# Pulsed Nuclear Magnetic Resonance

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Using aqueous glycerin solutions as test subjects, we investigate the powerful tool of pulsed Nuclear Magnetic Resonance. We take three principle sets of data - one to measure $T_1$, one to measure $T_2$, and one to explore the CPMG technique - and see the effects of Larmor precession and spin echoes. TODO state results.

## I. INTRODUCTION

The first half of the 20$^{\text{th}}$ century was an exciting time for those invested in particle physics. Prior to 1895, little was understood of what made up our world on an elementary level. The atom was believed to be the most fundamental particle. Then, slowly, physicists' understanding progressed. J.J. Thomson discovered the electron, Rutherford probed the atom and found the nucleus, Einstein and Planck came to understand light and photons, De Broglie suggested the wave-particle duality of particles, and Heisenberg postulated the uncertainty principle [2].

Then, in the 1940s, two teams working on opposite sides of the country separately came to discover what has become one of the most invaluable analytical tools for any field involving the study of particles. These teams were Bloch, Hansen, and Packard at Stanford, and Purcell, Torrey, and Pound at Harvard. They published their papers on *Nuclear Magnetic Resonance* just two weeks apart in 1946. Later, Bloch and Purcell would both receive the Nobel Prize in physics for their work [1].

Scientists jumped on board immediately. Russell Varian brought to market a basic NMR apparatus that made the technique much more accessible. He also published a series of advertisements in *The Journal of the American Chemical Society* that demonstrated the many applications of NMR spectroscopy. Between its applications in Chemistry, Physics, and Biology, this new science was everywhere.

TODO brief explanation of what NMR is

### A. Motivation

Pulsed Nuclear Magnetic Resonance is an extension of NMR in which a series of radio frequency pulses (either $\pi$-pulses of $\pi/2$-pulses) are applied to a sample. Here, we use this technique to find the relaxation time of a sample.

TODO A paragraph discussing the glycerin solutions, why its a good test subject, concentration vs. viscosity.

### B. Rotating Frame

TODO A paragraph discussing precession, larmor frequency

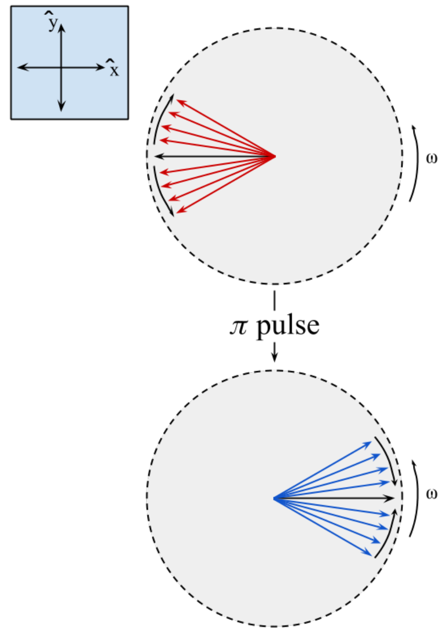


Figure I.1. tktktktkt

### C. Decoherence in Materials

TODO introduction to quantum decoherence, generally. How this impacts our experiment

### D. Pulse Sequences

TODO Discussion of ideal pNMR

TODO Use a description of the three pulse sequences we used to transition to next section.

## II. MEASURING $T_1$

### A. $T_1$ Pulse Sequence

To determine the $T_1$ relaxation time for the 5 glycerin solutions (with concentrations .5, .6, .7, .8, and .9) a two pulse sequence was executed. First, the sample would get a $\pi$-pulse, then some time $t_\Delta$ would pass, and finally a $pi/2$-pulse would be applied. The first pulse aligns the spins with the $-\hat{z}$ axis, the wait time allows the spins

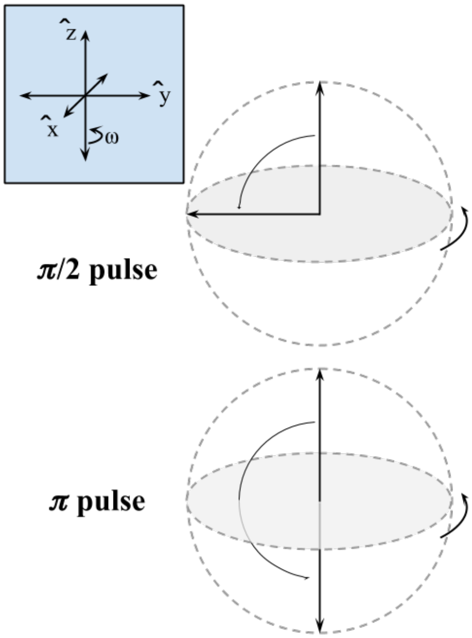


Figure I.2. tktktktkt

to decohere towards $+\hat{z}$, and the second pulse essentially indicates how much the spins have decohered at time $t_\Delta$.

For each sample, first the $t_\Delta$ was found such that the measured $\sigma_x$ was zero (i.e. when the spin is aligned with the $\hat{x}$ direction before the $\pi/2$-pulse). 5 additional sets of data were then collected - 3 before this zero point and two after.

