Pulsed NMR

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***Abstract* – For 9 solutions containing different ratios of water and $CuSO_4$ pulsed NMR techniques that are detailed throughout this paper were used to find T1, T2, T2* and the gyro-magnetic ratio of the different solutions. Using the results to find how the water to $CuSO_4$ ratio effects those components and compare between the measured gyro-magnetic ratio to the theoretical one. One of the solution's ratio was unknown and by fitting T1 as a function of water to $CuSO_4$ ratio the unknown ratio was found.**

I. INTRODUCTION

Spin in a constant magnetic field:

Classical point of view:

From a classical analysis of a magnetic moment μ that is generated from a spinning particle in a constant magnetic field H along the z axis the angular momentum S does precession around the z axis. That is S length does not change in time and the z component of S remains constant as the xy component spins around the Z axis in a constant rate. the exact motion of the spin S can be derived from:

$$\frac{d\mathbf{S}}{dt} = -\mu \times \mathbf{H} \tag{1}$$

As the spinning particle is modeled as a charged sphere ($\mu = \gamma\mathbf{S}$) Where left side of (1) is the total angular momentum, and the right side is the torque. From (1) it is possible to derive the motion of S and the angular frequency:

$$\omega = \gamma\mathbf{H} \tag{2}$$

ω - the "Larmor frequency".
γ - the Gyro magnetic ratio/Constant describe the ratio of the magnetic moment and angular momentum.
the theoretical value of the gyro-magnetic ratio is

$$\gamma = 26752.218744 \pm 1.1 \times 10^{-5}[\frac{hz}{gauss}] \tag{3}$$

Quantum mechanical point of view:

The Hamiltonian of a spin in a magnetic field is:

$$\mathscr{H} = -\mu \cdot \mathbf{H} \tag{4}$$

When H is constant and along the Z axis there are two energy levels for S described in S_z base:

$$E_{S_z} = \gamma\hbar H S_z = \omega\hbar S_z \quad , \quad S_z = \mp 0.5 \tag{5}$$

A spin in the lower energy level can get to the higher one by absorbing a photon with a specific energy of $\omega\hbar$

In a system containing many non-interacting spins in a magnetic field at a constant temperature and equilibrium the ratio between spin up($S_z = 0.5$) and spin down ($S_z = -0.5$) is derived from Boltzmann statistics:

$$\frac{N_\downarrow}{N_\uparrow} = \exp\left(\frac{\omega\hbar}{Tk_B}\right) \tag{6}$$

In this case the total magnetization M is:

$$M = \gamma(N_\uparrow - N_\downarrow) = N\mu\tanh\left(\frac{H\mu}{Tk_B}\right) \tag{7}$$

The resonance phenomenon:

When the strong magnetic H is applied along the z axis, looking from a coordinate system rotating around the original z axis at a rate ω the angular momentum S is constant, when applying an additional constant magnetic field along x' of the rotating frame S will do precession around x' since in the rotating frame S is only in the $x'z$ plain. applying the pules for a short time Δt is a method to rotate S, for example:

$$\omega \cdot \Delta t = \frac{\pi}{2} \tag{8}$$

This is a 90^o pules (for 180^o and 270^o it is similar) that rotates S to the xy plain of the laboratory system.

Since a generating a constant magnetic field in a rotating system is hard to implement most of the experiments use a small magnetic field relative to H ($H >> H_1$):

$$H_x = 2H_1cos(\omega_0 t) \tag{9}$$

By writing H_x as a sum:

$$\begin{aligned} H_x = H_1cos(\omega_0 t)\hat{x} + H_1sin(\omega_0 t)\hat{y} + \\ +H_1cos(\omega_0 t\hat{x} - H_1sin(\omega_0 t) = \tilde{H}_1 + H_1' \\ \tilde{H}_1 = H_1cos(\omega_0 t)\hat{x} + H_1sin(\omega_0 t)\hat{y} \\ H_1' = H_1cos(\omega_0 t)\hat{x} - H_1sin(\omega_0 t)\hat{y} \end{aligned} \tag{10}$$

When $\omega_0 = \omega_{Larmor}$ $\tilde{H}_1$ rotates around the z axis at the same rate as the system where S is constant- this is the resonance phenomenon. The equation of motion in the laboratory system is:

$$\frac{d\mathbf{M}}{dt} = \mathbf{M} \times \gamma[H\hat{z} + \tilde{\mathbf{H}}_1 + \mathbf{H}_1'] \tag{11}$$

Since $H >> H_1$ the effect of $\tilde{H}_1$ and H_1' will be significant only if they line up with M, otherwise they rotate around M causing a small torque in different directions that cancels out overtime. For that reason, H_1' can be ignored at equation (10).

$$\frac{d\mathbf{M}}{dt} = \mathbf{M} \times [H\hat{z} + \tilde{\mathbf{H}}_1] \tag{12}$$

The equation connecting the M to M' the magnetization in the rotating frame is:

$$\frac{d\mathbf{M}}{dt} = \frac{d\mathbf{M}'}{dt} + \omega\hat{z} \times \mathbf{M} \tag{13}$$

From (11) and (12):

$$\frac{d\mathbf{M}'}{dt} = -\gamma \mathbf{H_{eff}} \times \mathbf{M} \tag{14}$$

$$\mathbf{H_{eff}} = (H - \frac{\omega}{\gamma})\hat{z} + H_1\hat{x'}$$

This is the presession equation for a constant field H_{eff} and for $\omega_{Larmor} H_{eff} = H_1\hat{x'}$, So in practice it is possible to create a magnetic field that rotates with M in ω_{Larmor} by applying H_x in the laboratory system.

T_1 *Processes* :

When the magnetization M is not at equilibrium M will try to return to its equilibrium value. If M_0 is the state of M at equilibrium when $t = 0$ than the z component of M returns to equilibrium as follows:

$$M_z = M_0(1 - exp(-\frac{t}{T_1})) \tag{15}$$

If $M_0 = -M_0\hat{z}$ than the z component is:

$$M_z = M_0(1 - 2exp(-\frac{t}{T_1})) \tag{16}$$

to understand those equations it is useful to look from a quantum mechanical point of view, as spins at room temperature want to return to equilibrium value(6) by exchanging photons with one and other. so at time t_0 if M is not at equilibrium there will be more spins that want to absorb or release (depending on the initial state) a photon, the number of spins that want to absorb or release a photon is proportional to the distance of M_z from equilibrium:

$$\frac{d\mathbf{M_z}}{dt} = \frac{\mathbf{M_0} - \mathbf{M_z}}{T_1} \tag{17}$$

T_2 *transverse relaxation* :

The model of non-interacting spins in a constant magnetic field is not exact, in most materials and most systems there will be some interaction between the spins and some inhomogeneous in H the constant magnetic field.

T_2 relaxation describes a process that the signal is decreasing in the xy plane as a result of a loss of coherence. to understand the source of that phenomena we need to pay attention that the magnetization is a sum of small magnetic dipoles $\mathbf{M} = \sum_i \mu_i$ where i is a spin in the system. every spin is in another place in the sample, feel collisions, and interactions with another spin's, and move in barony motion.

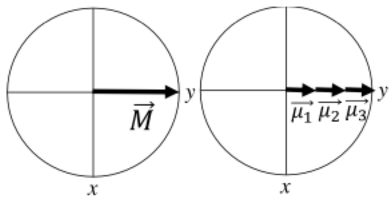


Fig. 1. Magnetization as a sum of spins

after a characteristically time T_2 the moments has a difference in phase for all that reasons, that phase is random. in a result from that the total moment decrease

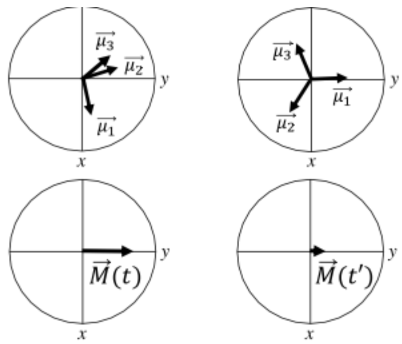


Fig. 2. Magnetization as a sum of spins loss of coherence

When placing M is the xy plane the probability of a spin at time at t_0 to dephase from Larmor frequency is constant and does not depend on t_0 so the amount of spins that dephase at t_0 is proportional to M_xy so M_xy dephases as follows:

$$\frac{d\mathbf{M_{xy}}}{dt} = -\frac{\mathbf{M_{xy}}}{T_2}$$

$$M_{xy} = M_{xy}(0)exp(\frac{-t}{T_2}) \tag{18}$$

T_2 is built from 2 different components:

$$\frac{1}{T_2*} = \frac{1}{T_2} + \frac{1}{T_{2,\Delta H}} \tag{19}$$

Where T_2* is the observed measurement of (16) T_2 is caused by spin interactions and $T_{2,\Delta H}$ is caused by the inhomogeneous in H.

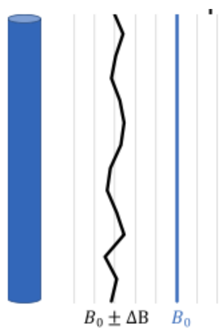


Fig. 3. in-homogeneous in a magnetic field

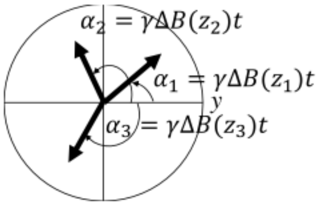


Fig. 4. spin's in a in-homogeneous field

Ions affect on T_1 and T_2 :

Paramedic ions in a sample has a higher magnetic moment from the nucleus. from that the ions affect the relaxations times from the connections to the magnetic moment of the samples by a inverse power connection:

$$\frac{1}{T_{1/2}} \propto \frac{N_{ion}}{N_{sample}} \propto \%_{ions\ in\ sample} \tag{20}$$

II. MEASUREMENTS METHODS

Measuring Larmor frequency:

by using a mixer that effectively multiples the frequency of the oscillating magnetic field (H_x) with the precession's frequency of the magnetization(Larmor frequency) the result is a signal with a frequency that equals to the difference of the precession's frequency and the frequency of H_x and the signal's amplitude. so when frequency of H_x equals to Larmor frequency there will be no oscillations in the output, by experimenting with different frequencies one can find some small range were the mixed signal is not oscillating and find by that find some small range for Larmor frequency.

Measuring M_x :

In the experiment the system has a coil that generates the pulses (H_x) it is possible to use this coil to measure the magnetization's amplitude along the x axis. When M is not at equilibrium it preforms a precession around the z axis, then the magnetization along the x axis is:

$$M_x = M_0 sin(\omega_{Larmor} t) cos(\theta) \tag{21}$$

θ is the angle between M and xy plain and M_0 is the magnitude of M in equilibrium. Denote the density of the loops in the coil as n, the cross-sectional area as A and by definition the magnetic field is $B = 4\pi M$. Then the voltage generated from the magnetic field is as Faraday's law of induction states:

$$V = \frac{4\pi}{c} nAM_0 \omega_{Larmor} cos(\omega_{Larmor} t) cos(\theta) \tag{22}$$

the amplitude of V is proportional to M_0 than in the experiment it is useful to look only at V as a function of time. Since it is possible to measure only $M'_x s$ amplitude the measurement methods of $T1$ and $T2$ is not trivial and will be discussed in the following section. to send a pulse and measure M_x (for example a 90 pulse) the system measure also a capacitor charge alike phenomenon so for a signal f(t) the voltage V that is actually measured is:

$$V = (1 - exp(-\frac{t}{T_2})) * f(t) \tag{23}$$

in our case of measuring T1 and T2 T1,T2 » $T_R C$ so it is possible to take only points at t» $T_R C$ as the data and ignore this effect.

Measuring T_2 :

T_2 is the constant that controls the dephase of the xy component when M was in the xy plain at $t = 0$. To measure T_2 one needs to wait until the system is at equilibrium state, and then send a 90^o pulse as described in previous section, so that M is at xy plain exactly after the pulse and starts to defase at a rate of T_2. By measuring the change of amplitude on the x axis one could find T_2.

Measuring T_1 :

T1 is the time that M_z returns to its equilibrium value, so one needs to wait until the system is at equilibrium state and then send a 180^o pulse. New the system returns to equilibrium as described in equation (15). To measure M_z at time t_0 one needs to send a second pulse of 90^o to rotate M to the xy plain and measure the amplitude to get the Absolute value of M_z at t_0. By repeating this process for different t_0 and by putting the different point on a graph to understand when M_z is negative and when it is positive, one can calculate T1. Note that for every t_0 one needs to wait until the system is at equilibrium state before sending the next 180 pulse, if we want to measure T1 in different t_0 at the same process we would have to send a 180 pulse and 90 pulse and than immediately another pulse to put M on the Z axis. this is problematic for two reasons- one is that the instrument that send the pulses can not be programmed to send such sequence, it can be programmed only to send 2 pulses and repeat the second one for many times in some suspension time between the pulses. and after a 180 pulse and a 90 pulse another 90 pulse would not reset M to the right place. The second reason is that the third pulse would have to be exactly after the 90 pulse so we would not measure T2 effects on our T1 measure, and this requires a more advanced instrument.

