Dynamic Nuclear Polarization, Nuclear Magnetic Resonance, and their Applications in Medical Physics

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UNH-NPG

Introduction

The Solid State Effect, discovered in 1958 is the simplest view of DNP [2, 5]. Any particle with a magnetic moment precesses about an external magnetic field at its larmor precession which is the product of that particle's gyromagnetic ratio, and the external magnetic field strength. DNP side-steps the difficulty of directly polarizing the nucleon by instead polarizing free-electrons that are spin-coupled with the nucleon. DNP uses microwaves to excite free electrons into a higher energy state, and the nucleon or nuclei in this two-level system can undergo a spin-flip. A few milliseconds later, the electron relaxes out of this excited state, and is able to spin-pair again with another nucleon, leaving its former nucleon polarized for tens of minutes or until the next spin-flip. In this repetitive fashion, materials are polarized [4,5].

NMR was discovered in 1946 and since then, many NMR-based technologies have been developed. A well-known application of NMR is NMR spectroscopy, which is a analytic tool used to identify elements by their unique magnetic resonance. NMR also has an application in Magnetic Resonance Imaging (MRI) which is a non-invasive clinical imaging technique. Despite the success of these NMR applications, they are still held back by their low sensitivity that comes from the low magnetic energy of the thermally-polarized nuclear spins. Although MRI is an effective imaging technique, the polarizations of the contrast that produce MRI images are relatively low. Since NMR signal strength is directly related to MRI image quality, If the MRI contrast is able to be pre-polarized with DNP (to increase the NMR signal) MRI image resolution could be effectively increased.

This poster delves into the physics behind DNP and NMR, and lays the foundation for my undergraduate capstone project to be completed in the 2020 Fall semester.

