NMR

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Introduction

In this experiment we:

- Exposed sample protons* to a magnetic field, B_0
- Used pulses of a second field, B_1, to perturb their alignment with B_0
- Studied the amount of time it took protons to return to equilibrium in different pulse situations

*from glycerin, water, and fluorine

NMR Basics

- Bare protons have an intrinsic angular momentum and a magnetic moment

$$\boldsymbol{\mu} = \gamma \mathbf{s}$$

- A proton will precess about the direction of a magnetic field at the Larmor frequency

$$\omega_0 = \gamma B_0$$

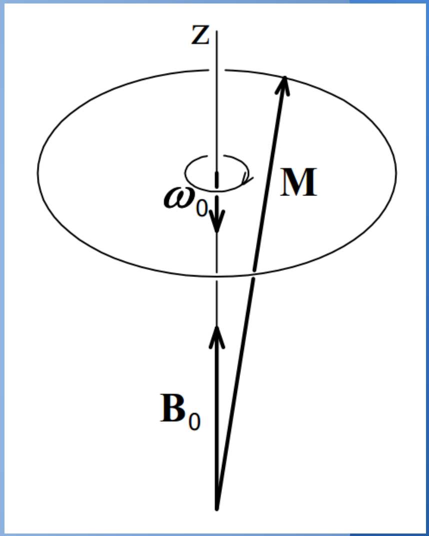
- Two eigenstates, spin up or spin down

- The macroscopic behavior will show a net angular momentum and net dipole moment

$$\mathbf{L} = \sum \mathbf{s}$$

$$\begin{aligned} \mathbf{P} &= \sum \boldsymbol{\mu} \\ &= \sum \gamma \mathbf{s} \\ &= \gamma \mathbf{L} \end{aligned}$$

$$\mathbf{M} = \mathbf{P}/V.$$



NMR Basics

As the magnetization precesses, it produces a changing magnetic flux which is our resultant signal.

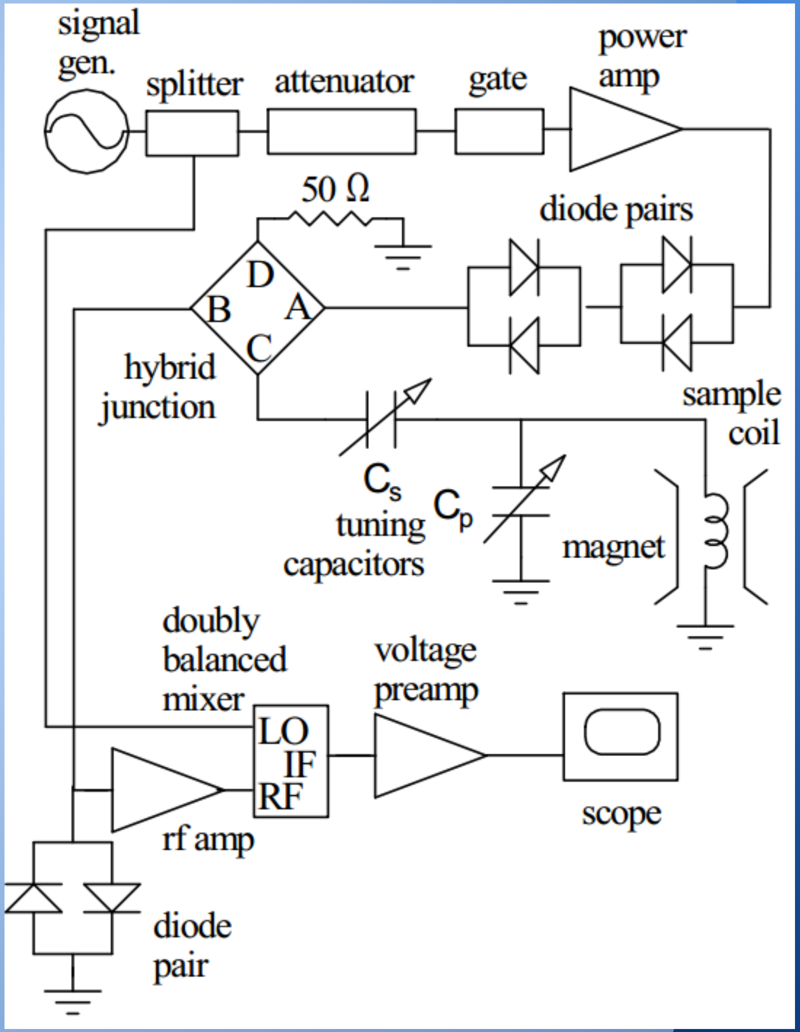
Based on these principles, we observed the behavior of sample protons after applying combinations of pulses that 'bump' the magnetization out of alignment.

The types of pulse are called

- $\pi/2$-pulse
- π-pulse

Apparatus

- 9.5 MHz signal
- Surrounding our sample is a coil that supplies the 'bump' and also picks up the changing flux
- The apparatus allows the 'bump' to be sent and the signal to be received.
- The large magnet is set at approximately 2 kG



