Module 6 - Answers

Observation Experiment: T_2 Relaxation - Guided Inquiry Questions

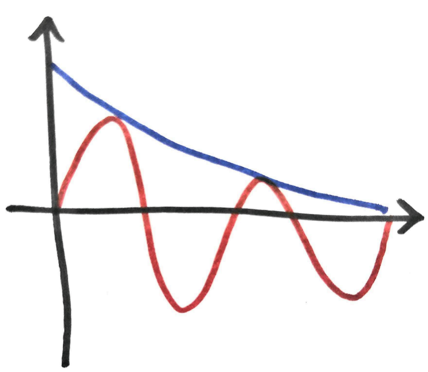
1. First, let's initialize our spin state and then knock the spins down into the x-y plane using a hard-90° pulse. Is there any MR signal decay? Explain how you came to your conclusion.

   No signal decay because the magnitude of the net nuclear magnetization vector stays constant, so $|M_{xy}|$ stays constant.

2. In the upper-left menu, click on 'Relaxation: Off', and you can see that both 'T1' and 'T2' are set to infinity. Why is having both 'T1' and 'T2' set to infinity the same as having the relaxation turned 'off'?

   Because the time constant is related to the time it takes for the signal to decay, if the signal never decays, then it takes an infinite amount of time to decay.

3. Now change the 'T2' value to some finite value (while leaving 'T1' at infinity). Describe what happens to the net nuclear magnetization vector, $\vec{M}$, and sketch the resulting plot of $|M_{xy}|$ and M_x.



As the T_2 values are set to a finite value, the magnetization vector cylinder gets shorter and shorter over time, showing the magnitude decreasing, so M_x and $|M_{xy}|$ decrease over time.

4. Describe how T_2 relaxation appears to cause the MR signal to decay.

This material is based upon work supported by the National Science Foundation under award DUE-2120545. Making Nuclear Magnetic Resonance Resonate With Students: Integrating NMR Into the Undergraduate Science Curriculum,

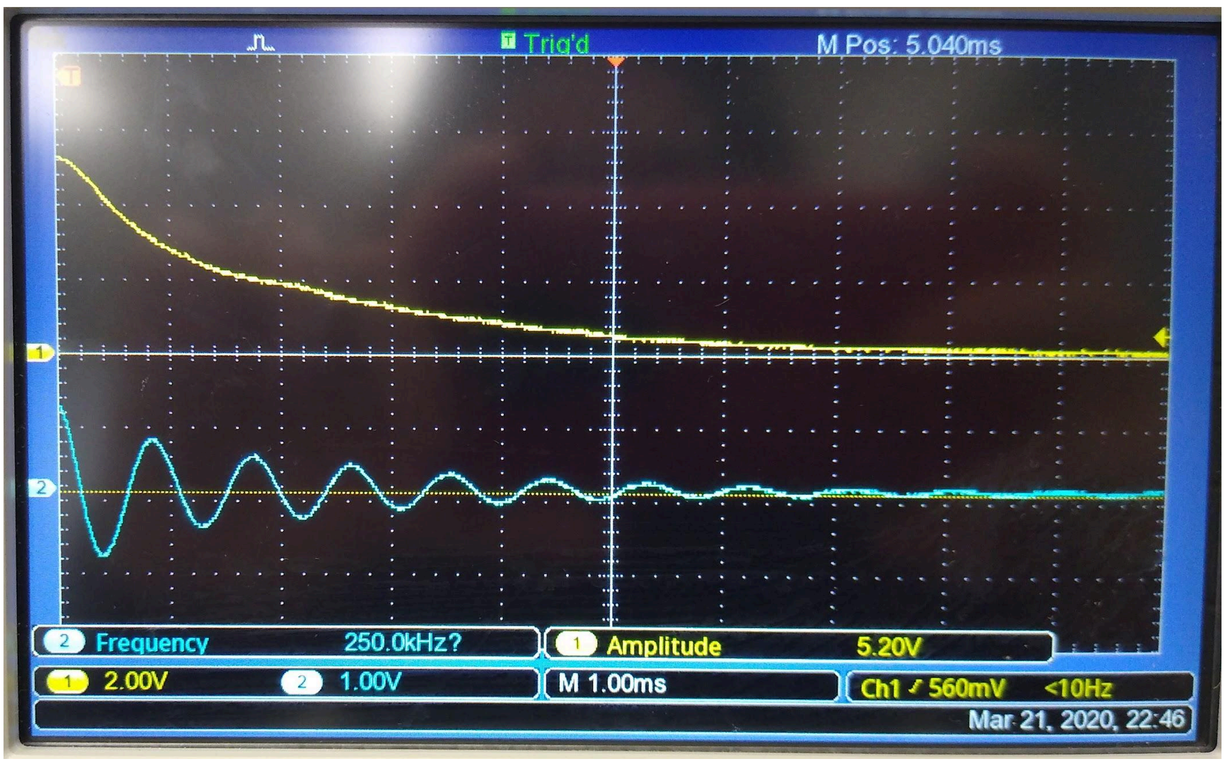
The T2 relaxation is primarily caused by the magnitude of the magnetization vector, |M|, decreasing over time, which causes M_x and $|M_{xy}|$ to also decrease over time.

*Recall what you saw in the last module when you added inhomogeneities, where the different spins would have slightly different precession frequencies and get more and more out of phase, causing the total magnetization vector magnitude to decrease. This suggests maybe some sort of dephasing of the spins is happening here as well!

5. Given the description of what causes T_2* relaxation versus T_2 relaxation, which do you think is always the larger value, T_2 or T_2*? Why?