DNP and NMR System

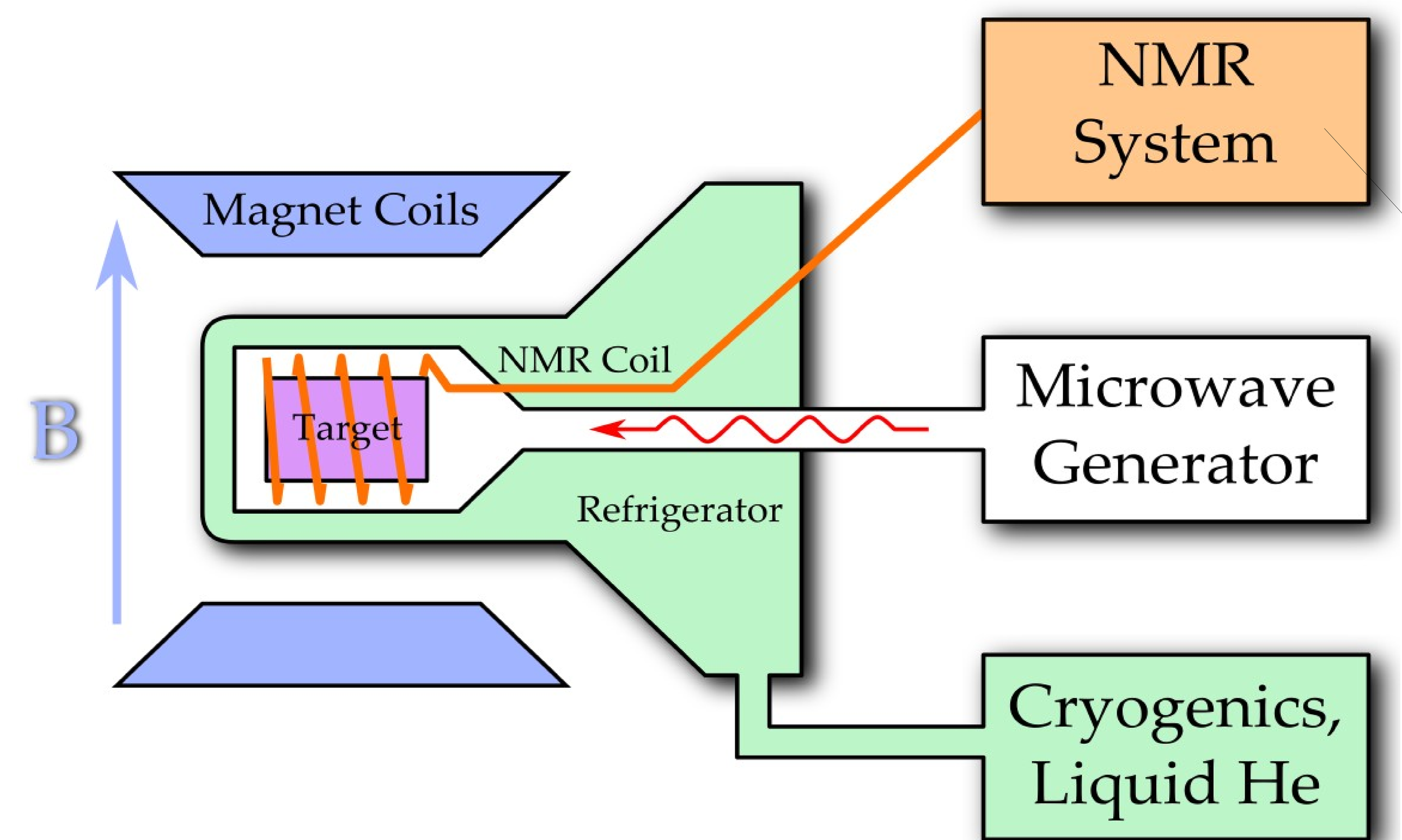


Figure 1: Schematic overview of the sysyems required for dynamic nuclear polaization. Courtesy of Maxwell [5]