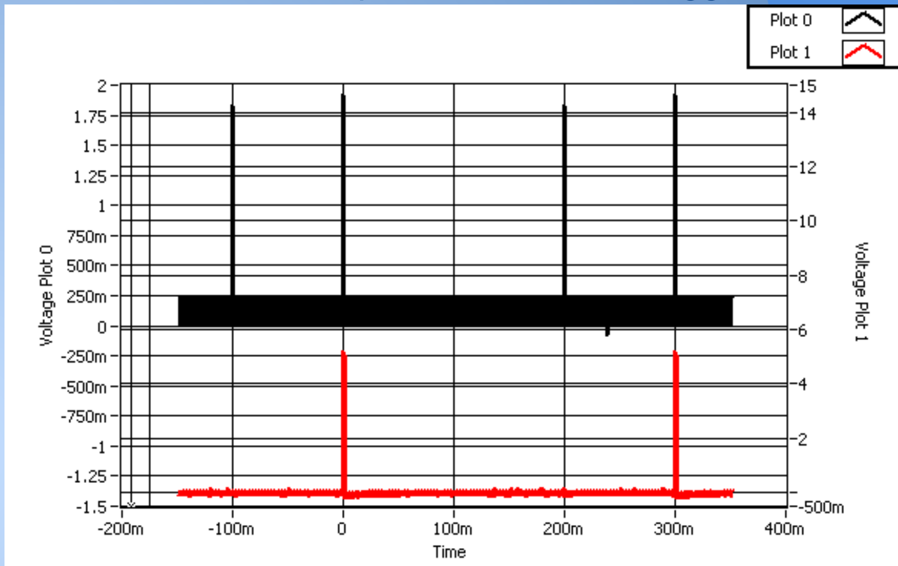
Pulses

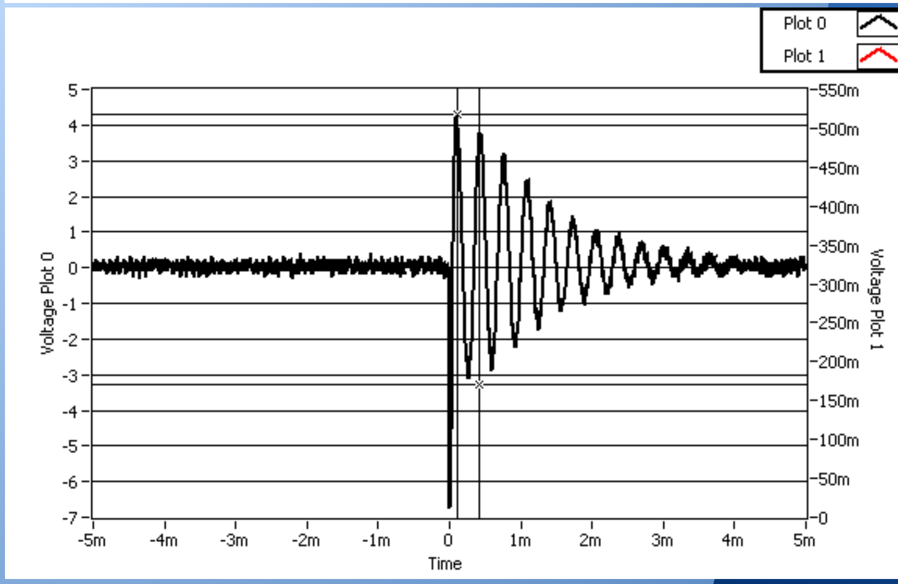
The Labview control allowed us to make two repeating pulses separated by a delay

- A 8.2 μs pulse is a π/2-pulse
- A 16.4 μs pulse is a π-pulse

The perturbed system returns to equilibrium after some time. This behavior manifests as a free induction decay (FID).

Black is the pulses, red is the trigger

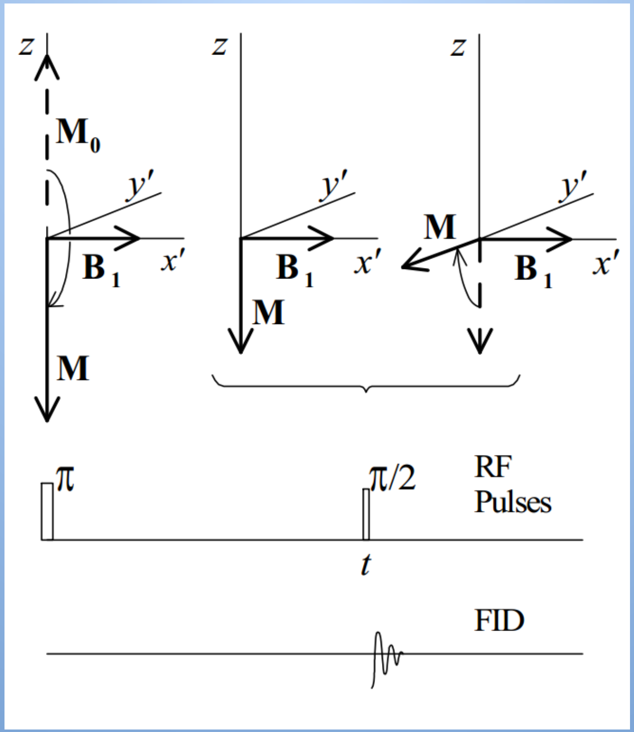




Inversion Recovery

Procedure:

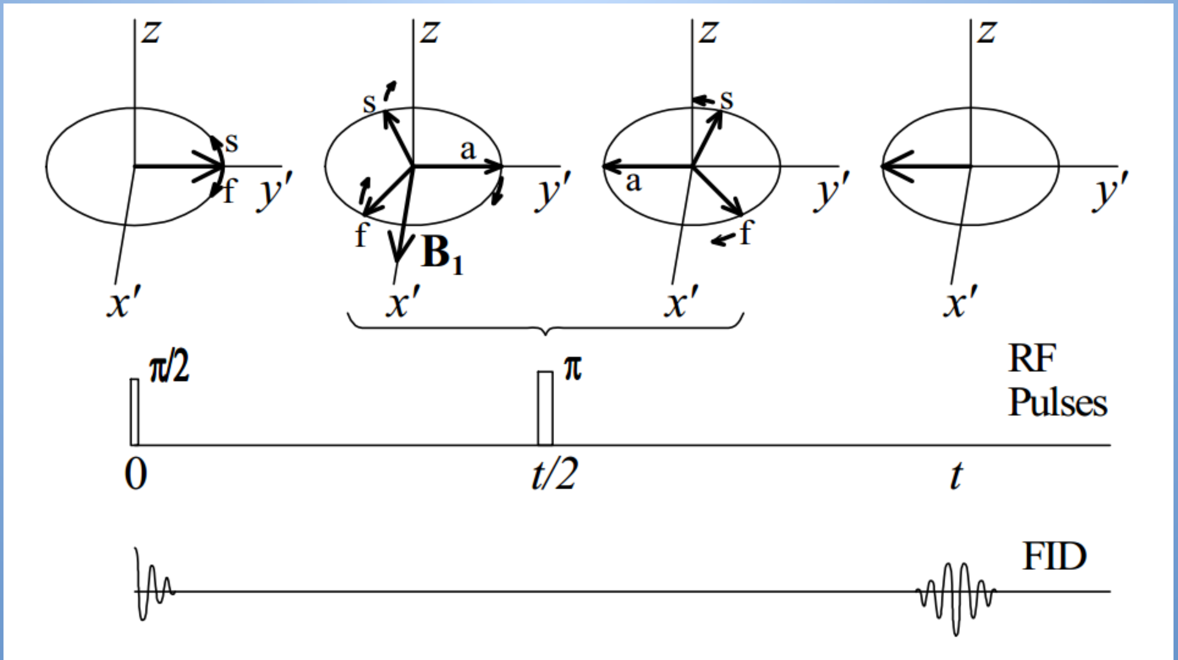
- bump the aligned sample with a π-pulse
- later, bump with a π/2-pulse