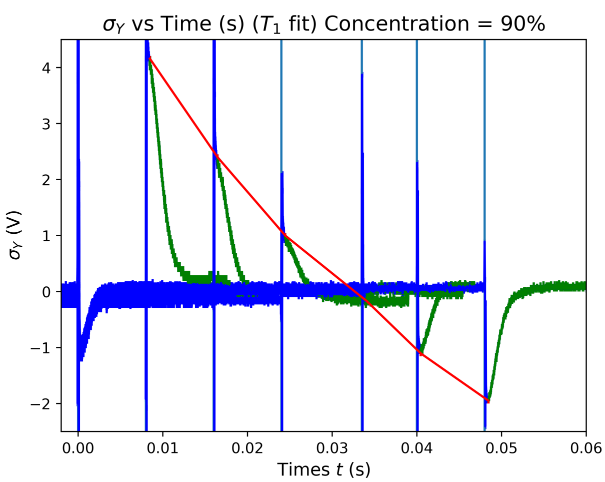


Figure II.1. Example Pulse Sequence for $T_1$ Method at 90% Concentration

### B. $T_1$ Decoherence

TODO What causes $T_1$ decoherance

TODO Diagram. how to represent this type of vague decoherence?

### C. Analysis and Results

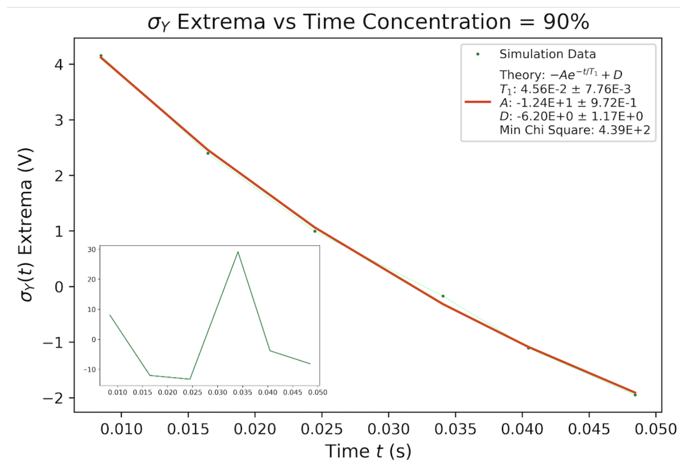


Figure II.2. Example Exponential Fit on Extrema of **??** at 90% Concentration to get $T_1$