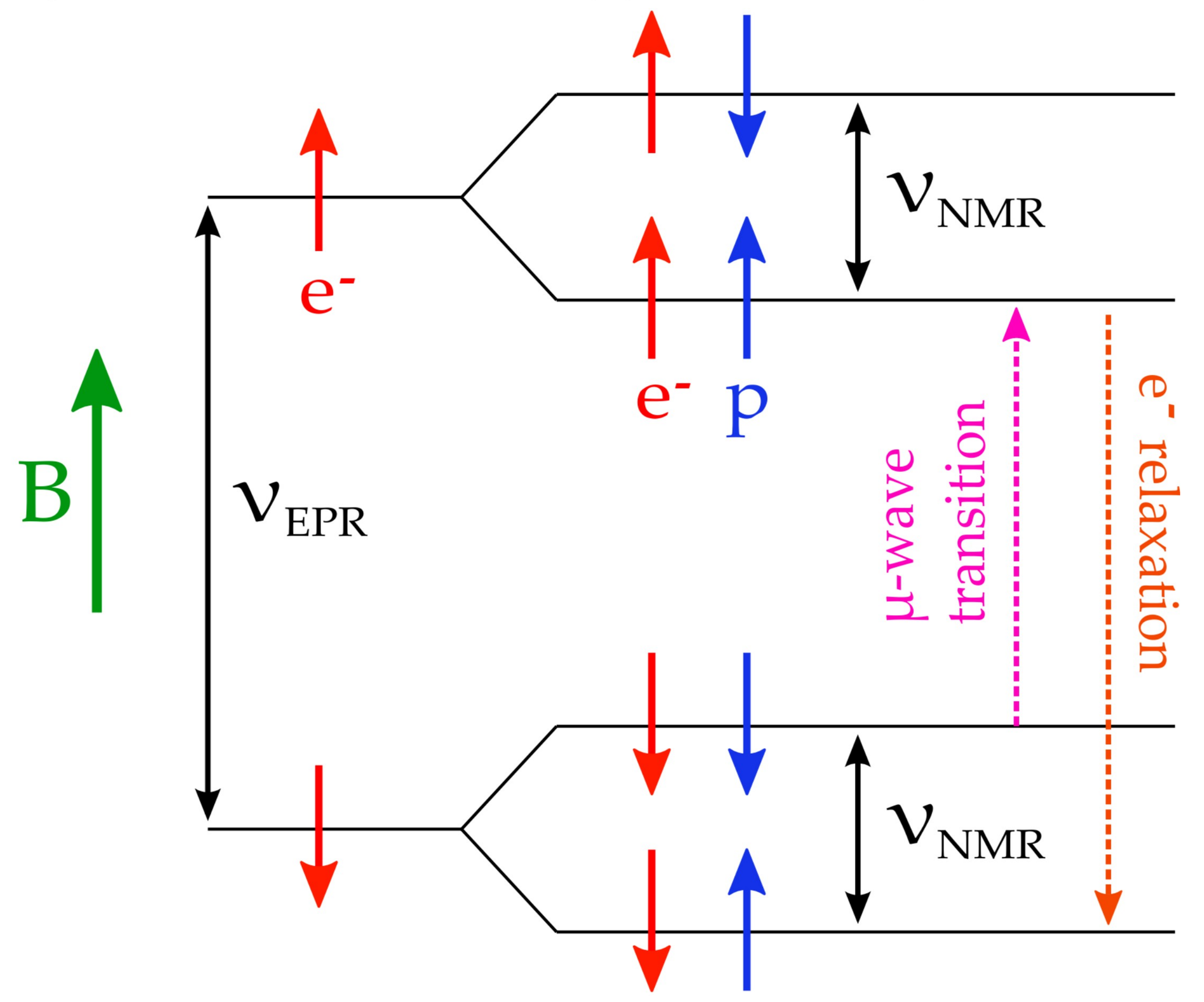


Figure 2: *Reproduced from [5]. Energy levels of an electron-Proton system in a magnetic field. The violet arrow indicates the coupled spin flip we induce with the microwave radiation during DNP.*

Thermal Equilibrium Polarization

The thermal equilibrium (TE) polarization of a material is the response of the spins in the material at thermal equilibrium to an applied magnetic field [4,5]. This quantity is exactly calculable if the temperature T and the magnetic field B are known. Constants μ, and k are the magnetic moment of the nucleon or nuclei, and the Boltzmann constant respectively.

$$P_{TE} = tanh(\frac{\mu \cdot \vec{B}}{k \cdot T})$$

The Slifer laboratory measures the degree of spin orientation, or "polarization" of a material using Nuclear Magnetic Resonance (NMR). The output signal of the NMR system is a complicated function of the geometry of the NMR pickup coils, the structure of the material, the filling factor of the coils and the amplification of the NMR circuit. It is extremely difficult to calculate the system response from first principles. So instead, we determine the correspondence between system response (NMR signal) and material polarization by measuring the NMR signal when the material is at Thermal Equilibrium. Below is a TE NMR signal.