Spin Echo

Procedure:

- bump with π/2-pulse
- bump with π-pulse

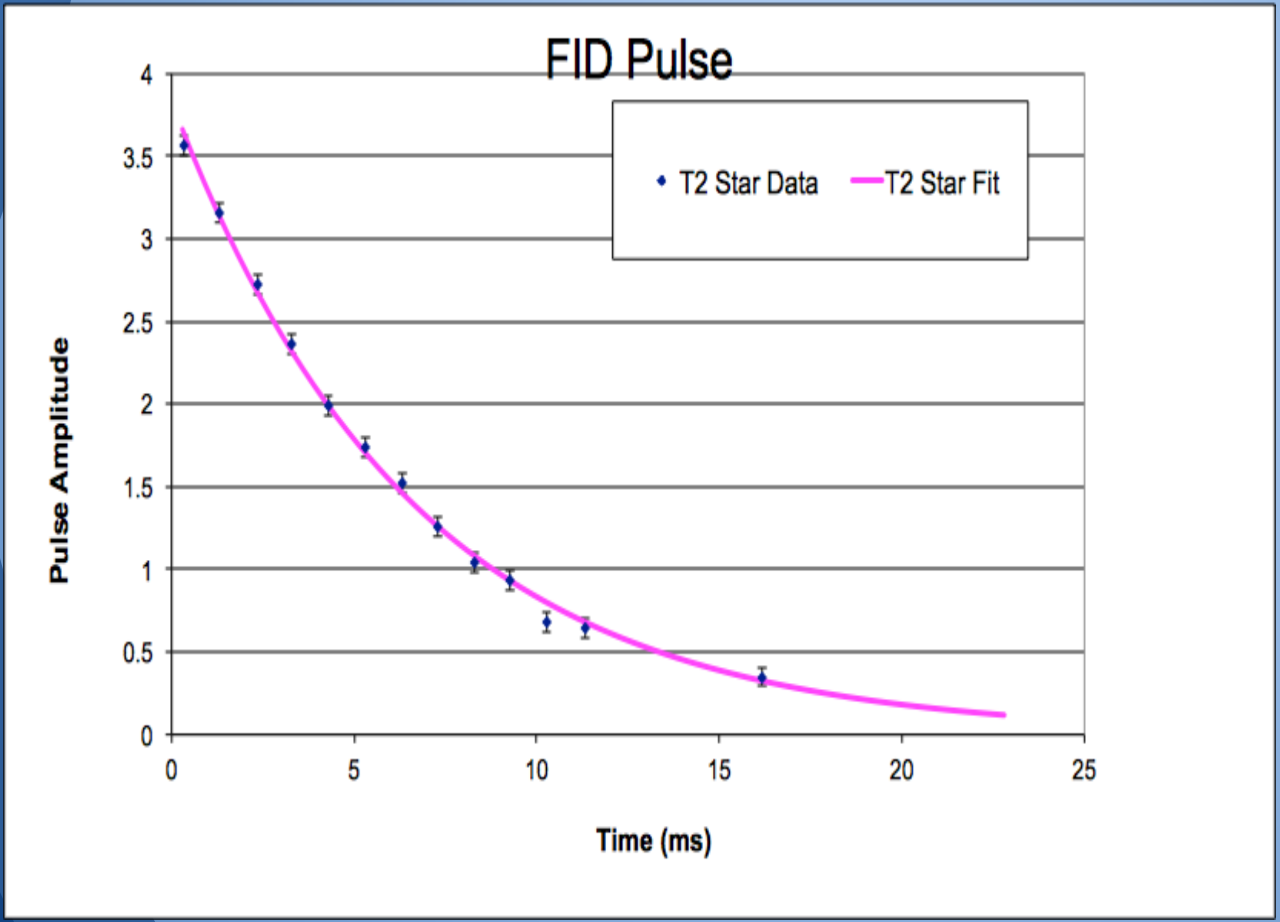


Uncertainties

Systematic Uncertainties include

- Sample placement within the magnet assembly
- Capacitor calibration
- Sample placement within the B1 coil
- Fluctuations in the B0 magnet especially after running for extended times.