Measuring $T_{2,\Delta H}$:

It is possible to isolate the homogeneous component caused by spin interactions with the environment and calculate $T_{2,\Delta H}$, there are two main strategies to find $T_{2,\Delta H}$both strategies start with a 90^o along the x' axis pulse:

CPMG – After time τ, a 180^o pulse is sent from the y' axis that creates a "spin echo"- because of the in-homogeneous in H different parts of the material experiment a slightly different Larmor frequency so some parts spin a little faster or a little slower than the average Larmor frequency that is measured, the 180^o pulse causes the faster frequencies that were previously ahead of Larmor frequency to be behind it and the slower frequencies to be ahead so after time τ after the 180^o pulse the spins will resonate one again to cancel the in-homogeneous effects. The echo will be smaller than the original signal because the process did not cancel the spin interactions with the environment. So by creating a sequence $90x'^{\sim}\tau - 180y'^{\sim}\tau - 180y' \ldots - \tau - 180y'$ one can maximal value of each echo to calculate $T_{2,\Delta H}$ by fitting this data to equation (16)

CP – this method is like the previous one with the change that the 180° pulse is now on x' and not on y'. This change

results that this method is more susceptible to errors in the pulses, since sending a 180^0 pulse is usually mean to send a $180+\delta$ pulse this method would measure a slightly smaller $T_{2,\Delta H}$ when in the CPMG this effect cancels itself out every two pulses Fig(5,6)*.
In both methods the signal is a multiple peaks signal as shown in Fig(7), that decay with the rate that shown in eq(18).

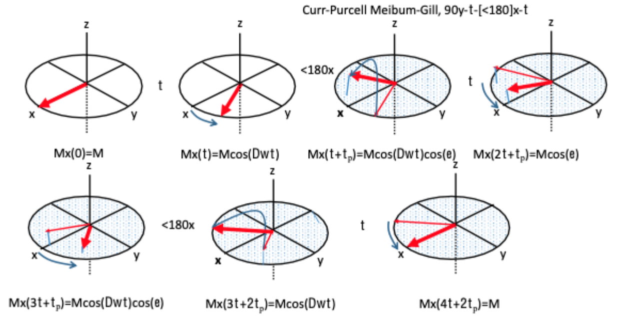


Fig. 5. spin's in CPMG sequence

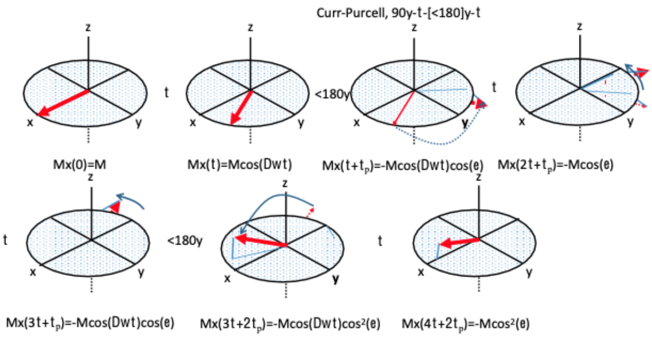


Fig. 6. spin's in CP sequence

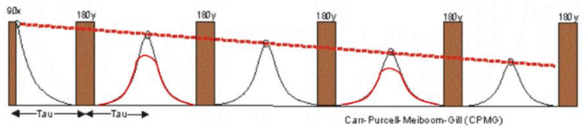


Fig. 7. signal in CPMG sequence

III. EXPERIMENT SETUP

The measurements were taken using TeachSpins's PS1-A system. The components of the experiment are shown in Fig(8):

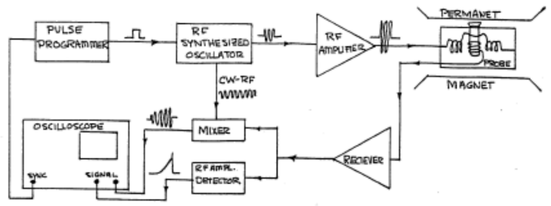


Fig. 8. the instrument

H the constant magnetic field is created by a strong magnet and was measured by a hall probe. the liquid was in a tube has a special case in the instrument so all measurements will be the same as mach as possible. the pulse sequence that the instrument can create is this: send a pulse A for time Δt_1 that can be programmed and wait t_0 until sending a second pulse. The second pulse can be programmed to be at length Δt_2 and can be sent in x' or y' axis, is is possible to repeat the second pulse for N times(N < 100) when t_0 is the time that separates between those repetitions. the magnetization can only be measured in the xy plane as described in (20). Δt_2 and Δt_1 are programmed to create a 180 or 90 pulse by experimenting and finding the smallest or biggest signal before measuring.
A mixer is able to make a multiplication of sine signals, from that we can get a differential signal that will correspond in its oscillation to the frequency difference from the signal that generated at the probe and the reference signal from the signal generator.in that way we can be in the "rotating frame"
Amplifier is able to amplify the signal to visualisation help.

IV. RESULTS

A. Gyro Constant

gyro constant as found directly from (2)

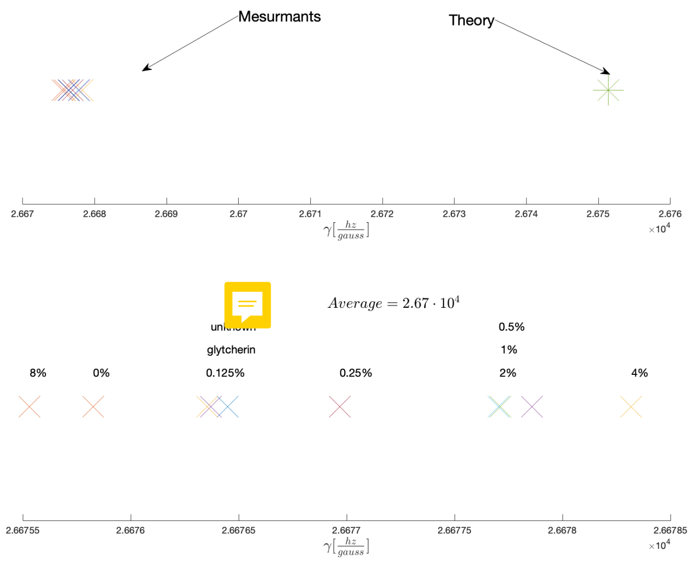


Fig. 9. gyro constant results.full range with theoretical value and measurements

TABLE I
gyro constant Results

Sample	$Larmor[Mhz](interval)$	$B_0[kgauss]$	$\gamma[\frac{hz}{gauss}]\times 10^4$
8%	(15.410,15.412)	3.63±0.01	2.6676±0.0021
4%	(15.412,15.414)	3.63±0.01	2.6678±0.0020
2%	(15.412,15.414)	3.63±0.01	2.6678±0.0022
1%	(15.411,15.414)	3.63±0.01	2.6678±0.0020
0.5%	(15.412,15.414)	3.63±0.01	2.6676±0.0020
0.25%	(15.410,15.413)	3.63±0.01	2.6676±0.0021
0.125%	(15.411,15.413)	3.63±0.01	2.6676±0.0020
0%	(15.410,15.413)	3.63±0.01	2.6676±0.0021
gly	(15.411,15.413)	3.63±0.01	2.6676±0.0020
unknown %	(15.411,15.413)	3.63±0.01	2.6676±0.0020

gyro constant Average:

$$\gamma_{Ave} = 2.6677 \times 10^4 [\frac{hz}{gauss}] \pm 0.0042$$

$$N_{\sigma} = 1.8$$

B. T_1

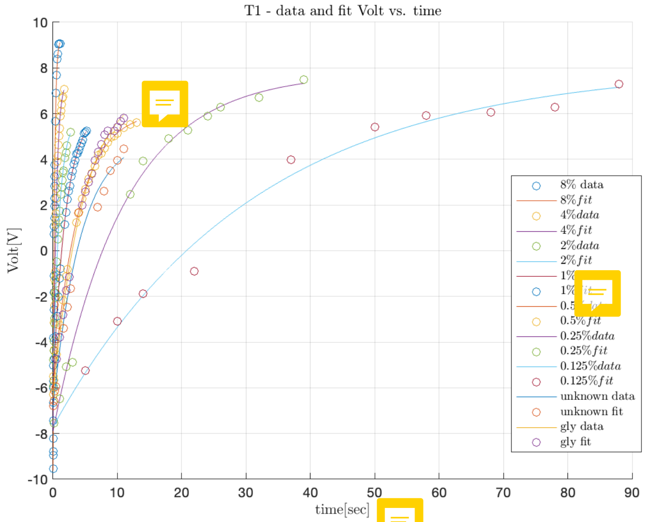


Fig. 10. T1 fits full range

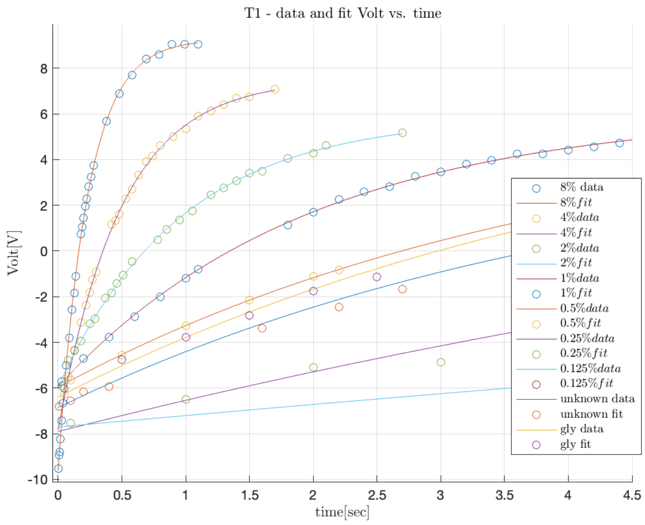


Fig. 11. T1 fits zoom in

TABLE II
T_1 *Results*

fitting function: $a*(1-2\exp(-b*(t-c)))$			
Sample	**b**	**$T_1[sec]$**	**P-prob**
8%	4.39 $\pm$0.05(1.1%err)	0.23$\pm$0.0026(1.1%err)	1
4%	2.03$\pm$0.03(1.38%err)	0.72$\pm$0.0073(1%err)	1
2%	1.03$\pm$0.03(2.77%err)	0.97$\pm$0.03(2.9%err)	1
1%	0.51$\pm$0.008(1.67%err)	1.96$\pm$0.031(1.6%err)	1
0.5%	0.25$\pm$0.002(0.94%err)	4$\pm$0.032(0.8%err)	1
0.25%	0.091$\pm$0.006(6.85%err)	10.87$\pm$0.72(0.58%err)	0.18
0.125%	0.032$\pm$0.006(17.47%err)	31.[illegible].05(2.3%err)	0
gly	0.21$\pm$0.01(5.5%err)	4.[illegible].23(4.8%err)	0.96
unknown %	0.23$\pm$0.04(15.6%err)	4.35$\pm$0.75(17%err)	0