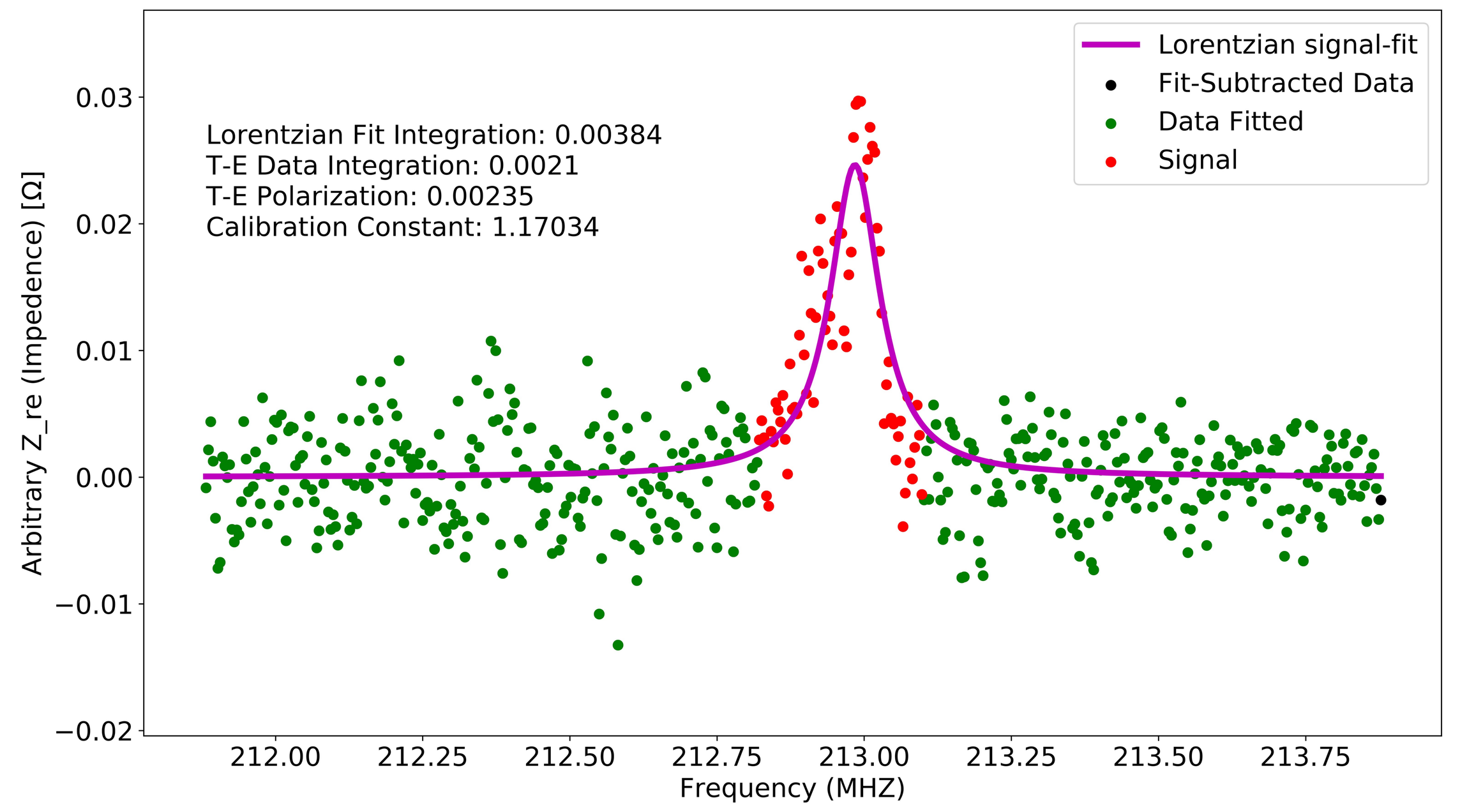
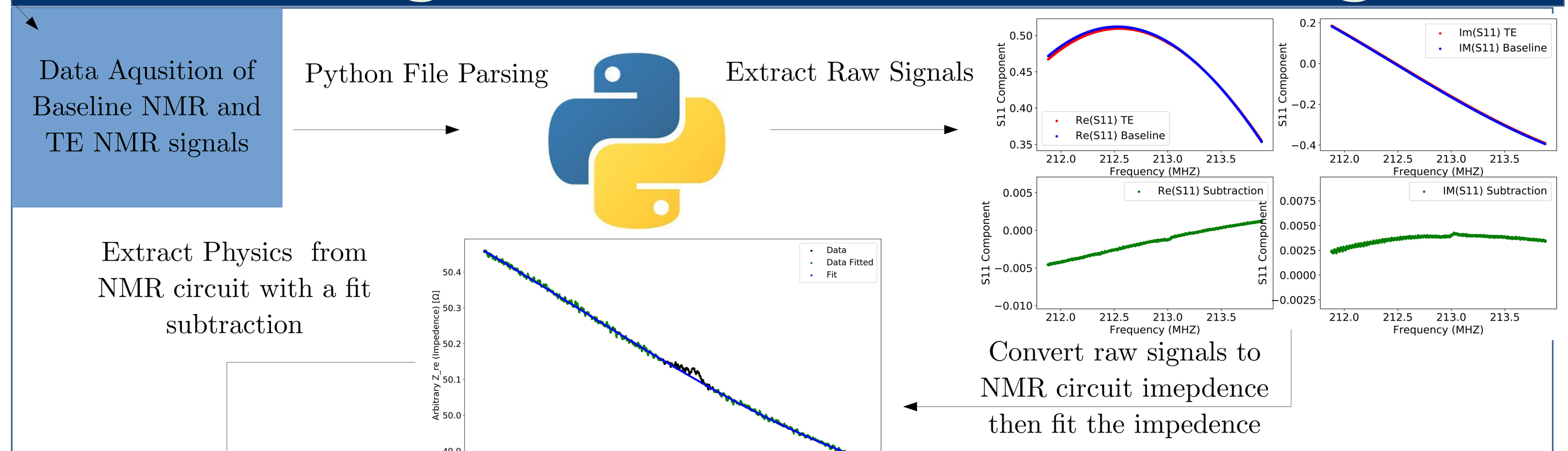