Results - Free Induction Decay Pulse



$$M_r(t) = M_i e^{-t/T_2^*}$$

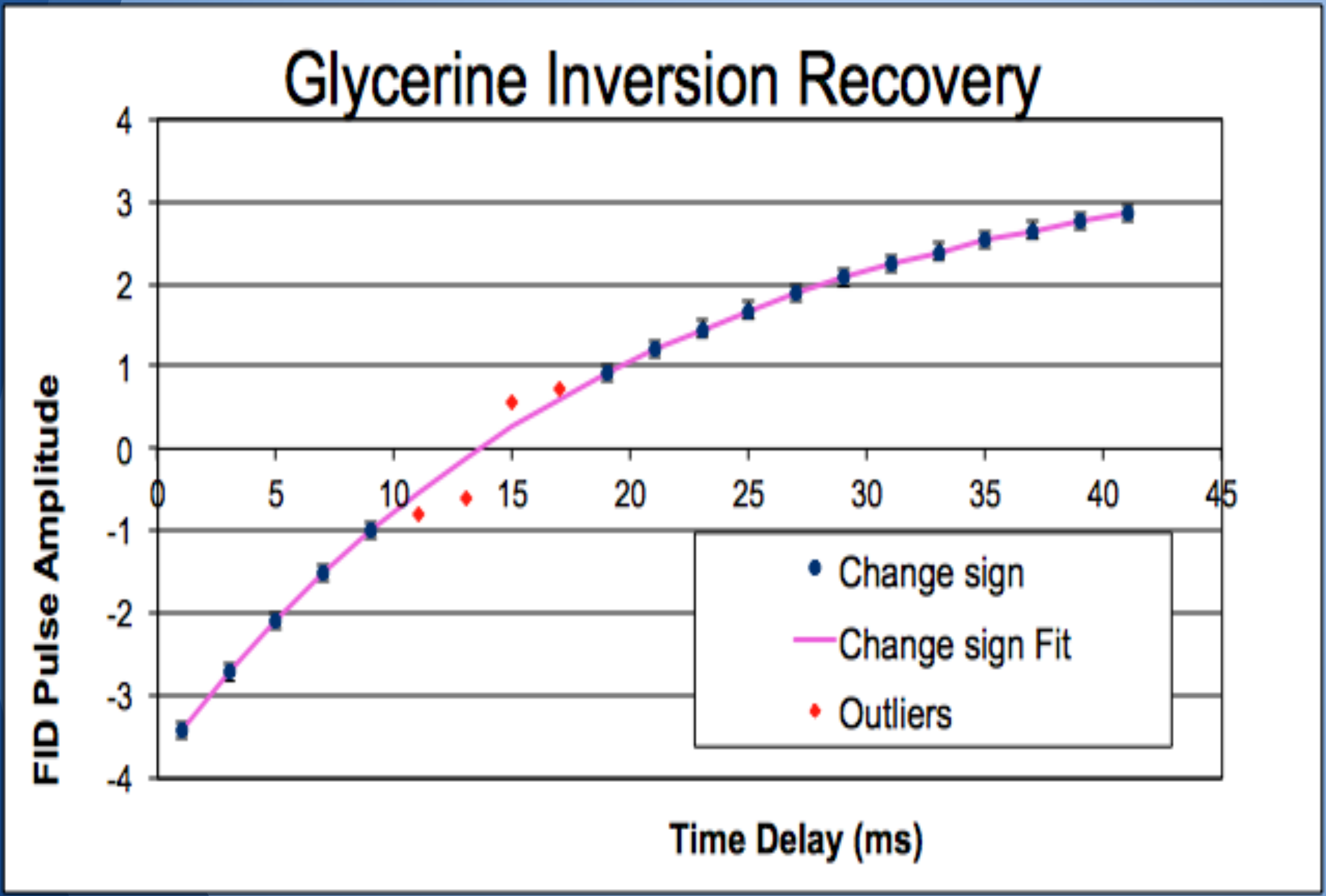
X^2 = 10.28

Mi = 3.83 +- 0.049 (A/m)

T2* = 6.55 +- 0.14 (ms)

Results - Glycerin Inversion Recovery

$$M_z(t) = M_0 \left(1 - 2e^{-t/T_1}\right)$$



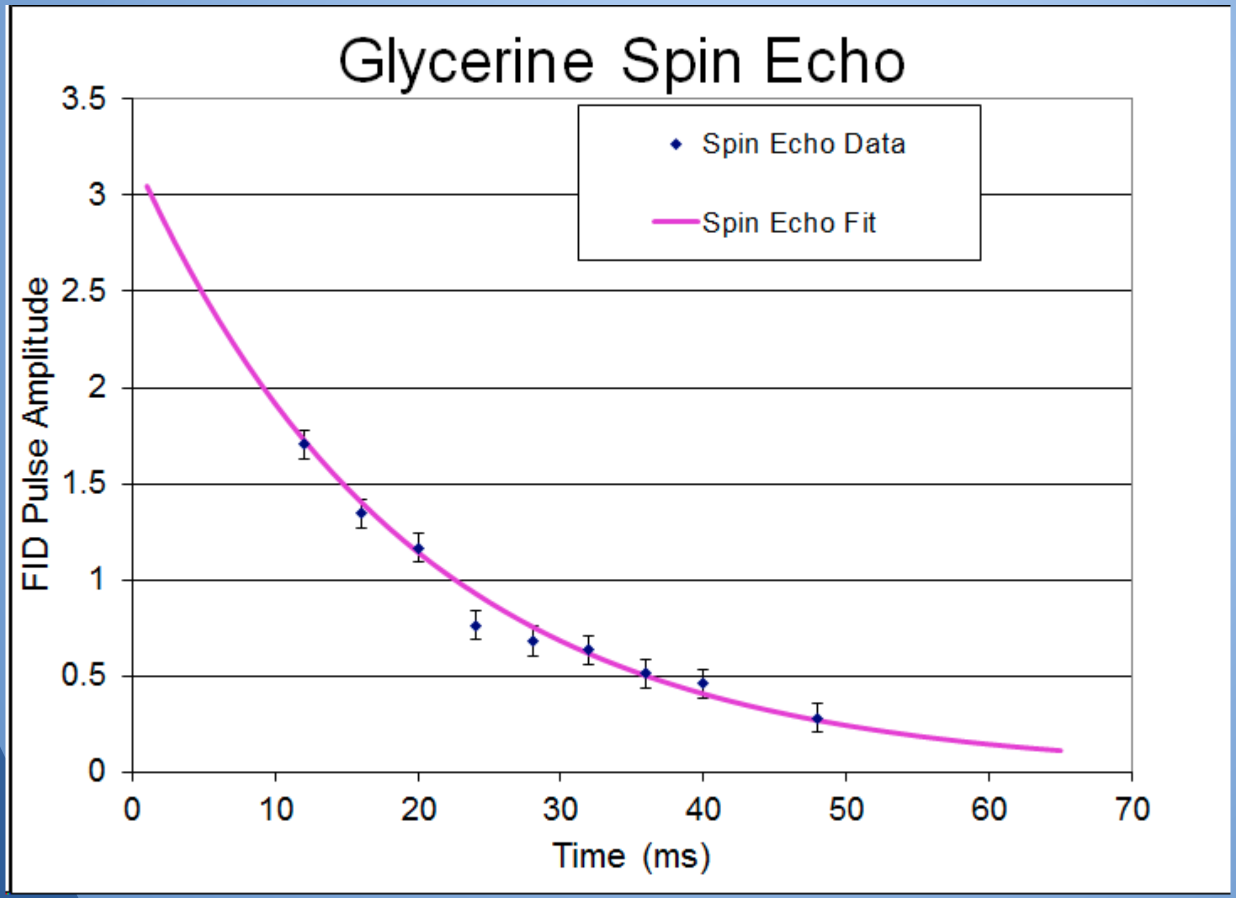
X^2 = 1.51

M0 = 3.79 +/- 0.06 (A/m)