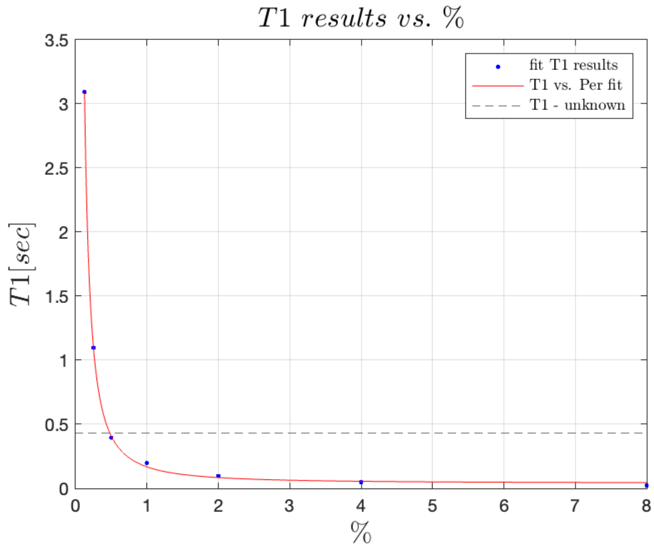


Fig. 12. T1 vs ions % results power fit

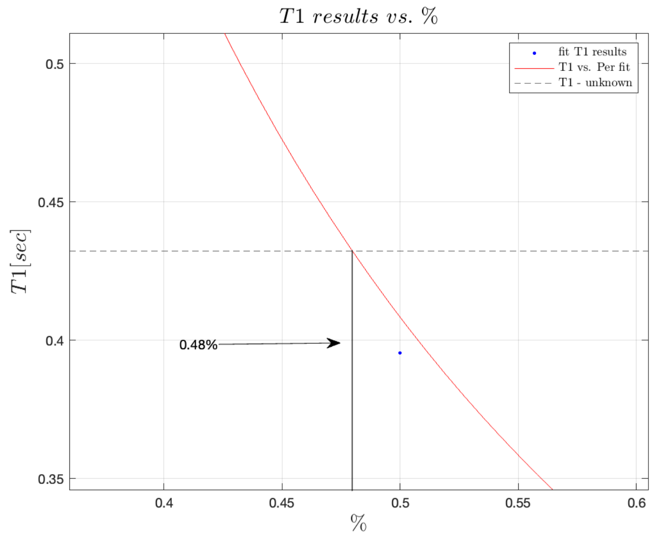


Fig. 13. T1 vs ions % results power fit zoomed

fitting function:

$$a*x^b+c$$

Power result:

$$b = -1.53 \in (-1.61, -1.44)$$

C. T2 spin spin

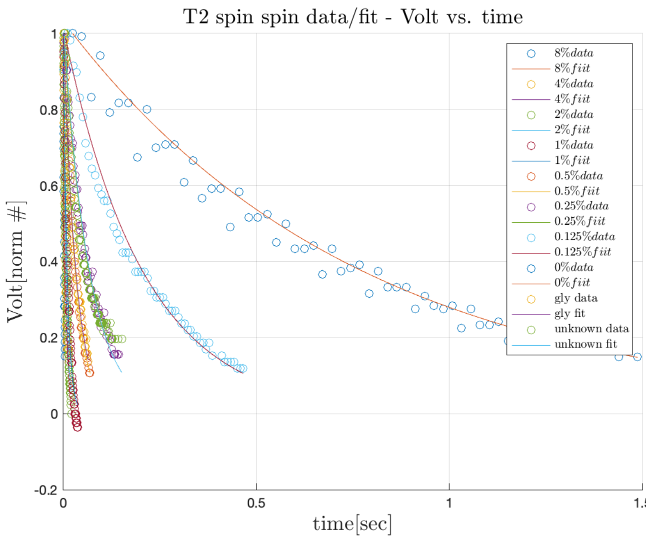


Fig. 14. T2 spin spin fits full range

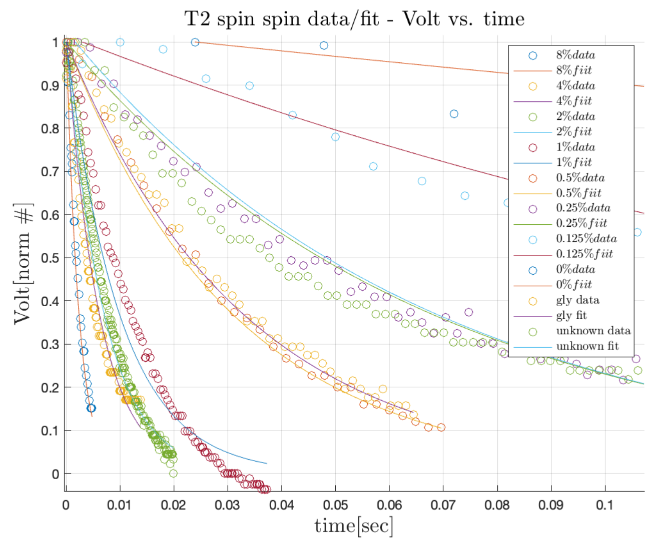


Fig. 15. T2 spin spin fits zoomed

TABLE III
T_2 *spin − spin Results*

fitting function: $a*\exp(-b*(t-c))$			
Sample	**b**	**$T_2[msec]$**	**P-prob**
8%	425.27±3.6(0.85%*err*)	2.35±0.012	1
4%	162.91±2.45(1.50%*err*)	6.14±0.092	1
2%	142.69±1.09(0.77%*err*)	7.01±0.054	1
1%	101.13±2.20(2.17%*err*)	9.9±0.22	1
0.5%	32.37±0.36(1.12%*err*)	31.0±0.34	1
0.25%	14.70±0.24(1.61%*err*)	68.0±1.11	0.18
0.125%	4.85±0.090(1.84%*err*)	206±3.824	1
0%	1.31±0.030(2.10%*err*)	763±17.48	0.16
gly	30.40±0.34(1.11%*err*)	33.0±0.37	1
unknown %	14.87±0.40(2.63%*err*)	67.2±1.81	0

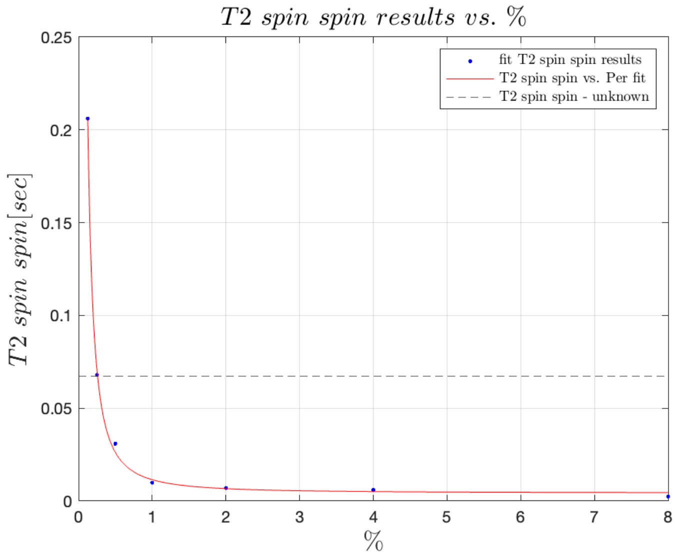


Fig. 16. T2 vs ions % results power fit

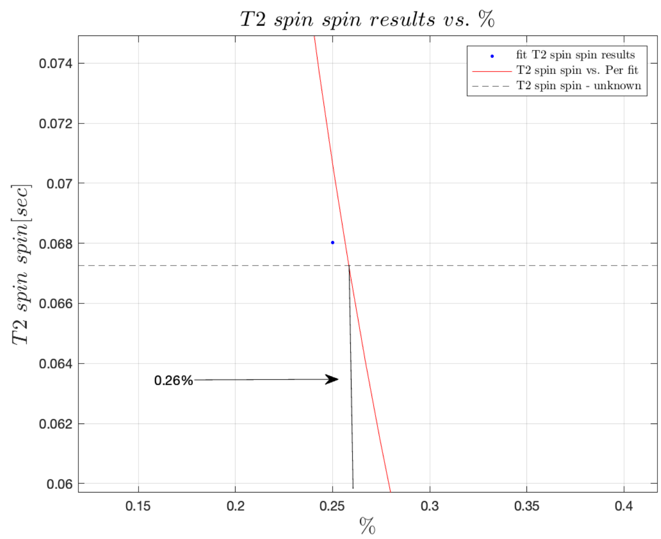


Fig. 17. T2 vs ions % results power fit zoomed

fitting function:

$$a*x^b+c$$

Power Result:

$$b=-1.60\in(-1.80,-1.40)$$

D. CPMG vs. CP 8% sample

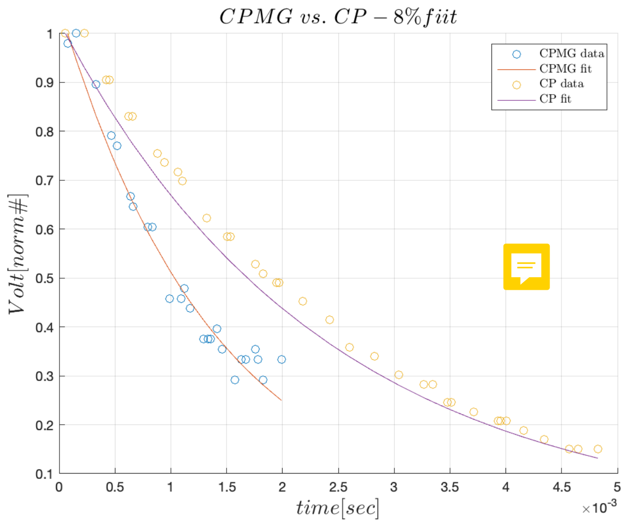


Fig. 18. CPMG vs. CP - T2 spin spin results

TABLE IV
CPMG vs. CP T_2 *spinspin Results*

Method	b	$T_2[msec]$	P-prob
CPMG	$425.27\pm3.6(0.85\%err)$	$2.35\pm0.02(0.85\%err)$	1
CP	$724.65\pm36.2(5.00\%err)$	$1.3\pm0.069(5.3\%err)8$	1

E. T_2^*

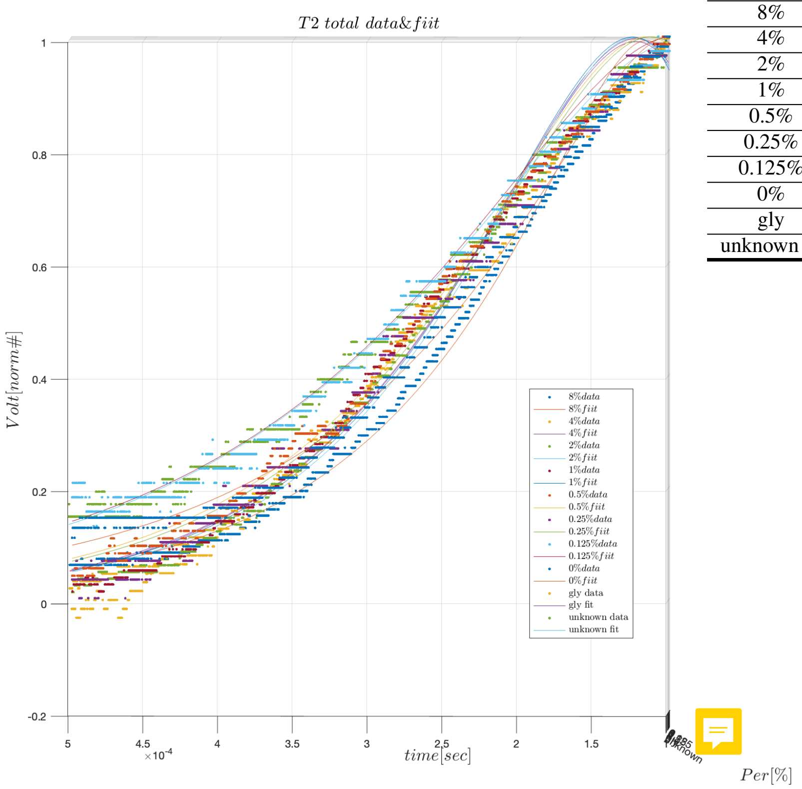


Fig. 19. T2* Volt vs. time

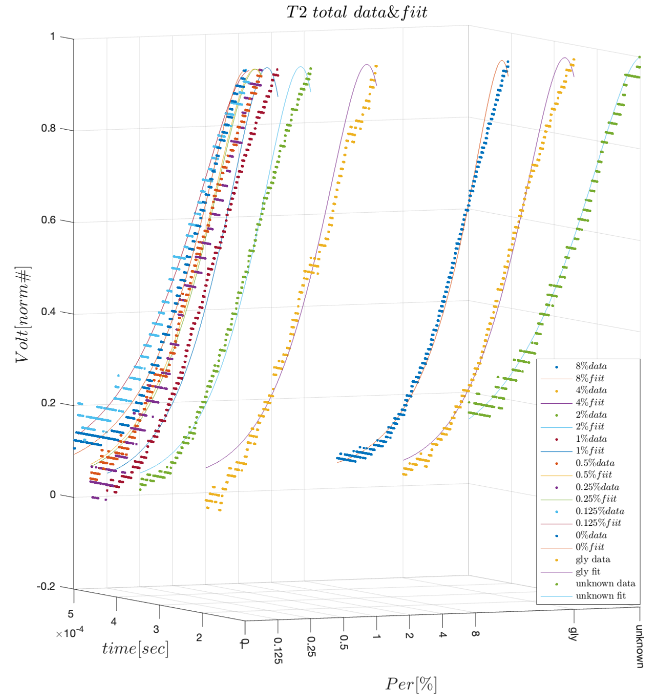


Fig. 20. T2* Volt vs. time vs. sample %

TABLE V
T_2^* *Results*

fitting function: $a*\exp(-b*(t-c))(1-\exp(-d*(t-c))$			
Sample	**b**	$T_2[\mu sec]$	**P-prob**
8%	$8218.4\pm41.87(0.51\%err)$	$1.22\pm0.0062(0.51\%err)$	1
4%	$11746.0\pm6687(57\%err)$	$0.85\pm0.48(56\%err)$	1
2%	$11664.0\pm1919(16\%err)$	$0.857\pm0.14(16\%err)$	1
1%	$11740\pm2648(23\%err)$	$0.852\pm0.19(23\%err)$	1
0.5%	$10094.6\pm867.6(8.6\%err)$	$0.991\pm0.085(8.6\%err)$	1
0.25%	$11083\pm6031(54\%err)$	$0.903\pm0.48(53\%err)$	1
0.125%	$6460.3\pm148(2.3\%err)$	$1.550\pm0.035(2.3\%err)$	1
0%	$6631.6\pm59.5(0.9\%err)$	$1.510\pm0.014(0.9\%err)$	0
gly	$10795\pm1050(9.7\%err)$	$0.926\pm0.090(9.7\%err)$	1
unknown %	$6315.2\pm121.5(1.9\%err)$	$1.584\pm0.03(1.9\%err)$	1

V. CONCLUSIONS

A. gyro constant

The gyro constant is found to be constant in the samples and corresponds with the theoretical value for protons. N-sigma value is 1.8 that in the range of 3. from that we have a statistical definite and the gyro magnetic constant that found in the experiment statistically mach the theory. we can see that the group of result are consecrated with some distance from theory from fig(9), the reason can be a systematic error, we find the most probabilistic such error a difference between the magnetic field that the sensor measured to the magnetic field that the sample "feels", the sensor measured the field and the sample in a sense do the same in the measurement of the geomagnetic constant than the systematic error can be the direct differences in the materials, for example a iron measurements will have a smaller systematic error because its similar to the sensor material.