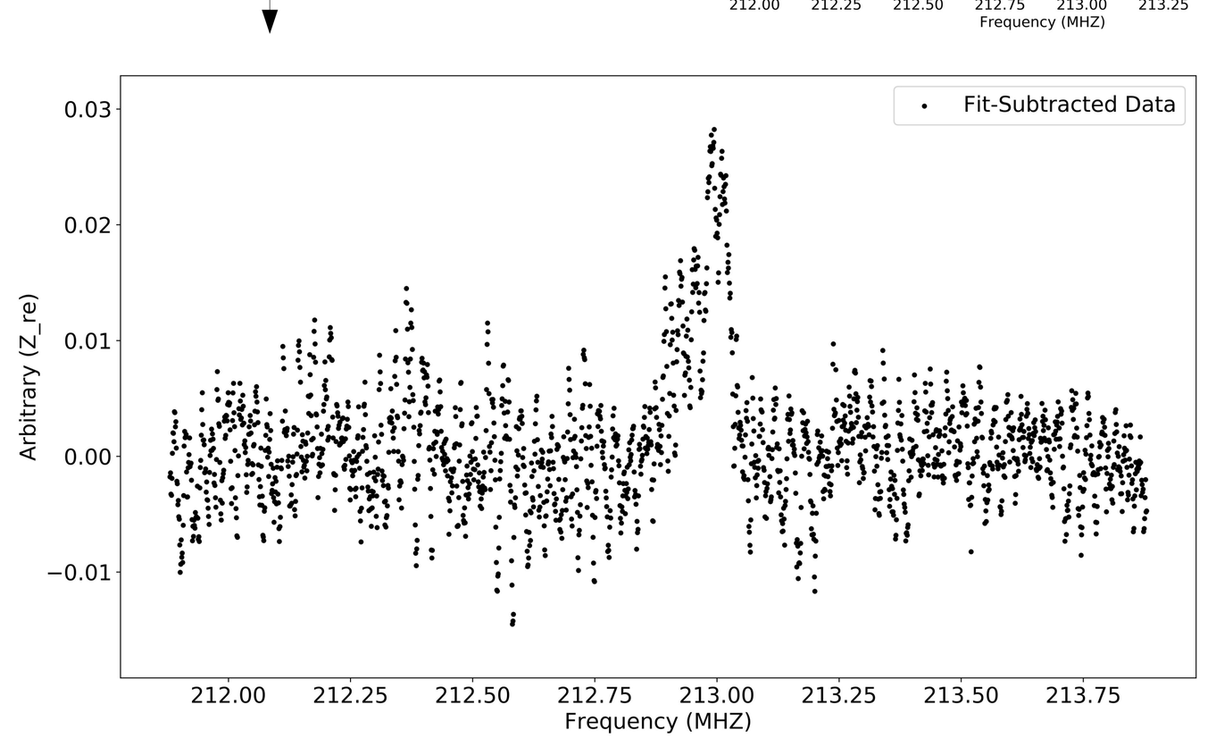