T1 = 19.6 +/- 0.3 (ms)

Results - Glycerin Spin Echo

$$M(t) = M_0\, exp\left[-t/T_2\right]$$



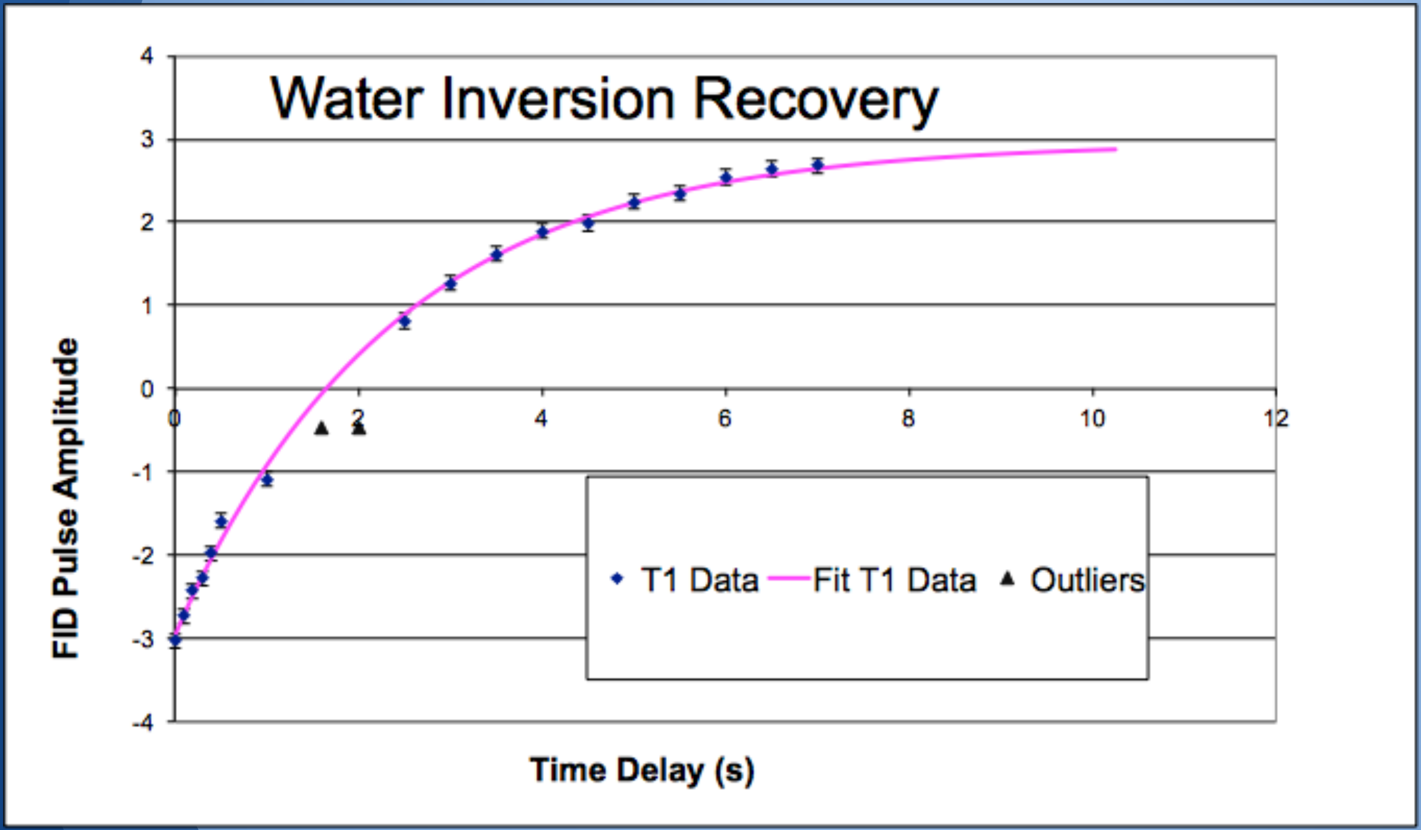
X^2 = 0.98

M0 = 3.1 +/- .15 (A/m)

T2 = 19.4 +/- 2 (ms)