B. T_1 and T_2 spin spin

T1 and T2 spin spin values goes asymptotic to the value of pure water. Since the result has a p-Prob value that does not represent a statistical definite we discuss in a asymptotic discussion, in the asymptotic matter the results are asymptotically corresponding to the theory and show that in that experiment we can understand the NMR behavior with respect to T1 and T2 spin spin times but we CAN'T get an statistical observation about the samples.

C. Comparison between CPMG and CP

Comparison between CPMG and CP methods show a T2 spin spin time shorter in CP method. The results show the CP method problem with 180 un-ideal pulse, the 180 pulse was generated manually and was very sensitive to human errors and can be said confidently that the pulse was not exactly 180 pulse, in that matter we can learn how much the pulse that was given was not ideal. The results is shown to be more accurate with the CPMG method as used in the experiment.

D. T_2*

$T2*$ relaxation time found to be non distinguish from the samples. The in-homogeneous relaxation time found to be the dominant factor of the relaxation time $T2*$ in general and in particular with the dependence of the ions percentages depends. from that we found that the physical knowledge that we can learn from T_2* experiment in our machinery is very limited, in theory this kind of measurement in the experiment can help the researcher in the knowledge of the in-homogeneous of the experiment magnet, but since the resolution of the noise and the scale difference we found from T_2 spin spin to T_2* fitting to find the in-homogeneous was a failure and deliver a non physical results. From that T_2 *spin spin* was the relaxation time that gives the physical value. In a sense T_2* measurement with the understanding that a gradient measurement of the difference in the magnetic field in the system are harder then the experiment himself bring to the understanding that T_2 *spin spin* its the phenomena that a researcher should focus on from a pure physical view with that setup.

E. The unknown ions percentage

sample found from the power fit to T1 and T2 spin spin, the experiment's result that was found to correspond strongly to the ions percentage. The interval of the ions percentage values estimated in the range $(0.26, 0.48)$ with a 10% error margin

F. The glycerin sample

found to be distinguished in the fit for T_2 *spin spin* and T_1 by not fitting the ions percentage in the sample. The glycerin has a higher viscosity than water that can be explained in the connection between the viscosity diffusion and relaxation time. assuming a movements of the spins that correspond to there magnetization direction a statistical movement of a high viscosity material are slower, and more sensitive to a gradient in the magnetic field, the sample movement/position in not averaging like water or another low viscosity material.

G. Asymptotic vs. statistic discussion

motivation:
Human errors factors in the measurements:
The experiment relies on human measurements. The pulses, larmor frequency, voltages are measured not only by machines. In that matter a lot of undefined errors are collected in the measurements of human errors.

A noisy data:

Because the scale of the voltages involved in the phenomena are in the scale of the measurement tools noise in relent intervals of the experiment they are "invisible" in that matter a intervals with a lot of physical information are immeasurable i.e Volt=0 area for T1 part. in the residuals plot in appendix we can see that the values of errors are in the range of the small voltage signals in T_1 part for example.

Fitting:

T2* depends on the experiments in capacitor time constant, which makes the problem a problem of 4 free parameters. The fitting functions and curve fitting tools were found to not deliver a good fit as we can see from the fits in fig(20) the fit not follow the data correctly, even after taking smaller intervals of the data with less complex functionality shown in the data. We found that the theoretical representation of the capacitor is not correct, the time that the capacitor is charged and discharging is not corresponding to the real physical phenomena measured, in that a more complex theoretical fit needs to be made, and that the complexity of the fitting will also increase. In that sense we find that a measurement tool with a capacitance charge/discharge time that can't be neglected can deliver asymptotic fit only as we seen in fig(19,20) and the residuals in appendix that have a tendentious that correspond to a miss fit.

From the above reasons all the fittings have a Pprob values that do not deliver a statistically significant and the discussion is in the asymptotic.

VI. APPENDIX

A. Data analysis

- In every measurement that the acquired data value of steady state (large time) was not zero the data was manipulate in a way that the data at the zero theoretical value of the signal will correspond to the zero in the measurements, set a reference frame.
- as the noise was the dominant factor of the errors in the sample, it was measured and was taken as a "effective resolution" of the Lab machines in the errors calculation.
- To make the fitting function less sensitive to a different time reference a parameter of "time movement" as set to the fitting functions as $(t-c) = t_{eff}$.
- Where the data was not clear enough the sample as been neglected.
- in the power fitting the power let to be different from -1, as we found the connection of the power -1 be approximation.
- Since a Gain manipulations as been made in the experiment, to help in the visualization of the data in the lab. a normalization as been made in the comparison fit and representation parts mainly in T_2*
- T_1 data for 0% sample was not physical, this part of the experiment is in another method from another samples and the time for measurement wasn't enough to measure that sample properly

1) T_1 : The data required as a Volt vs Tau measurements points approx' 25 Tau values for each sample. a High peak of the pulse and the response peak is in the data points. from every measurement we take the maximum value with MATLAB tools. in the area that the wanted peak is close to zero we didn't take the measurement because its too sensitive to human error. for that reason we sampled a relativity large sample of measurements. to find the fitting initial values a use in fitting curve tools gave a initial values to the fitting theoretical values and than the final fitting as made with EDDINGTON tool.

2) T_2 spin spin : The data required as a Volt vs time measurements points. for every sample the peaks as found with MATLAB tools. the number of peaks as taken to cover the range of decrees in the samples as large is possible, but with caution to not take noise peaks in the area of the small peaks. to find the fitting initial values a use in fitting curve tools gave a initial values to the fitting theoretical values and than the final fitting as made with EDDINGTON tool.

3) T_2* : The data required as a Volt vs time measurements points. to "help" the curve fitting tools the data where cut in a range where the phenomena we look to fit is the dominant, not in times close to zero where the Volt values are increasing. the fitting function had a limited curvature possibility, the only functions that made a good fit was functions that depends on a high number of parameters like a sine sum with a lot of elements, the number of elements made it over fitting and impossible to connect the parameters to the physical phenomena.