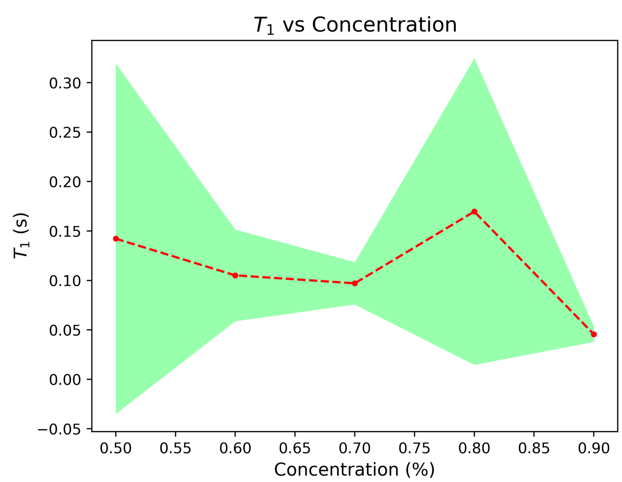


Figure II.3. $T_1$ varied over Concentration

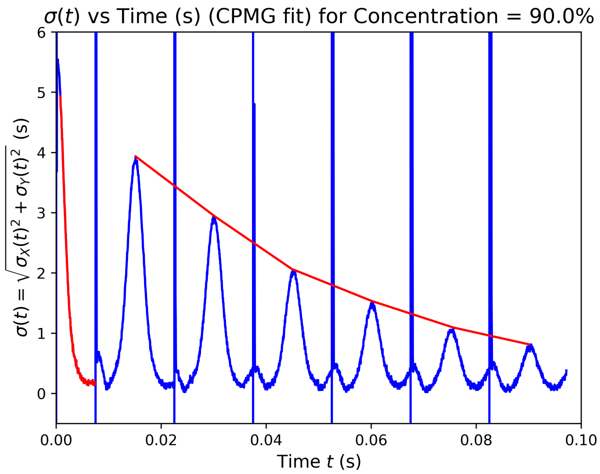


Figure III.1. Example Pulse Sequence for CPMG Method at 90% Concentration

## III. CPMG TECHNIQUE

### A. CPMG Pulse Sequence

### B. Spreading Decoherence $T_2^*$

### C. Analysis and Results

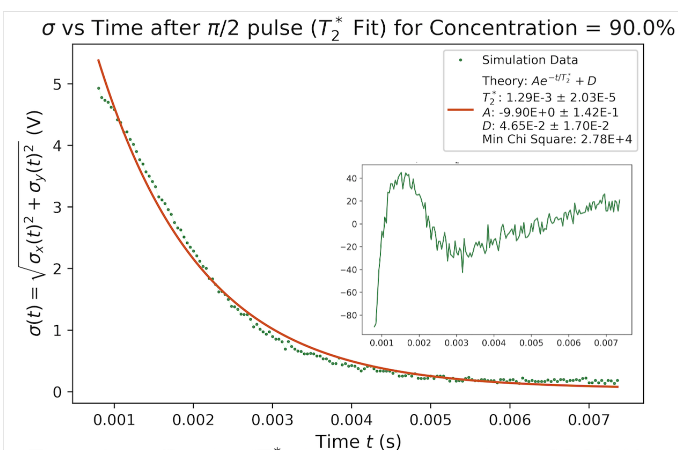


Figure III.2. Example Exponential Fit on Leftmost Exponential of **??** at 90% Concentration to get $T_2^*$

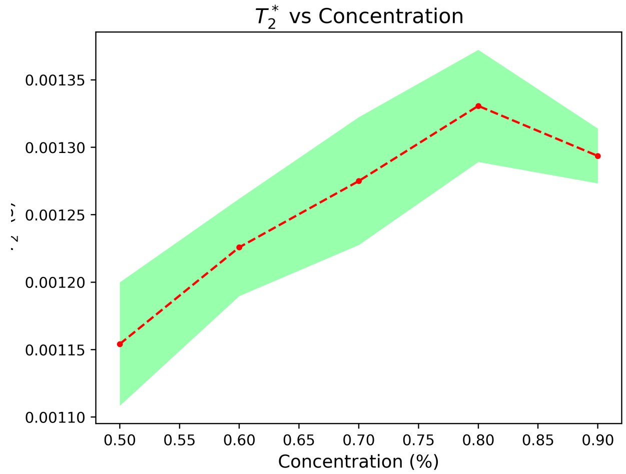


Figure III.3. $T_2^*$ varied over Concentration

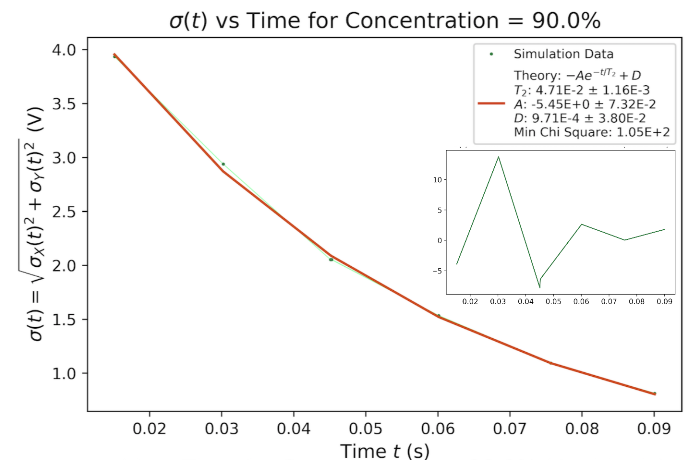


Figure III.4. Example Exponential Fit on Extrema of **??** at 90% Concentration to get $T_2$

## IV. CONCLUSION

### A. Comparison of Methods

### B. Final Thoughts

## V. APPENDIX

### A. Measurement Techniques

#### *1. $T_1$*

#### *2. $T_2$*

#### *3. CPMG*

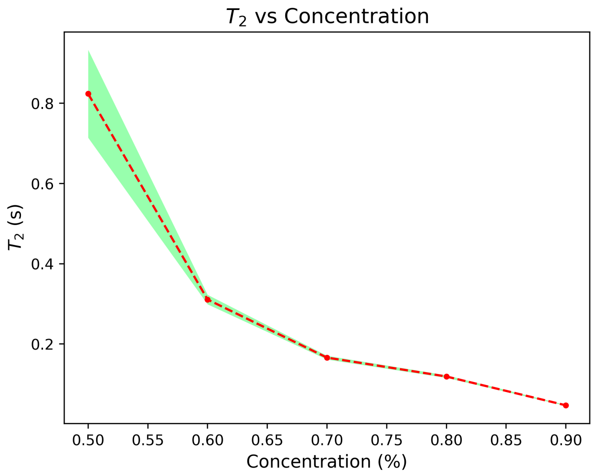


Figure III.5. $T_2$ varied over Concentration

| **Glycerol Concentration** | **Viscosity** | **Relaxation Time** | | |
|---|---|---|---|---|
| | | $T_1$ | $T_2$ | $T_2^*$ |
| .5 | 0.00771 | | | |
| .6 | 0.0146 | | | |
| .7 | 0.0315 | | | |
| .8 | 0.0803 | | | |
| .9 | 0.260 | | | |

Table IV.1. CITE viscosity calculator. Viscosity in units of $Ns/m^2$

[1] Becker, E. D. (1993), "A Brief History of Nuclear Magnetic Resonance," *Analytical Chemistry*, 65.
[2] Flores, J. (2009), "Evolution of Elementary Particle Physics in the 20th Century," *Fundamentals of Physics*, 1.