Results - Water Inversion Recovery

$$M_z(t) = M_0\left(1 - 2e^{-t/T_1}\right)$$

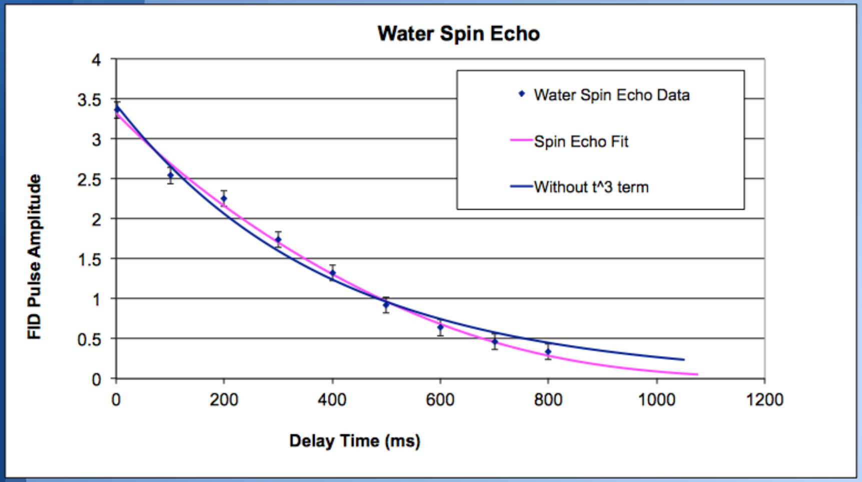


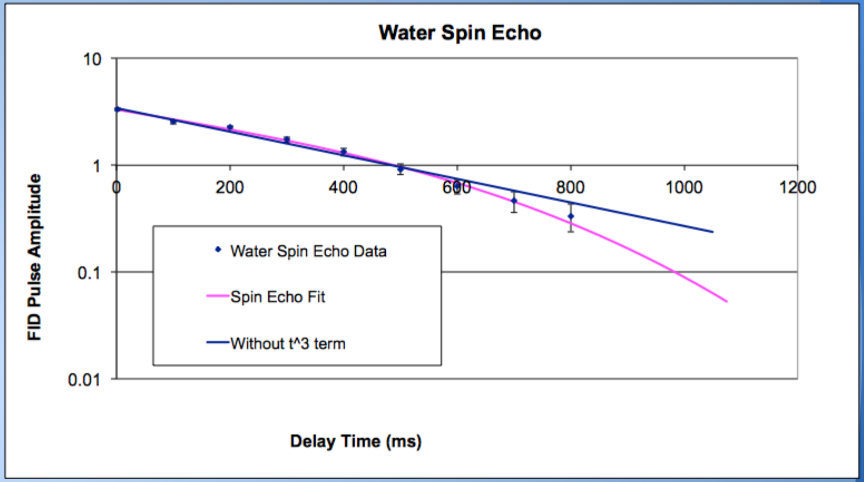
X^2 = .905

M0 = 2.96 +/- 0.03 (A/m)

T1 = 2.4 +/- 0.04 seconds

Results - Water Spin Echo





$$M(t) = M_0\, exp\left[-t/T_2 - (\gamma^2 G^2 D t^3)/12\right]$$

Without t^3 term
abs X^2 = 12.1

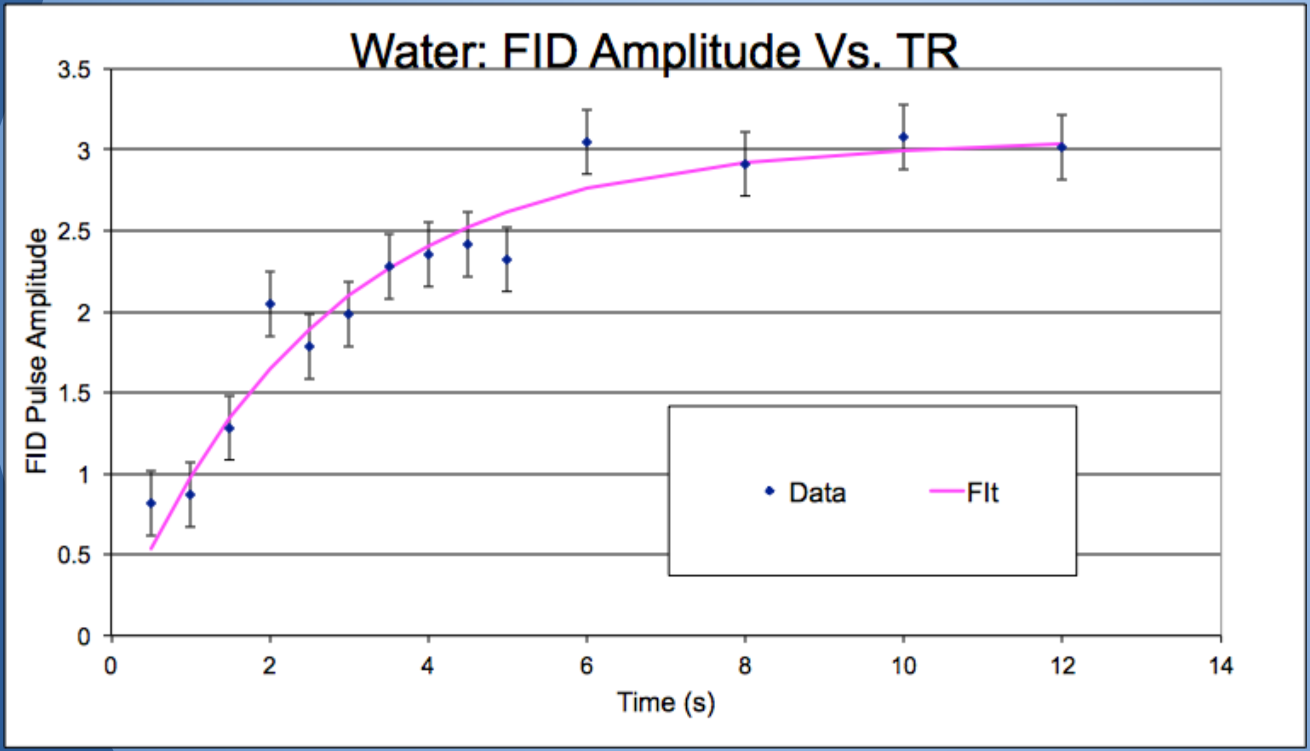
M0 = 3.4 +/- 0.1 (A/m)

T2 = 393.5 +/- 18 (ms)

With t^3 term
abs X^2 = 4.3
M0 = 3.3 +/- 0.1 (A/m)
T2 = 479 +/- 55 (ms)
G = .122 Gauss/mm
gamma = 2.675 x 10^8 rad / (sec tesla)
D = 2.3 x 10^-9 m^2/s