B. Fitting

T_1

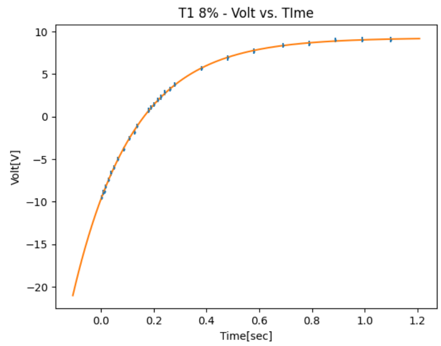


Fig. 21. T1 fit for 8% sample

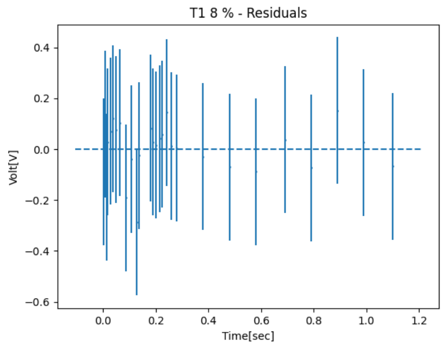


Fig. 22. T1 residuals for 8% sample

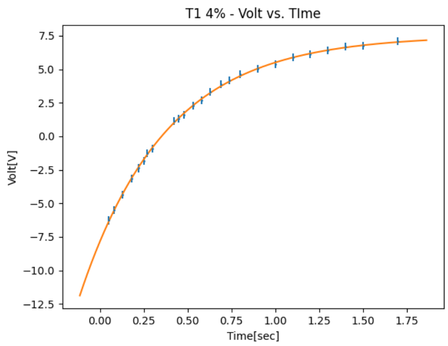


Fig. 23. T1 fit for 8% sample

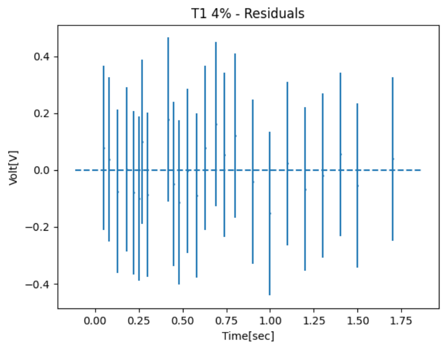


Fig. 24. T1 residuals for 8% sample

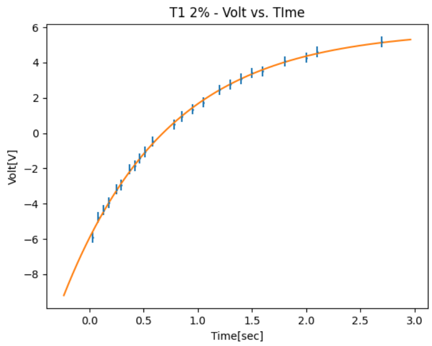


Fig. 25. T1 fit for 8% sample

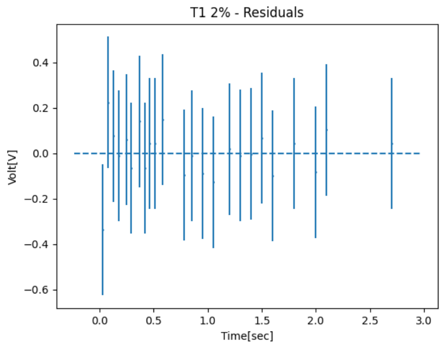


Fig. 26. T1 residuals for 8% sample

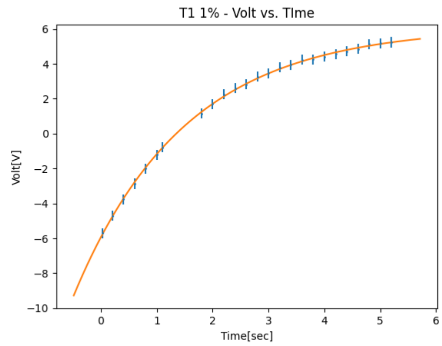


Fig. 27. T1 fit for 8% sample

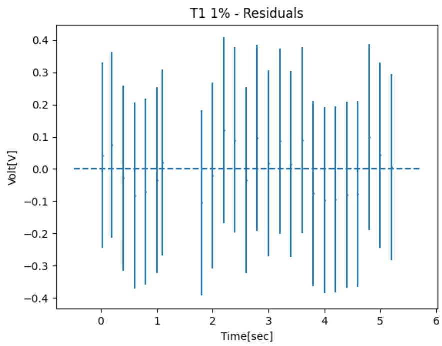


Fig. 28. T1 residuals for 8% sample

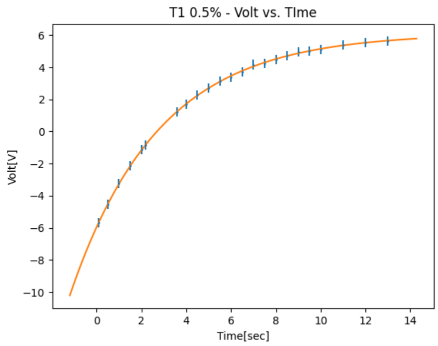


Fig. 29. T1 fit for 8% sample

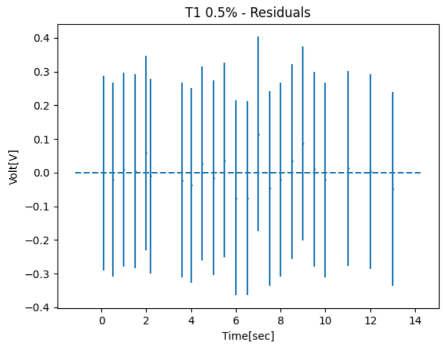


Fig. 30. T1 residuals for 8% sample

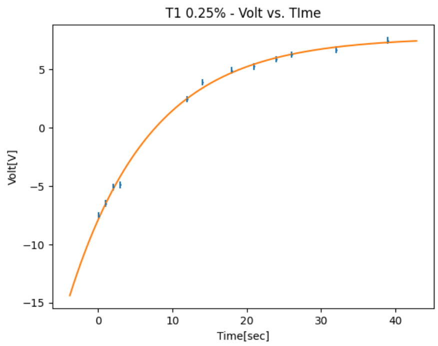


Fig. 31. T1 fit for 8% sample

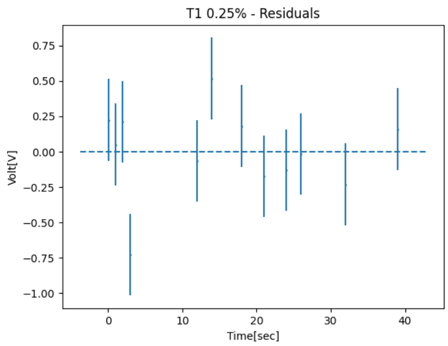


Fig. 32. T1 residuals for 8% sample

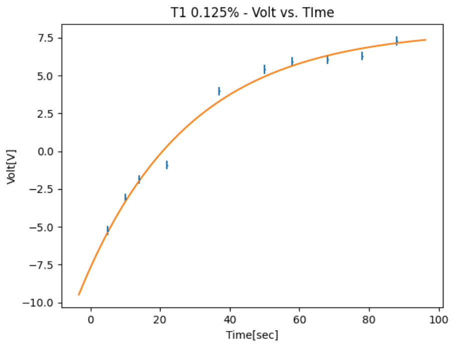


Fig. 33. T1 fit for 8% sample

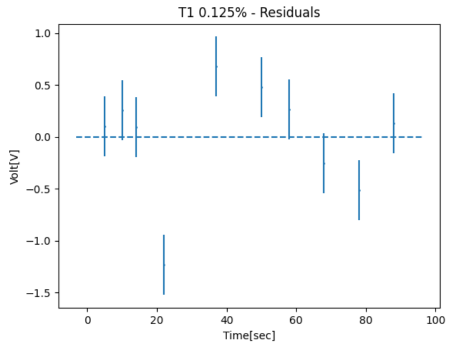


Fig. 34. T1 residuals for 8% sample

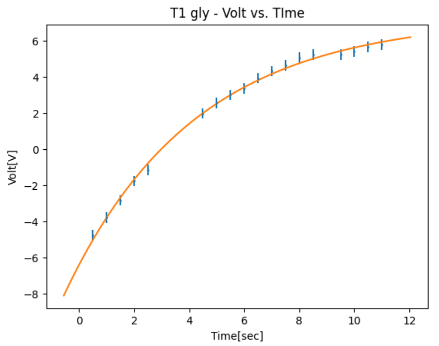


Fig. 35. T1 fit for 8% sample

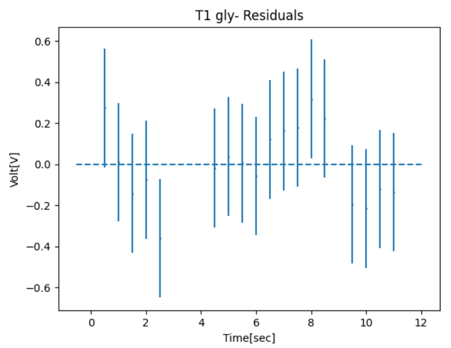


Fig. 36. T1 residuals for 8% sample

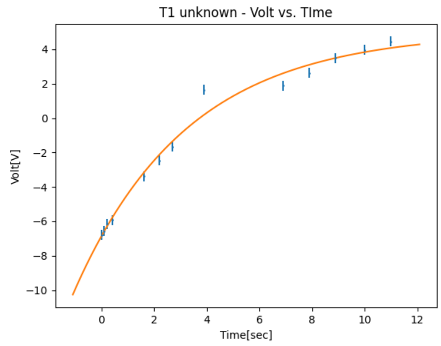


Fig. 37. T1 fit for 8% sample

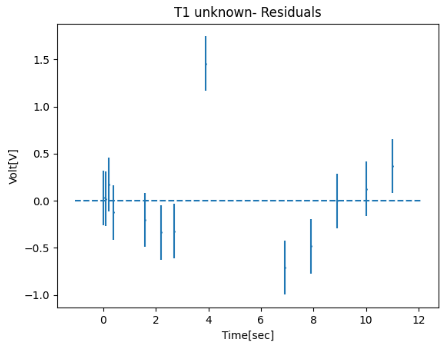


Fig. 38. T1 residuals for 8% sample

T2 spin spin

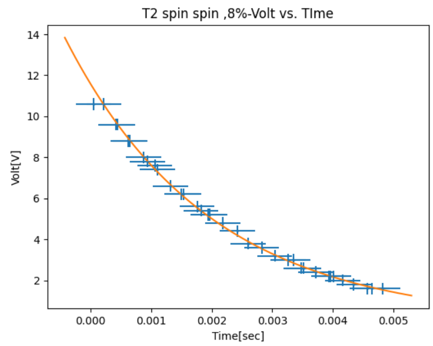


Fig. 39. T2 spin spin fit for 8% sample

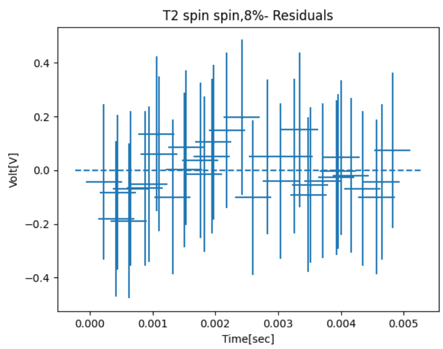


Fig. 40. T2 spin spin residuals for 8% sample

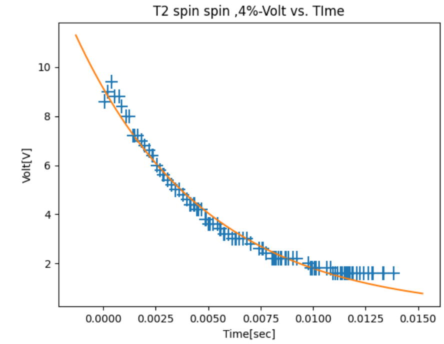


Fig. 41. T2 spin spin fit for 4% sample