Figure 3: NMR TE signal of TEMPO-doped Araldite at T=2.18 Kelvin, B=5 Tesla.

Extracting Polarization from NMR Signal





Integrate signal data to solve for the calibration constant as in **Fig. 3.** Then begin DNP to increase target polarization, and determine enhanced polarization by relating the area under the red curve, to the area under the black curve in **Figure 4.**

Enhanced Polarization

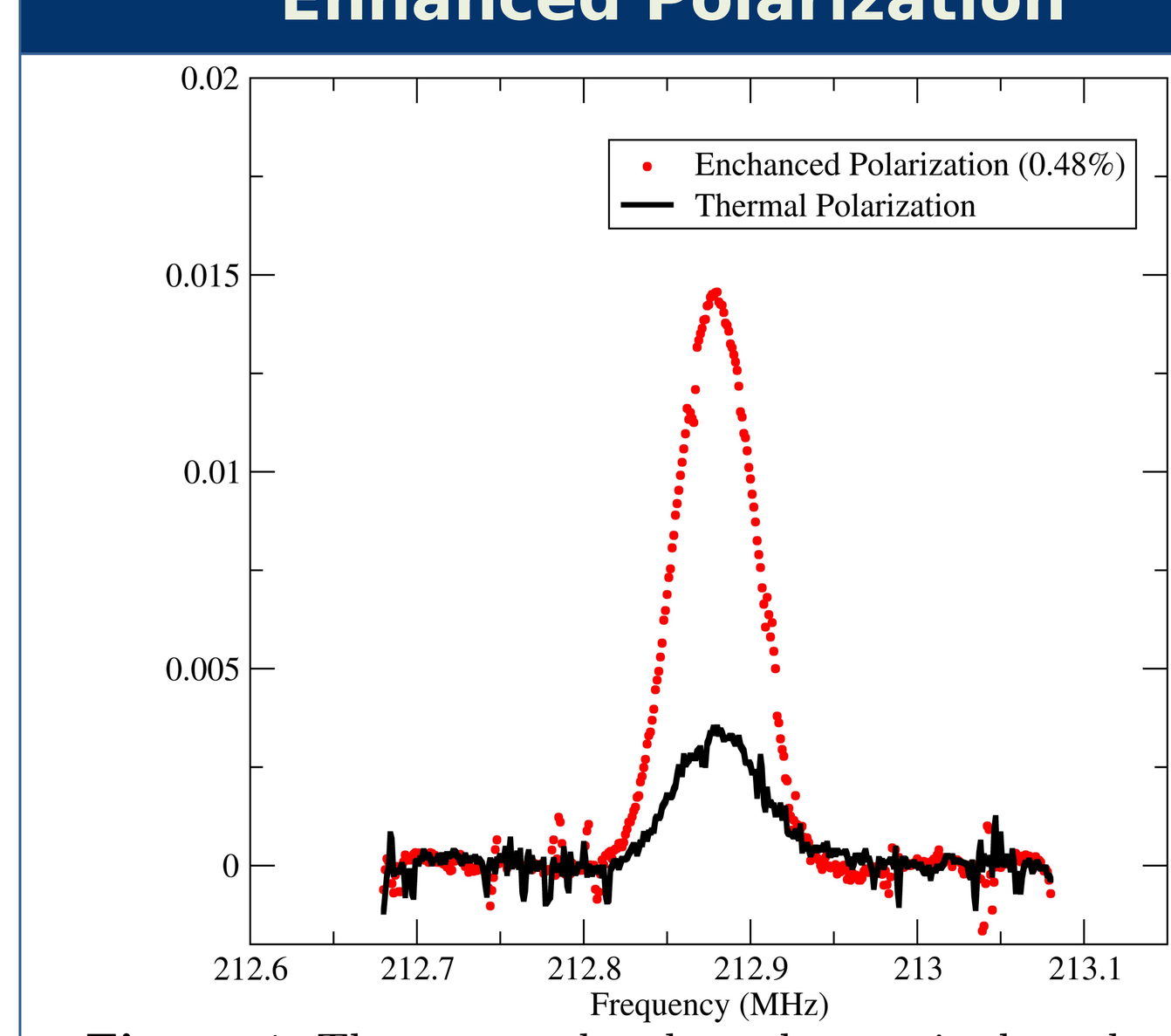
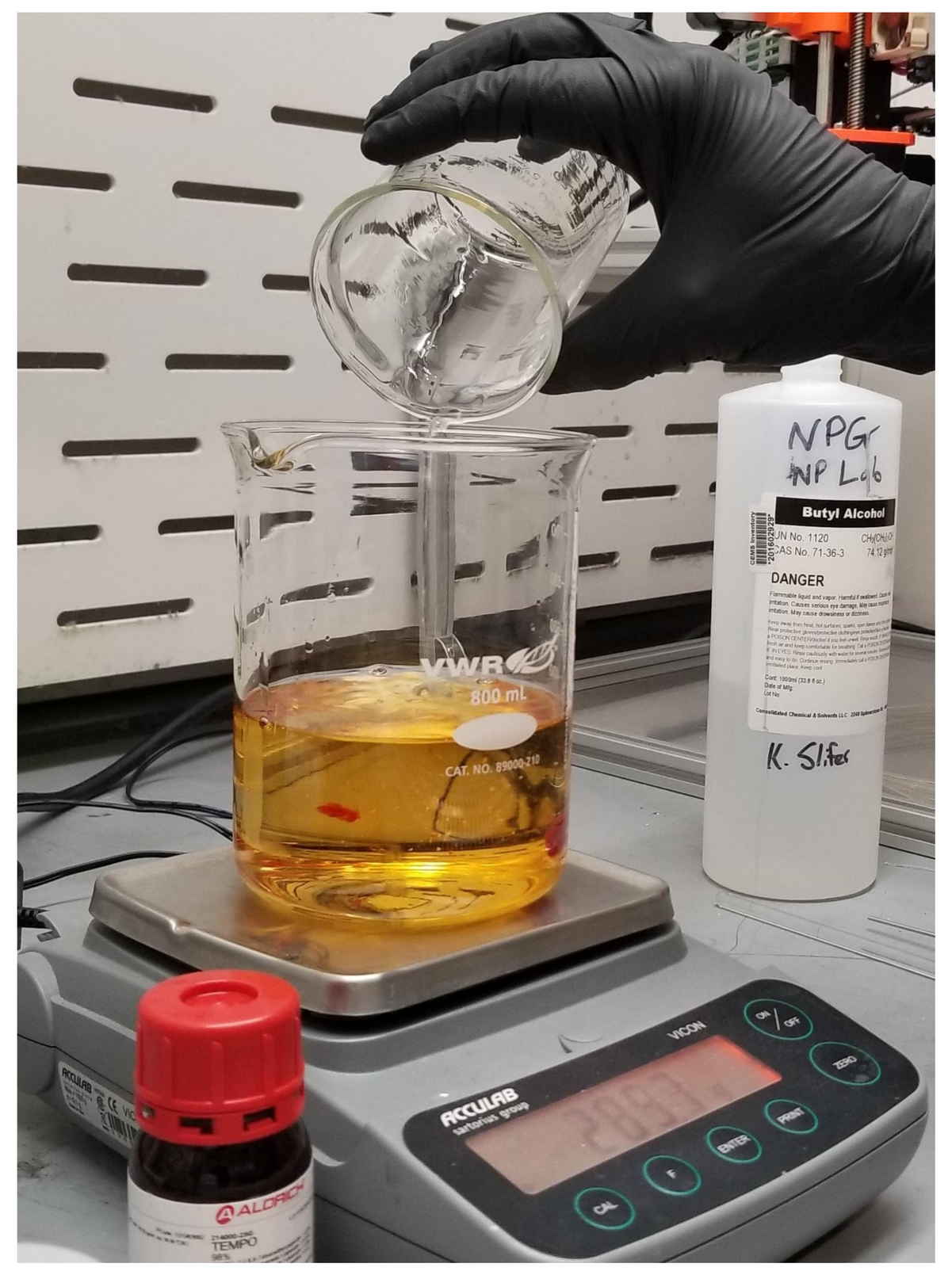