Results - Probing FID amplitude with Tr

$$M(T_r) = M_0 \left(1 - e^{-T_r/T_1}\right)$$



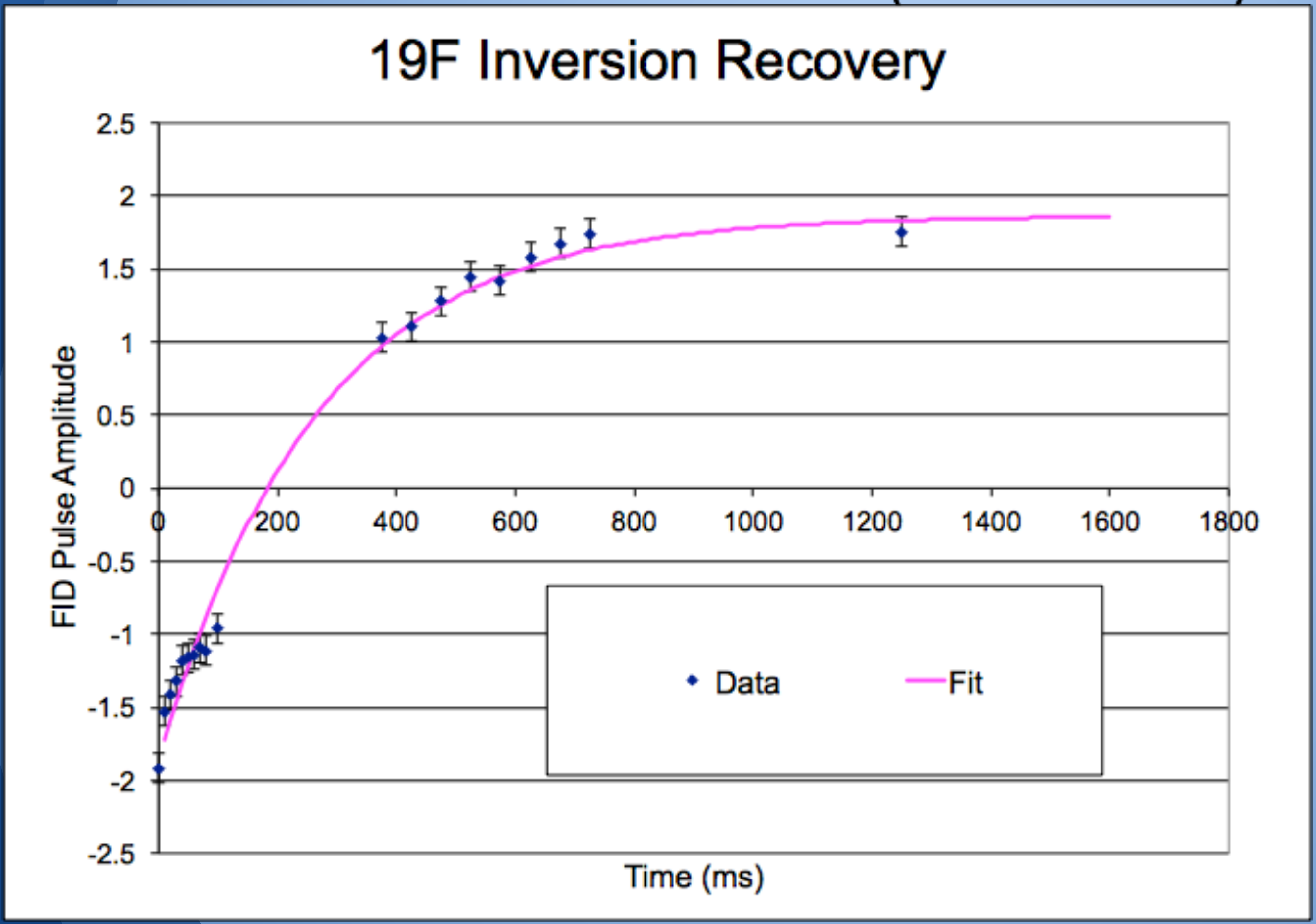
X^2 = 1.06

M0 = 3.1 +/- 0.14 (A/m)