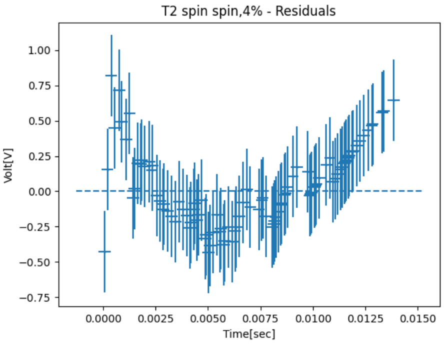


Fig. 42. T2 spin spin residuals for 4% sample

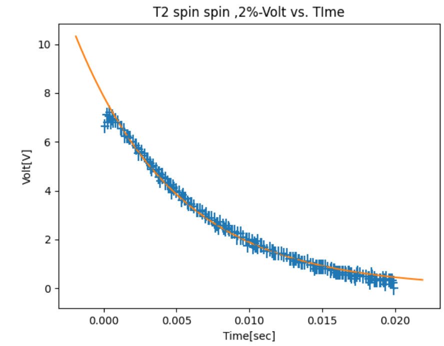


Fig. 43. T2 spin spin fit for 2% sample

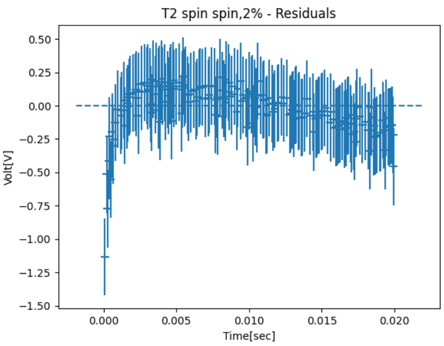


Fig. 44. T2 spin spin residuals for 2% sample

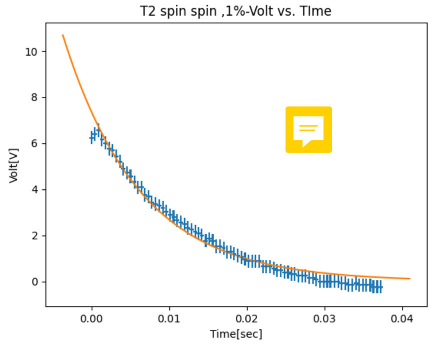


Fig. 45. T2 spin spin fit for 1% sample

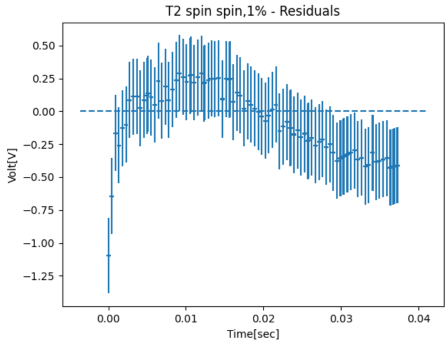


Fig. 46. T2 spin spin residuals for 1% sample

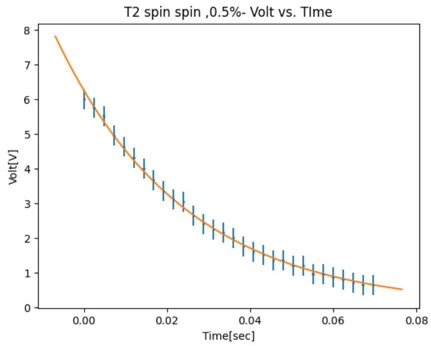


Fig. 47. T2 spin spin fit for 0.5% sample

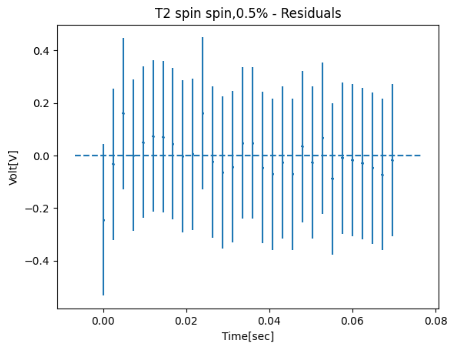


Fig. 48. T2 spin spin residuals for 0.5% sample

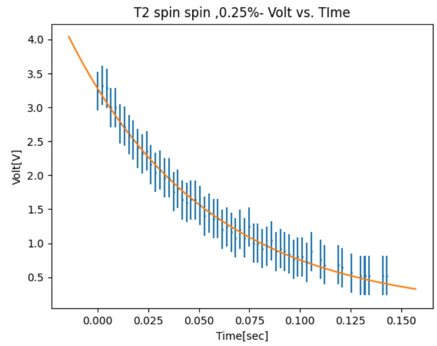


Fig. 49. T2 spin spin fit for 0.25% sample

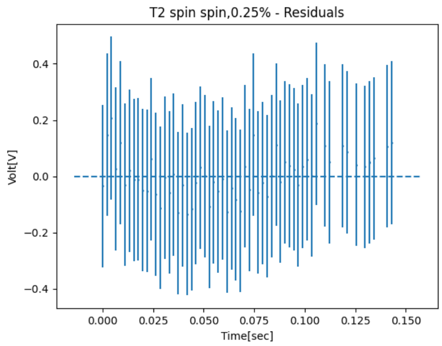


Fig. 50. T2 spin spin residuals for 0.25% sample

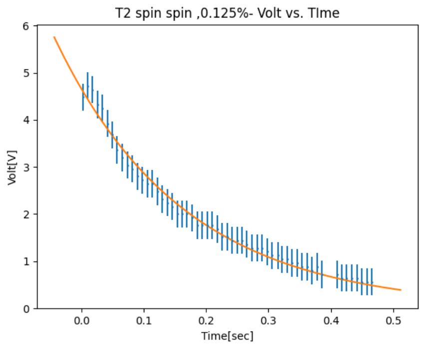


Fig. 51. T2 spin spin fit for 0.125% sample

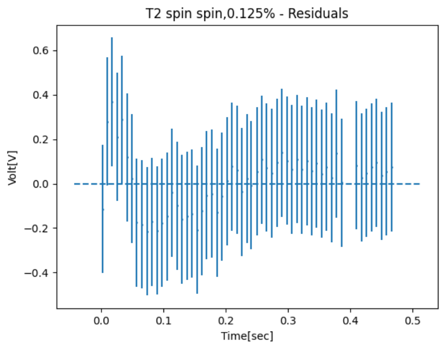


Fig. 52. T2 spin spin residuals for 0.125% sample

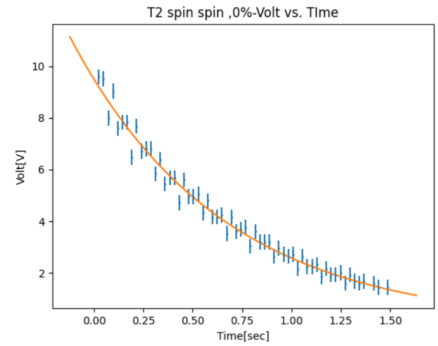


Fig. 53. T2 spin spin fit for 0% sample

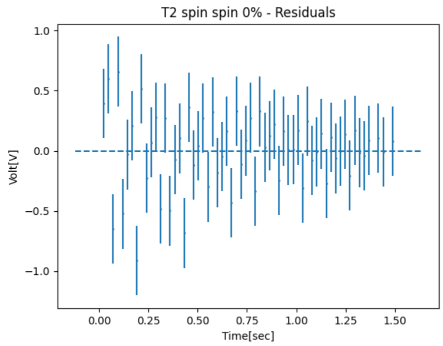


Fig. 54. T2 spin spin residuals for 0% sample

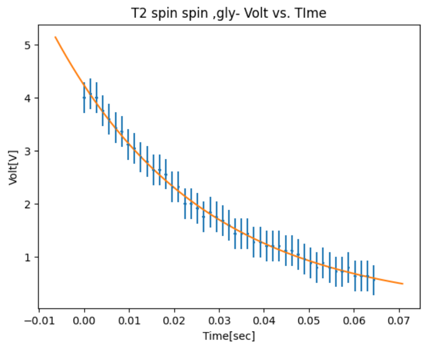


Fig. 55. T2 spin spin fit for gly sample

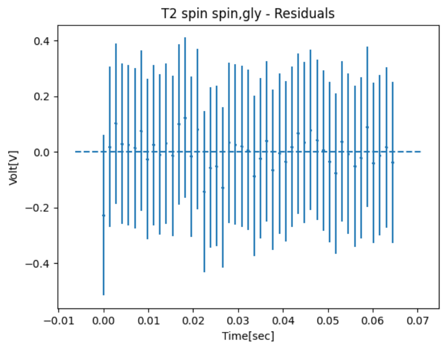


Fig. 56. T2 spin spin residuals for gly sample

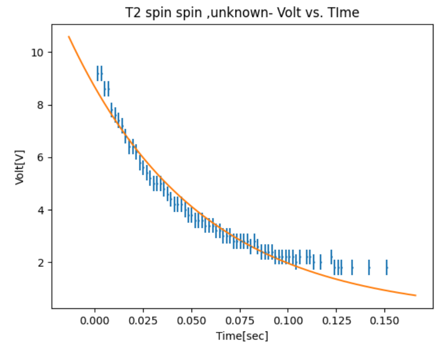


Fig. 57. T2 spin spin fit for unknown % sample

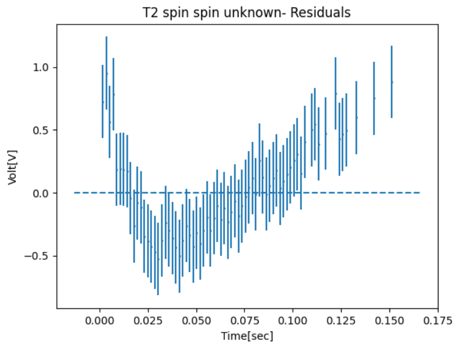


Fig. 58. T2 spin spin residuals for unknown % sample

T2 spin spin CP

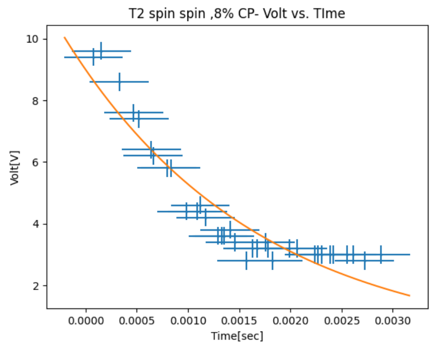


Fig. 59. T2 spin spin fit for 8% sample in CP method