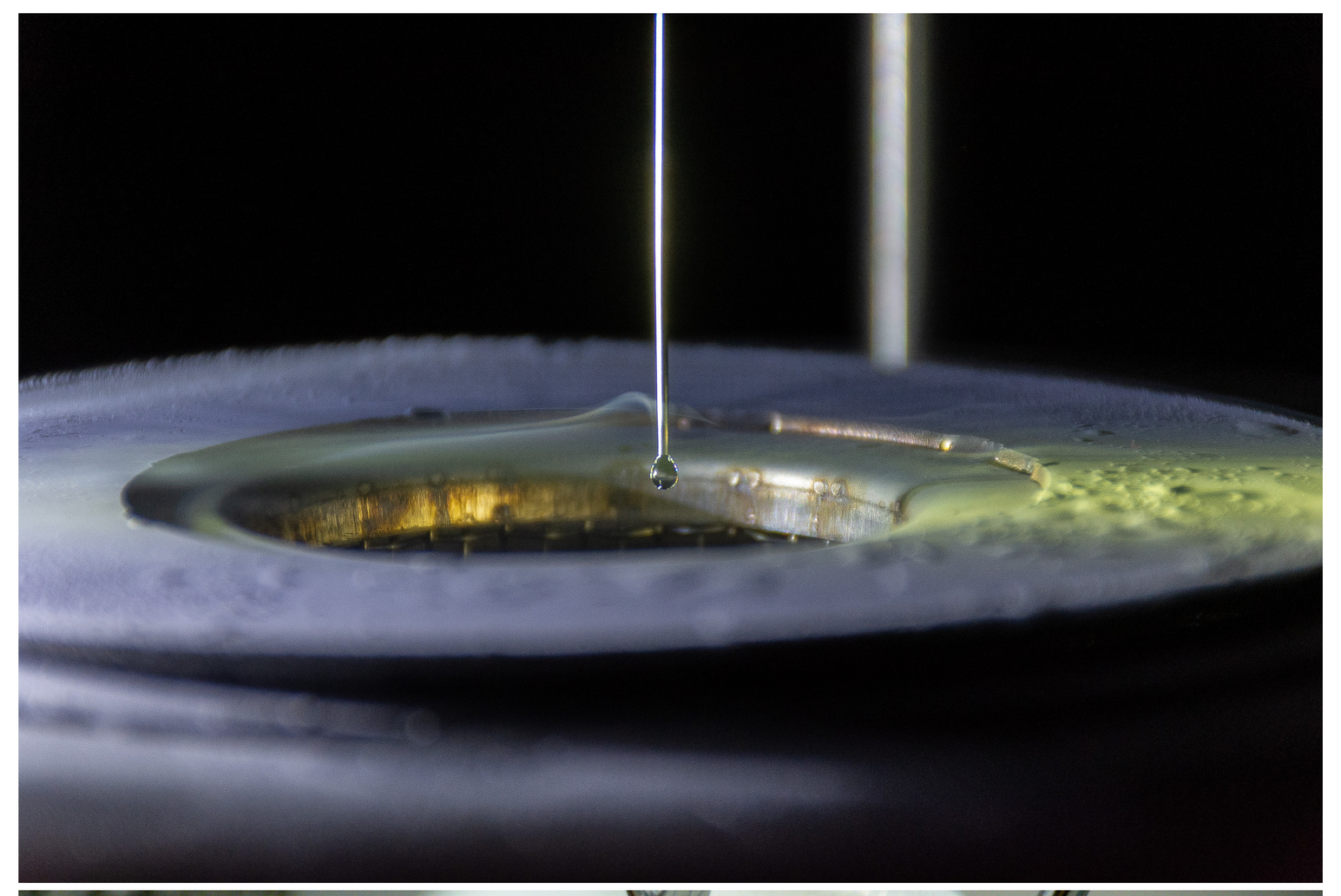
Figure 4: The area under the red curve is the enhanced polarization signal of the sample of n-butanol. The black line is the signal of the thermal polarization.