T1 = 2.6 +/- .33 seconds

Results - 19F Inversion Recovery

$$M_z(t) = M_0\left(1 - 2e^{-t/T_1}\right)$$



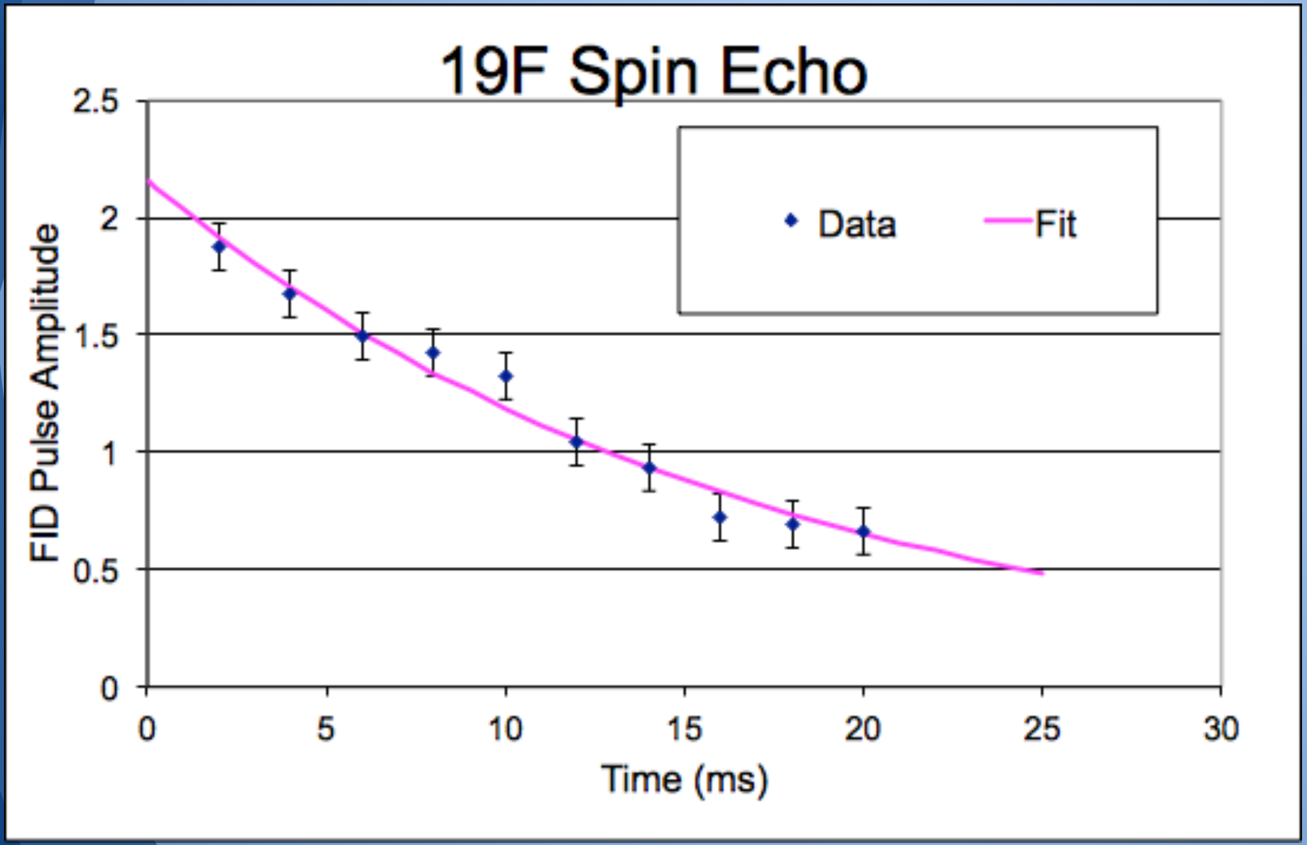
X^2 = 1.13

M0 = 1.9 +- .15 (A/m)

T1 = 263 +/- 27 (ms)

Results - 19F Spin Echo

$$M(t) = M_0 \, exp\left[-t/T_2\right]$$



$X^2 = 0.98$

$M_0 = 2.16 \pm .21$ (A/m)

$T_2 = 17 \pm 2$ (ms)

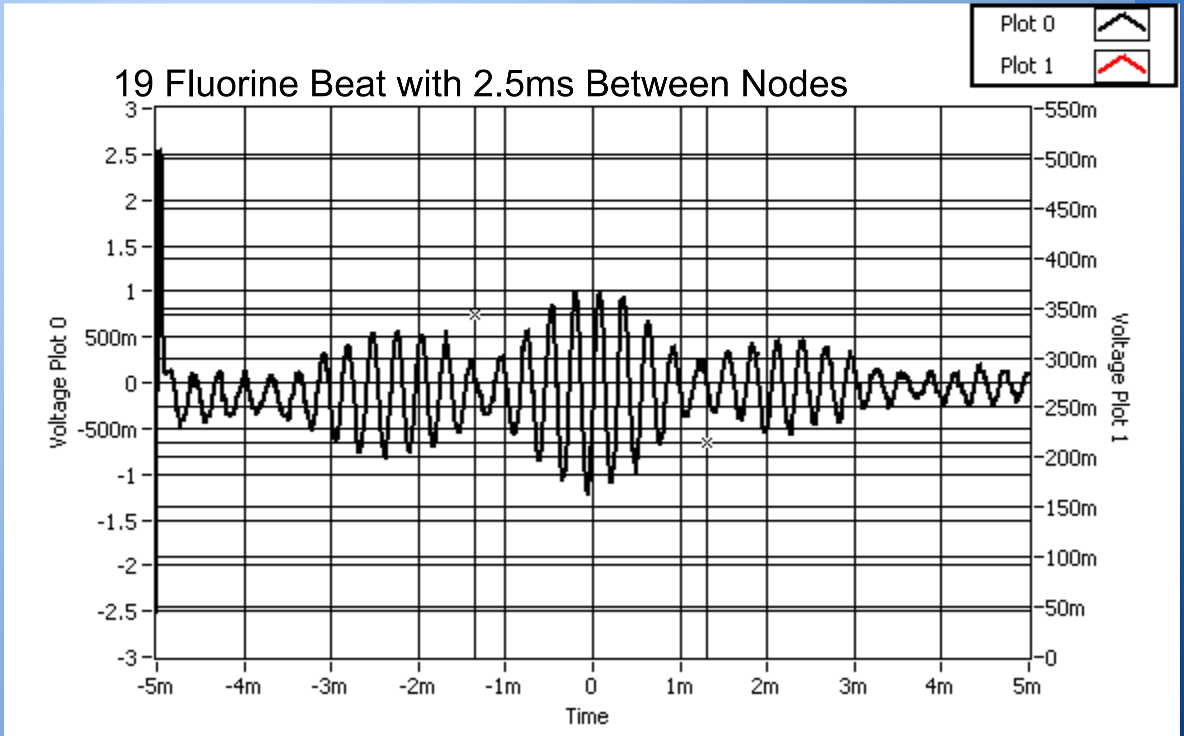
Results - Fluorine Beating

- 19 Fluorine contains two different nuclei which precess at different frequencies.

2.5ms =~400Hz

400Hz vs. 9.5MHz

Frequencies differ by approximately 42 parts per million.



Results

Material	T1	T2	M0 (A/m)
Glycerin	19.6 +/- 0.3 (ms)	9.4 +/- 2 (ms)	3.5 +/- .6
Water	2.4 +/- 0.04 seconds	479 +/- 55 (ms)	3.2 +/- 0.2
19 Fluorine	263 +/- 27 (ms)	17 +/- 2 (ms)	2.1 +/- .5
Adipose Tissue (B0=1.5T)*	250ms	80ms	-
Muscle (B0=1.5T) *	900 ms	50 ms	-

* **Chemicals of brain relaxation time at 1.5T.** Kreis R, Ernst T, and Ross BD "Absolute Quantification of Water and Metabolites in the Human Brain. II. Metabolite Concentrations" *Journal of Magnetic Resonance*, Series B 102 (1993): 9-19

Conclusion

In this experiment

- Pulsed NMR techniques were used to investigate properties of glycerin, water and fluorine
- Of the samples, water had the longest relaxation times
- Fluorine showed a beating pattern that was characteristic of two nuclei precessing at different rates
- NMR has many practical applications such as medical imaging in which these parameters are used to distinguish materials within a sample and produce images.

Thank you

Dr. Furic, Dr. DeSerio, and Dr. Hamlin