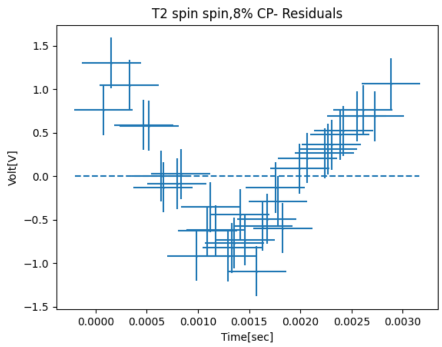


Fig. 60. T2 spin spin residuals for 8% sample in CP method

C. T_2^*

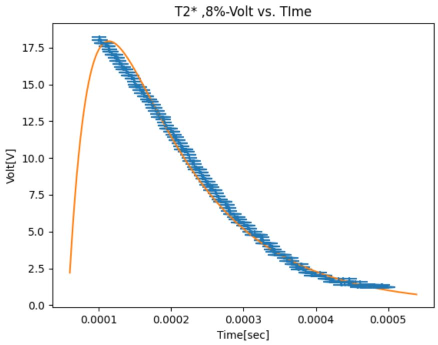


Fig. 61. T2* fit for 8% sample

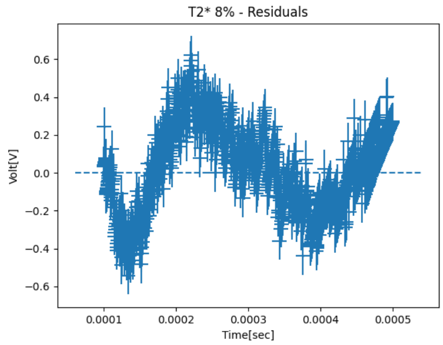


Fig. 62. T2* residuals for 8% sample

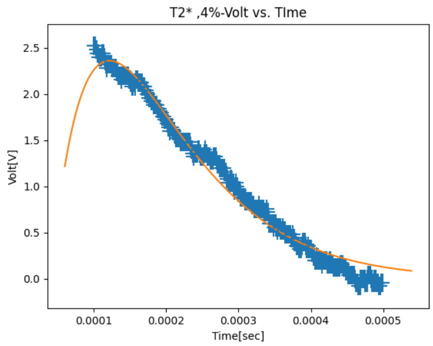


Fig. 63. T2* fit for 4% sample

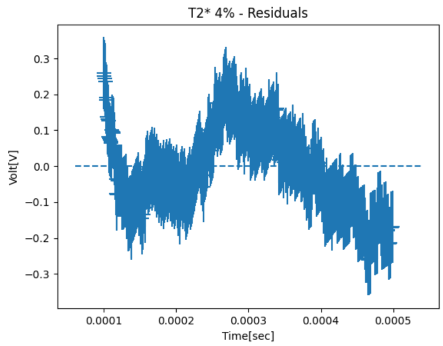


Fig. 64. T2* residuals for 4% sample

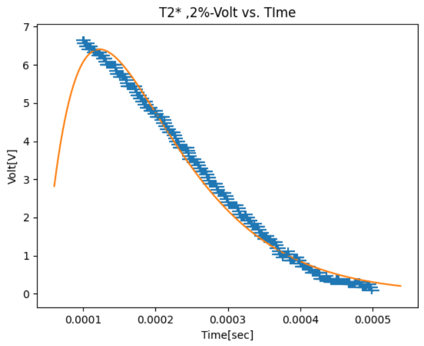


Fig. 65. T2* fit for 2% sample

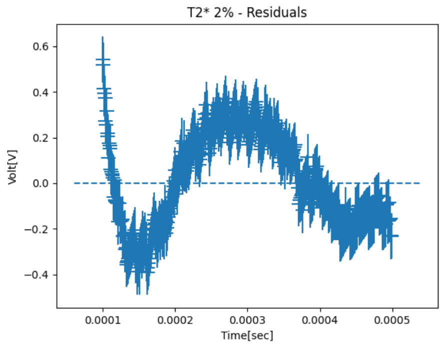


Fig. 66. T2* residuals for 2% sample

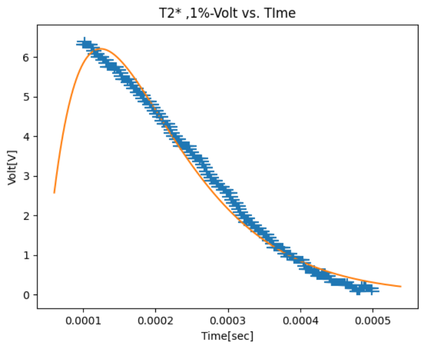


Fig. 67. T2* fit for 1% sample

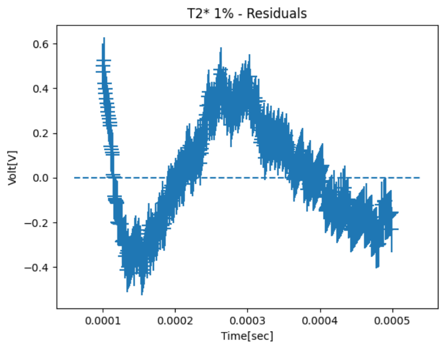


Fig. 68. T2* residuals for 1% sample

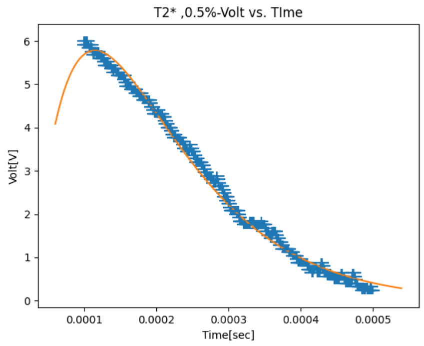


Fig. 69. T2* fit for 0.5% sample

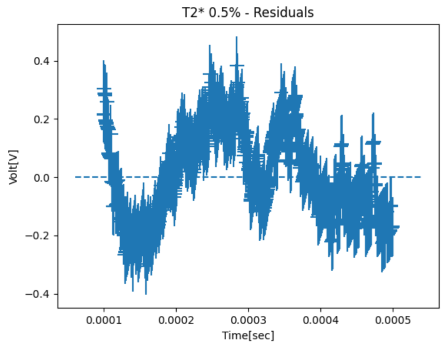


Fig. 70. T2* residuals for 0.5% sample

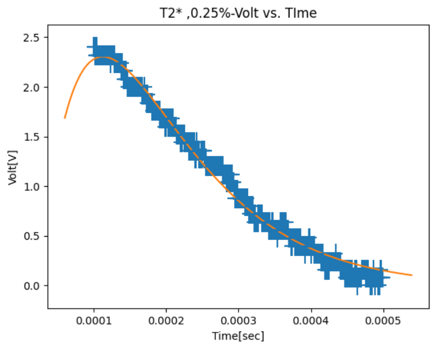


Fig. 71. T2* fit for 0.25% sample

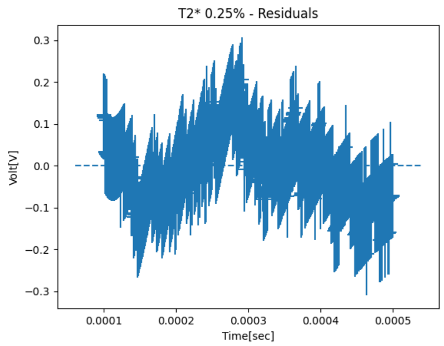


Fig. 72. T2* residuals for 0.25% sample

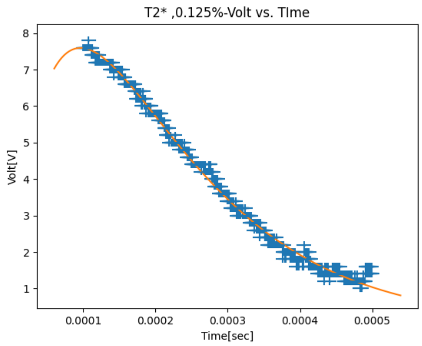


Fig. 73. T2* fit for 0.125% sample

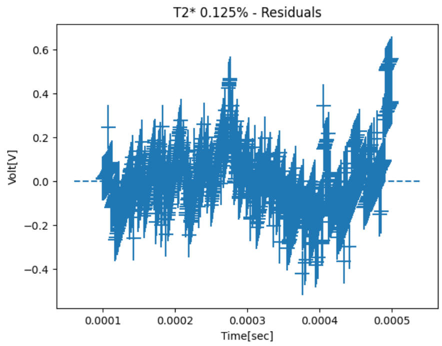


Fig. 74. T2* residuals for 0.125% sample

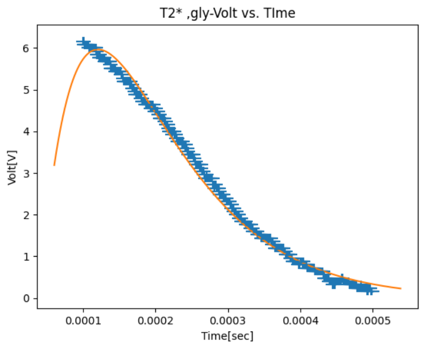


Fig. 75. T2* fit for gly sample

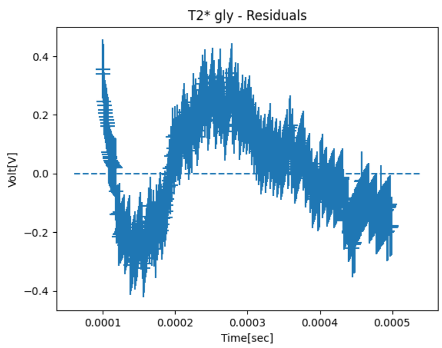


Fig. 76. T2* residuals for gly sample

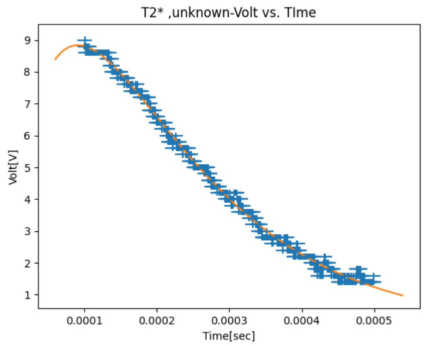


Fig. 77. T2* fit for unknown % sample

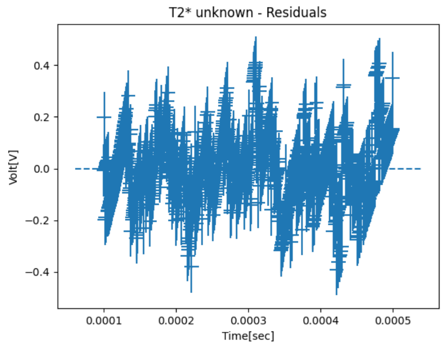


Fig. 78. T2* residuals for unknown % sample

D. MRI Presentation

MRI

Setup

Magnet -

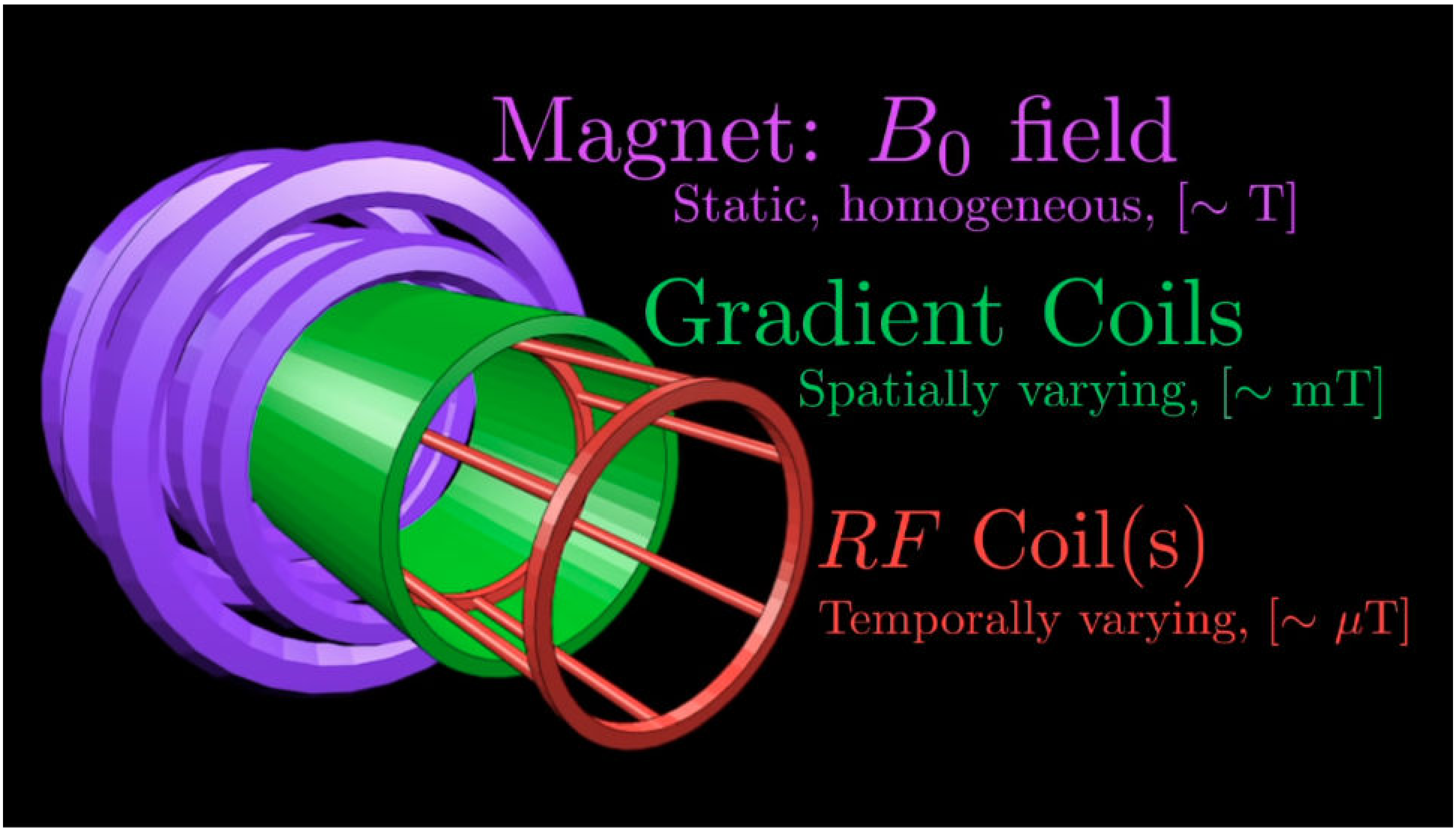
constant magnet field - as in our experiment