^{13}C Material Synthesis

Research that I conducted last academic year under the supervision of Professor Slifer focused on Target-Material production for polarized Nuclear Physics scattering experiments. This year's application of my earlier research has shifted the focus away from material production for nuclear-physics scattering experiments towards material production for MRI contrasts, motivated by [3]. Similar material synthesis techniques used in my 2019 UNH URC poster [1] will be used this coming 2020 Fall semester to create Trityl-Doped ^{13}C-Urea. The procedure for material synthesis is identical.



Step 1: ^{13}C-Urea will be disolved into glycol, and a free radical (Trityl) will be added to introduce free-electrons used in the DNP process.



Step 2: The homogenous ^{13}C-Urea solution will be frozen, harvested, then placed into the DNP system for polarization.

Step 3: Will focus largely on the polarization result of step 2. If the ^{13}C-Urea polarizes well using DNP, Slifer Lab and the UNH-NPG will continue testing the feasibility of possible in-vivo studies with ^{13}C.

Applications

The same DNP techniques we used here to polarize a proton, we can also use to polarize entire atoms like ^{13}C. **DNP polarized ^{13}C for use as a first-pass signal agent (contrast) improves MRI signal quality resulting in a stronger NMR signal** [3]. Research that I conducted last academic year under the supervision of Professor Slifer focused on Target-Material production for Nuclear Physics scattering experiments [1] focused on proton polarization. This year's adaptation of my earlier research has shifted the focus away from material production for nuclear-physics scattering experiments towards material production for MRI contrasts. **The same DNP technique has applications for both nuclear physics and medical imaging.**

What's Next?

- **Synthesize Trityl-Doped ^{13}C-Urea.**
- **Polarize ^{13}C material, and analyze the NMR spectra**
- **Conclude whether ^{13}C is suitable material for polarization in our lab.**

Contact Information

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