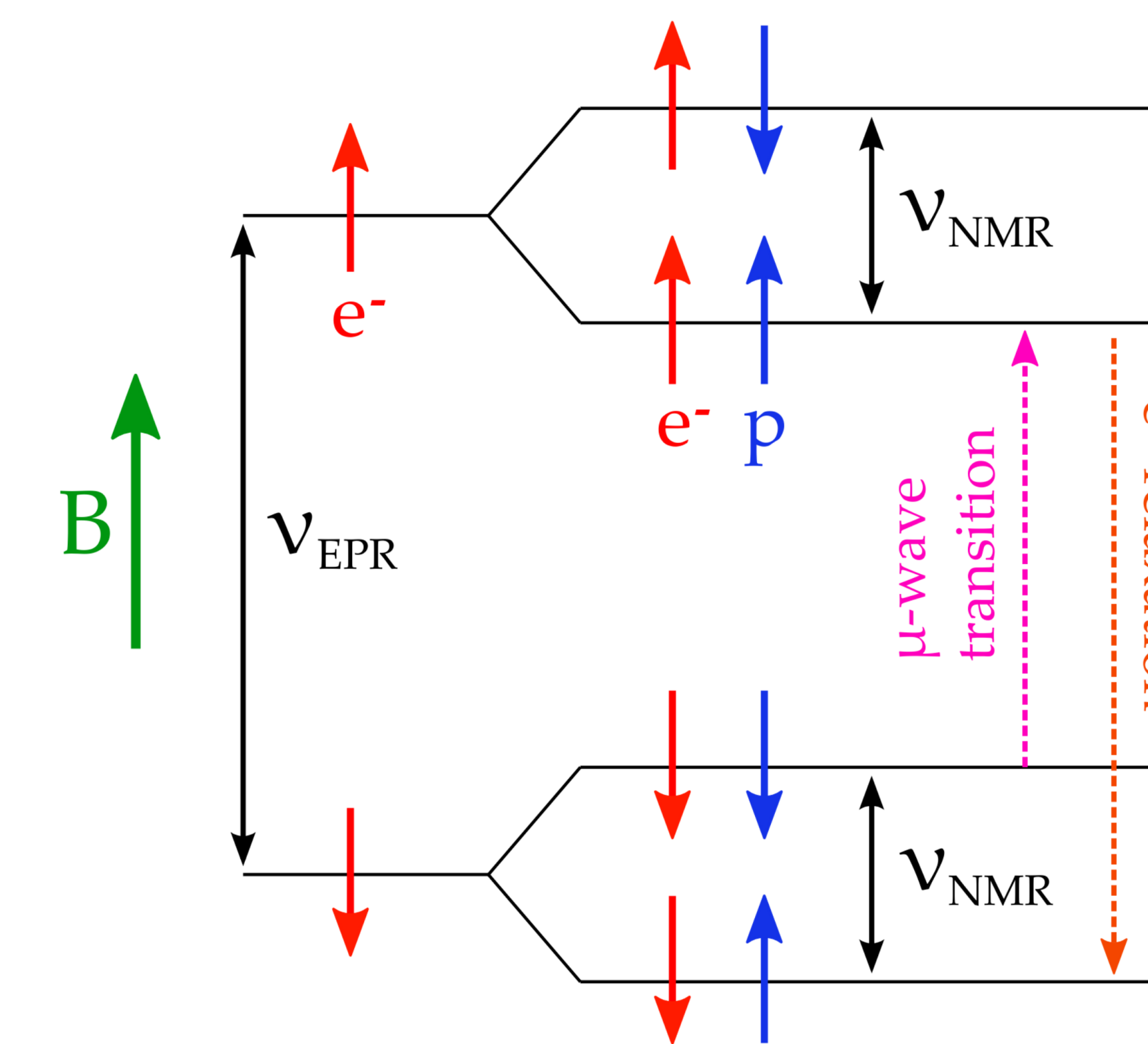


Figure 6: Reproduced from [1]. Energy levels of an electron-Proton system in a magnetic field. The violet arrow indicates the coupled spin flip we induce with the microwave radiation during DNP.

## Discussion

Professor Slifer suggested that I start by creating a TEMPO Butanol solution according to Pluckthun's process. This paper reported that a mass ratio of 1:200 for TEMPO and butanol could be polarized to 80% maximum polarization of 80%. My project expands upon this paper, choosing to vary the concentrations of TEMPO from -20% to +40% using the 1:200 ratio as a control group. Our thoughts were: if total polarization of a material directly corresponded to that materials electrons, then varying the amount of electrons we introduce to our sample should change our observed polarization.

Unfortunately we were not able to determine if samples of TEMPO butanol would achieve polarizations proportional to the concentration of TEMPO. The UNH-NPG plans to do those tests in the future.

The UNH-NPG measured an enhanced polarization signal of 0.48 % which is significantly lower than the 1:200 TEMPO doped butanol theoretical maximum. In retrospect of the events that lead up to March 15<sup>th</sup>, 2019 it was possible that our butanol and TEMPO were not of high quality. Maybe the butanol is not absorbing all of the microwave power. During the same cool-down, we were able to achieve high polarizations with Araldite, however we achieved nowhere near what we expected for butanol. We suspect the low observed polarization may be due to our microwave frequency not being properly matched to the EPR, or that insufficient microwave power was reaching the target material.

## Future Directions

- Improve TEMPO & n-butanol purity.
- Polarize different TEMPO ratios
- Adjust mm-wave frequency, considering that it may not have been perfectly matched to EPR

## Contact Information

Tristan Anderson  
University of New Hampshire Nuclear Physics Group

Email: tja1015@wildcats.unh.edu

## References

1. Maxwell, James Davis. "Probing Proton Spin Structure: a Measurement of  $g_2$  at Four-Momentum Transfer of 2 to 6 GeV<sup>2</sup>." Thesis, Dec. 2011, twist.phys.virginia.edu/Theses/Maxwell\_Thesis\_Final.pdf.
2. Mellor, Jonathan E, et al. "Studies and Measurements of Irradiated Solid Polarized Target Materials." Studies and Measurements of Irradiated Solid Polarized Target Materials, Aug. 2006, doi.org/10.18130/V3I670.
3. Noda, Yohei, et al. "Thermosetting Polymer for Dynamic Nuclear Polarization: Solidification of an Epoxy Resin Mixture Including TEMPO." Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, North-Holland, 8 Dec. 2014, doi.org/10.1016/j.nima.2014.11.114.
4. Pluckthun, M. "Polarization Measurements of TEMPO-Doped Butanol Targets." Polarization Measurements of TEMPO-Doped Butanol Targets, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Nov. 1997, doi.org/10.1016/S0168-9002(97)00902-9.

## Acknowledgments

It took a team of people to operate the Dynamic Nuclear Polarization system in the Slifer Lab. Without Professor Karl Slifer, Professor Ellie Long, Nathatly Santiesteban, David Ruth, and other researchers of the Slifer Laboratory, this project would not have been successful. Thank you, to all who contributed and or advised.