Gradient coils -

help us to distinguish between (X, Y, Z) tissues

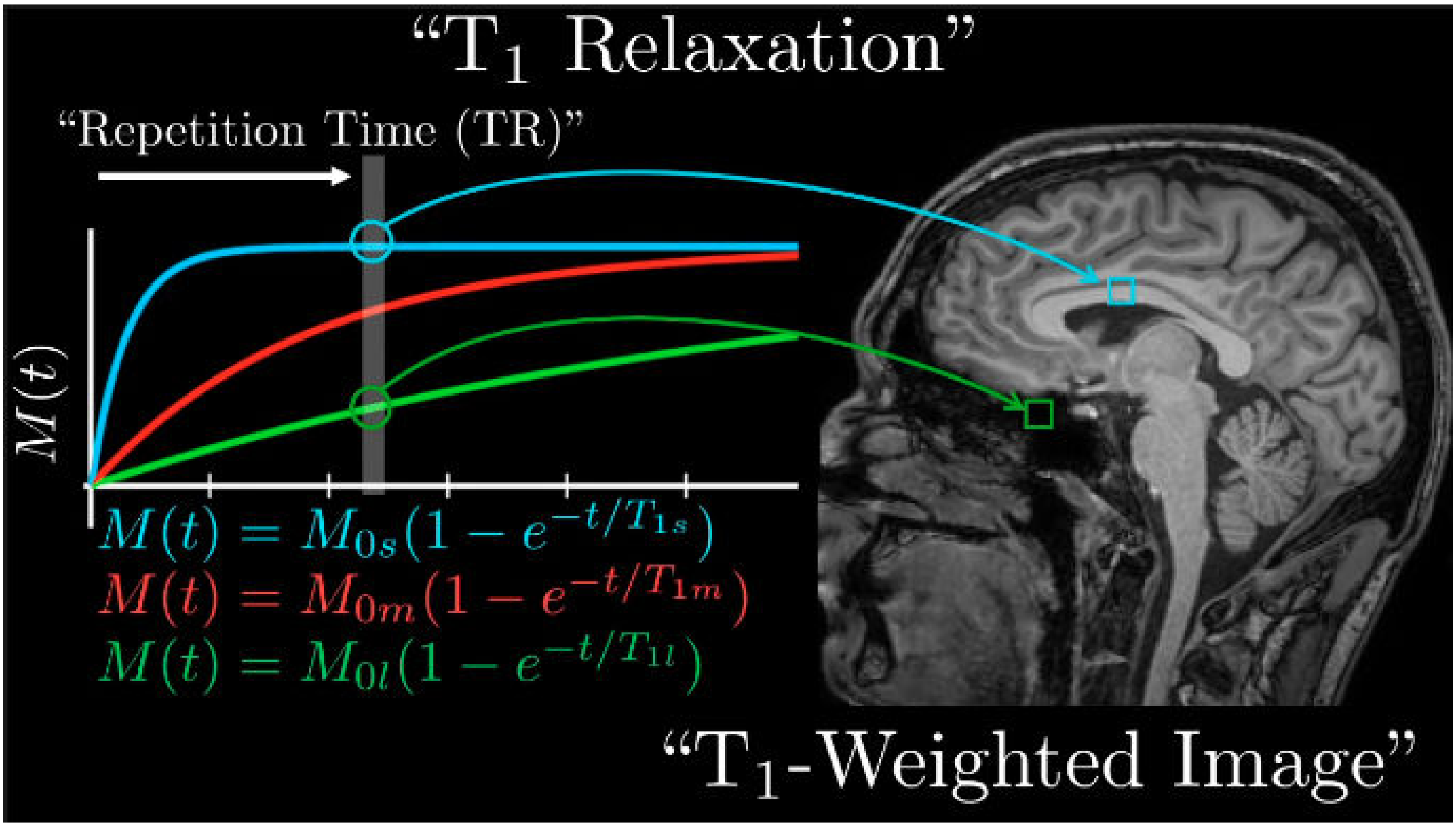
RF Coil(s)-

Pulses generators



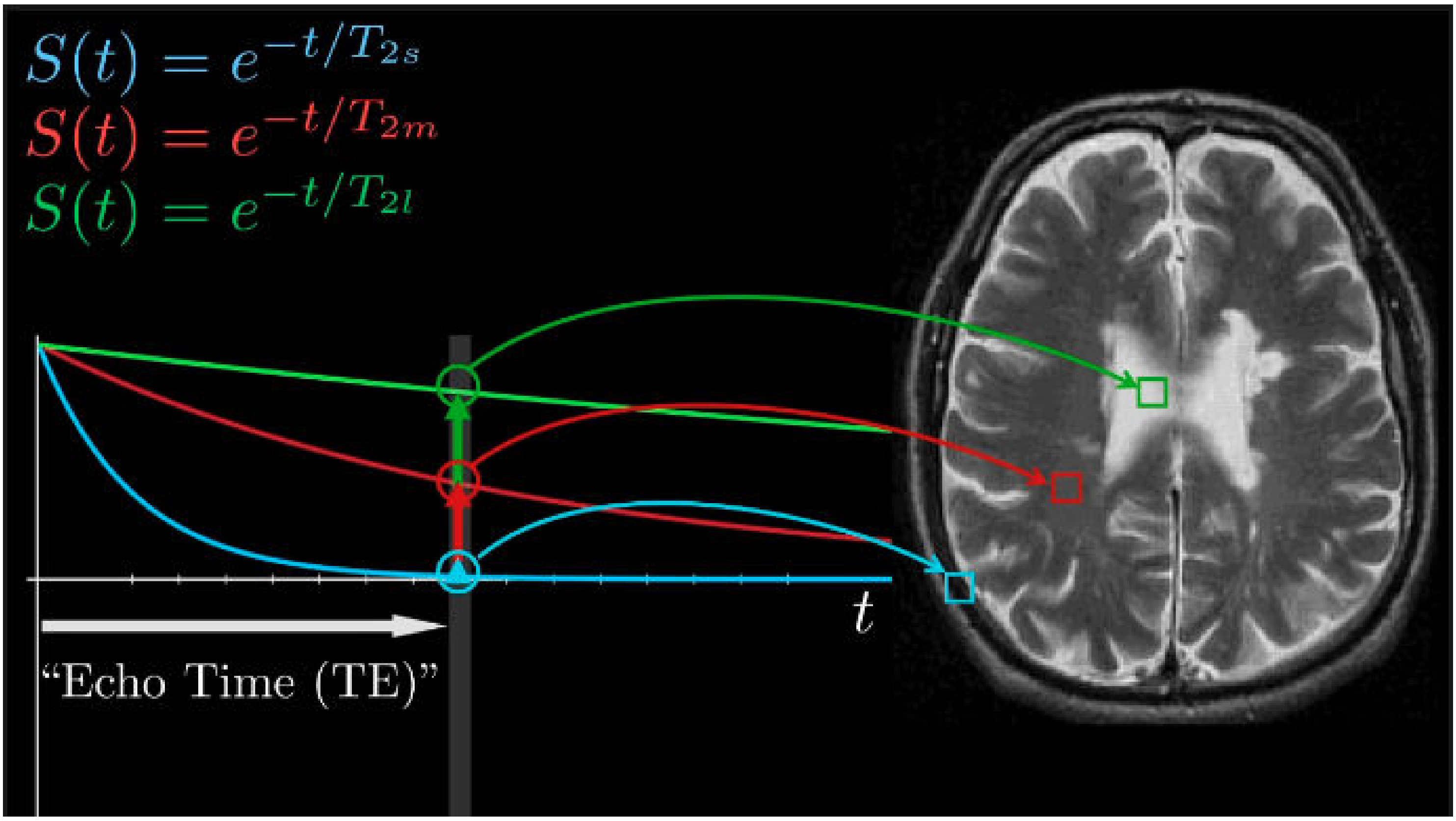
T1 Relaxation time

the time that we acquire the signal distinguish the tissues signal power, and corresponded to the TR time that we chose

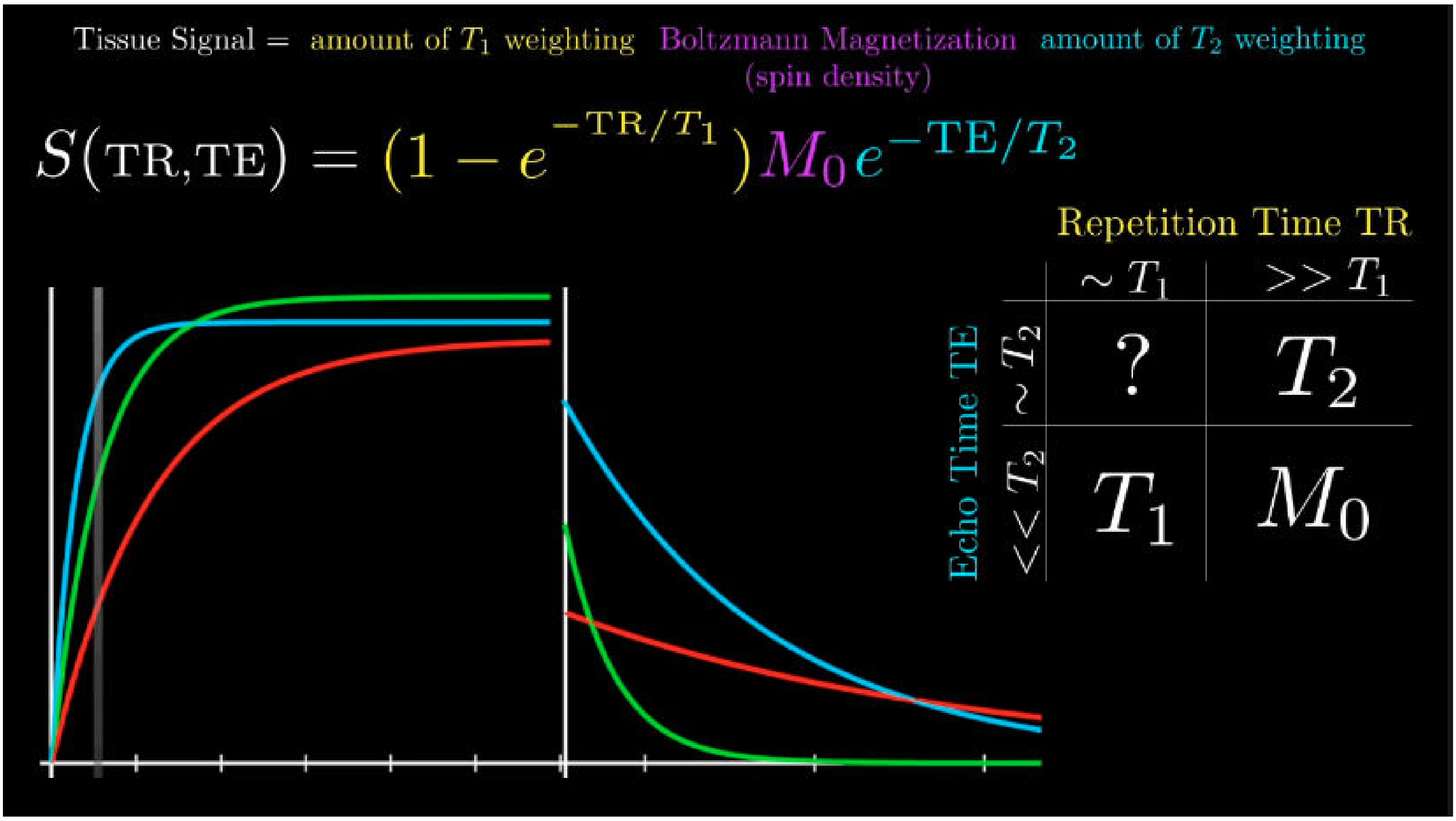


T2 Relaxation time

constant make the signal distinct from sample to sample and the echo time will correspond to the contract in the imaging



Along with the Magnetization equilibrium value that depends on the number of protons in the tissue we can chose the contract of the imaging by the organ.



we can take the T1 results and lock for glycerin for example, assuming that the viscosity is a negative result in an MRI

we will take the sample piece and normalized it to 0-1 range grey image. Let assume that glycerin is 0.3 T1 or T2 or M0 in the method we chosen.

we build a strip of tissues:

```
T=readmatrix("ima_table.xlsx")
```

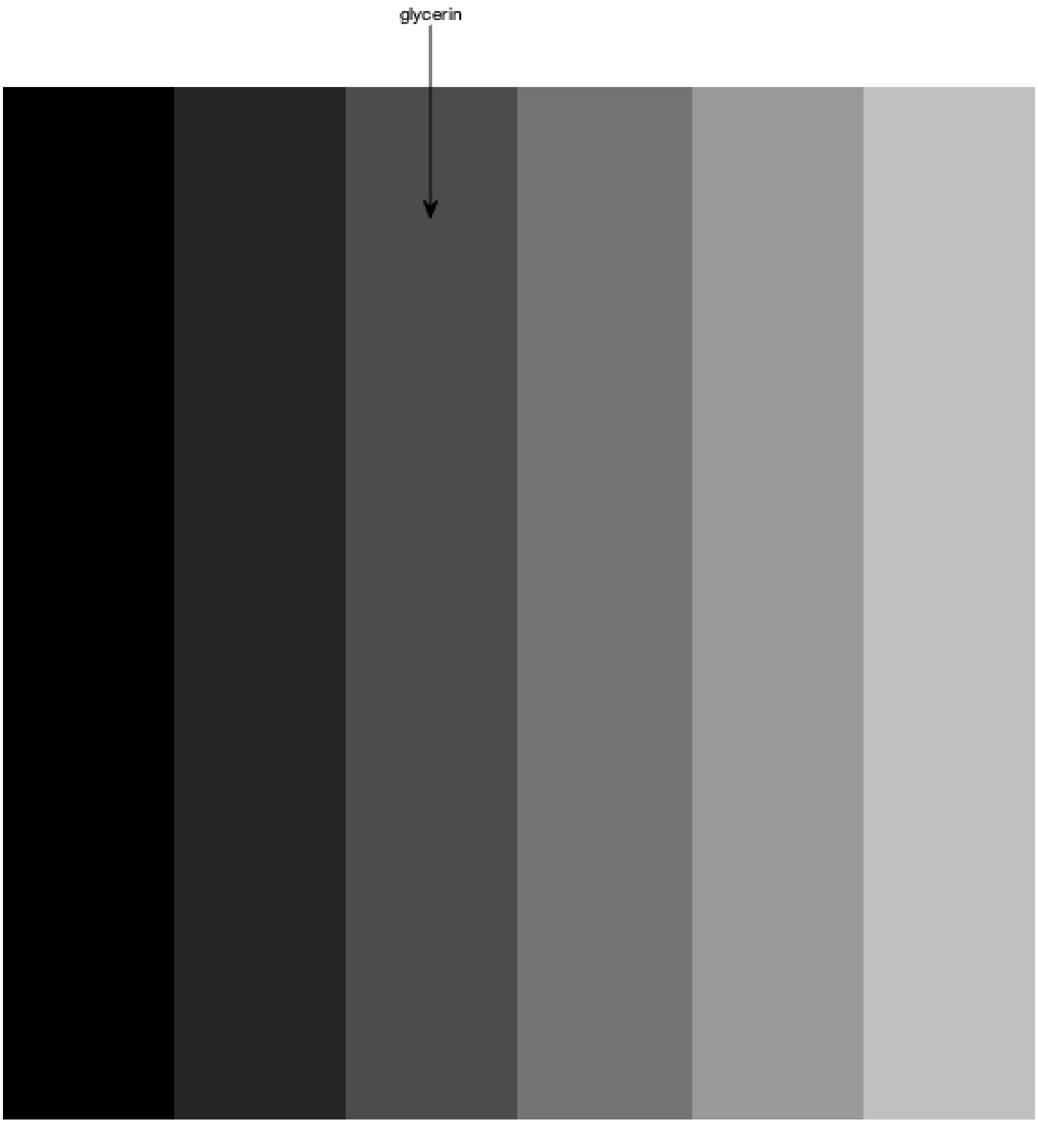
T = 36×36

0	0	0	0	0	0	0.1500	0.1500	···
0	0	0	0	0	0	0.1500	0.1500	
0	0	0	0	0	0	0.1500	0.1500	
0	0	0	0	0	0	0.1500	0.1500	
0	0	0	0	0	0	0.1500	0.1500	
0	0	0	0	0	0	0.1500	0.1500	
0	0	0	0	0	0	0.1500	0.1500	
0	0	0	0	0	0	0.1500	0.1500	
0	0	0	0	0	0	0.1500	0.1500	
0	0	0	0	0	0	0.1500	0.1500	
⋮								

```
% T = filter2(fspecial('sobel'),T);
% T=mat2gray(T)
```

```
figure
imshow(imread('scale.png'))
set(gcf,'position',[0,0,1000,1000])

annotation("textarrow",[0.4375 0.4375],[0.9303 0.7963],"String","glycerin")
```

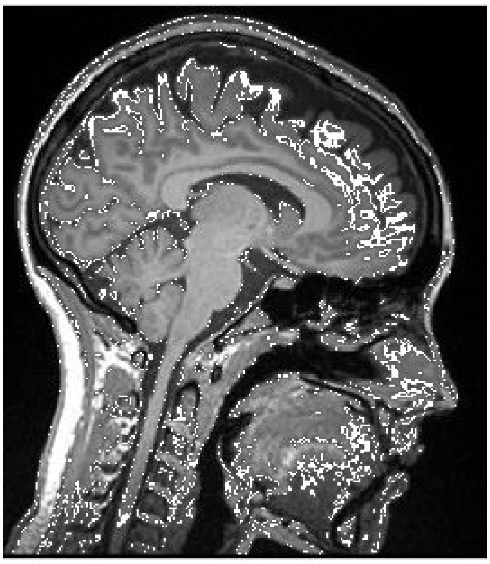


Now we can look for Gly in someone Brain MRI scan:

```
imdata1 = imread('MRI_BRAIN_SCAN.jpg');
```

```
imdata1 = mat2gray(imdata);
imdata2 = mat2gray(imdata);
imdata2(imdata2<0.37 & imdata2>0.33)=255;

figure
subplot(1,2,1)
imshow(imdata2)
subplot(1,2,2)
imshow(imdata1);
set(gcf,'position',[0,0,1000,1000])
```



BIOGRAPHIES

1. R. L. Dixon and K. E. Ekstrand, The physics of proton NMR.

2. J. P. Hornak, The basics of NMR, chapters 3-4,6.