   T_2 will be the larger value (slower decay) because if you add inhomogeneities in the applied field (on top of local magnetic field differences), you would be adding more dephasing and more decay, thus causing a shorter T_2*.

6. Below is some FID data acquired from a mineral oil sample in a 0.5-Tesla magnetic field. What is the approximate T_2* value for this sample? *Hint: You want to find the time when the signal reaches 37% of its initial amplitude.*



This material is based upon work supported by the National Science Foundation under award DUE-2120545. Making Nuclear Magnetic Resonance Resonate With Students: Integrating NMR Into the Undergraduate Science Curriculum,

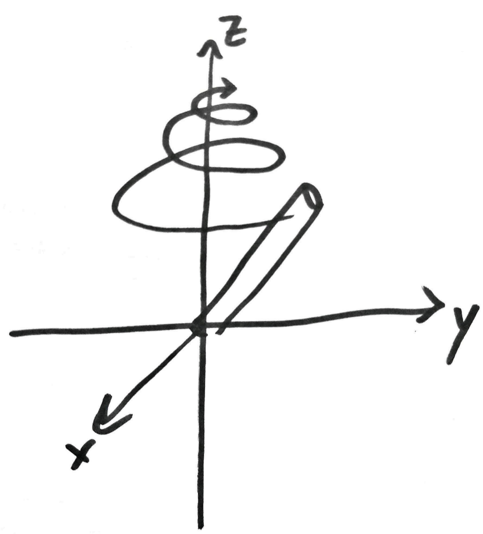
Looking for the time it takes for the signal to decay down to 5.20 V*0.37 ~1.924 V.
T_2* ~ 2.1 +/- 0.05 ms

7. If Sample A has a much longer T_2 time than Sample B, what can you say about the local magnetic environments of Sample A in comparison to Sample B?

   Since Sample A has a longer T_2 time, the signal is not decaying as quickly, so presumably Sample A has fewer differences in the local magnetic environments of the spins compared with Sample B.

Observation Experiment: T_1 Relaxation - Guided Inquiry Questions

8. Turn off relaxation (by setting 'T1' and 'T2' both to infinity), initialize the spin-state, and then knock the spins down into the x-y plane using a hard-90° pulse. Now change 'T1' to some finite value. Observe, sketch, and describe what happens.



The net magnetization vector stays the same size but starts spiralling back towards the z-axis (realignment with the applied magnetic field). The MR signal plotted still looks like an exponential decay, but this is now due to $|M_{xy}|$ getting smaller (as the M_z component increases).

9. You may have noticed that it is impossible to set 'T2' larger than 'T1'. This is not a bug in the simulator, but turns out to be a physical fact in MR experiments: $T_2 \leq T_1$. That means it may be difficult to fully disentangle the two from each other, but thinking about the difference in the spin dynamics compared with the T_2 relaxation observed above, how does T_1 relaxation contribute to the decaying MR signal ($|M_{xy}|$ and M_x)?

This material is based upon work supported by the National Science Foundation under award DUE-2120545. Making Nuclear Magnetic Resonance Resonate With Students: Integrating NMR Into the Undergraduate Science Curriculum,

T1 relaxation causes the spins to realign with the z-axis so that the net magnetization vector's xy components decrease.

10. If T_2 relaxation is also called transverse (xy) relaxation, what might be a good name for T_1 relaxation?

    Pick one that makes sense to you!

11. Given the description of what causes T_1 relaxation versus T_2 relaxation, why do you think the T_1 time is always longer than T_2?

    T_1 relaxation involves exchanging energy with the environment in order for spins to realign with the magnetic field and go back to the alpha state, so it makes sense that this would take longer than the T_2 process. The T_2 process also incorporates both local and external magnetic field inhomogeneities, leading to faster decay and a shorter time constant.

12. Describe the magnetic environment that would be necessary for T_2 to be equal to T_1.

    There would have to be no local magnetic environment inhomogeneities in order for T_2 to be equal to T_1.

13. We can only acquire signal along the transverse (xy) plane, but T_1 is most easily determined from plotting M_z at different time points. How might we acquire the M_z information? *Hint: the first point of an FID experiment is essentially the M_z value right before the hard-90° pulse.*

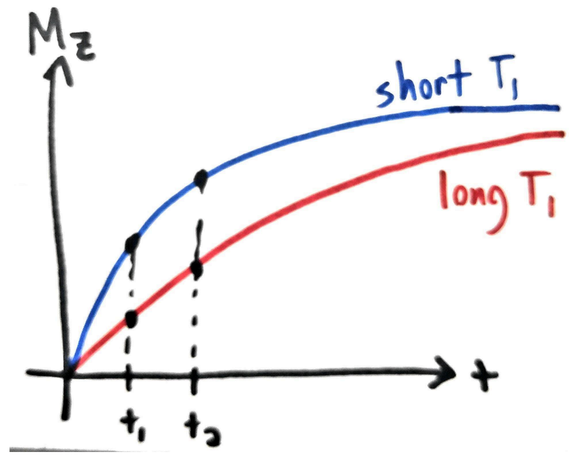
    We can use different repetition times between 90° pulses and look at the first point of signal right after each pulse to get the Mz value. If we plot the Mz values versus the time between the 90-degree pulses, we can get the desired plot.

Application Experiment: Which sample has the longest T_1? - Guided Inquiry Questions

14. How would the amplitude of the FID change if you ran the experiment with a longer repetition time (TR)? Would a sample with longer T_1 time or shorter T_1 time have the largest change in amplitude when going from short TR to slightly longer TR times?

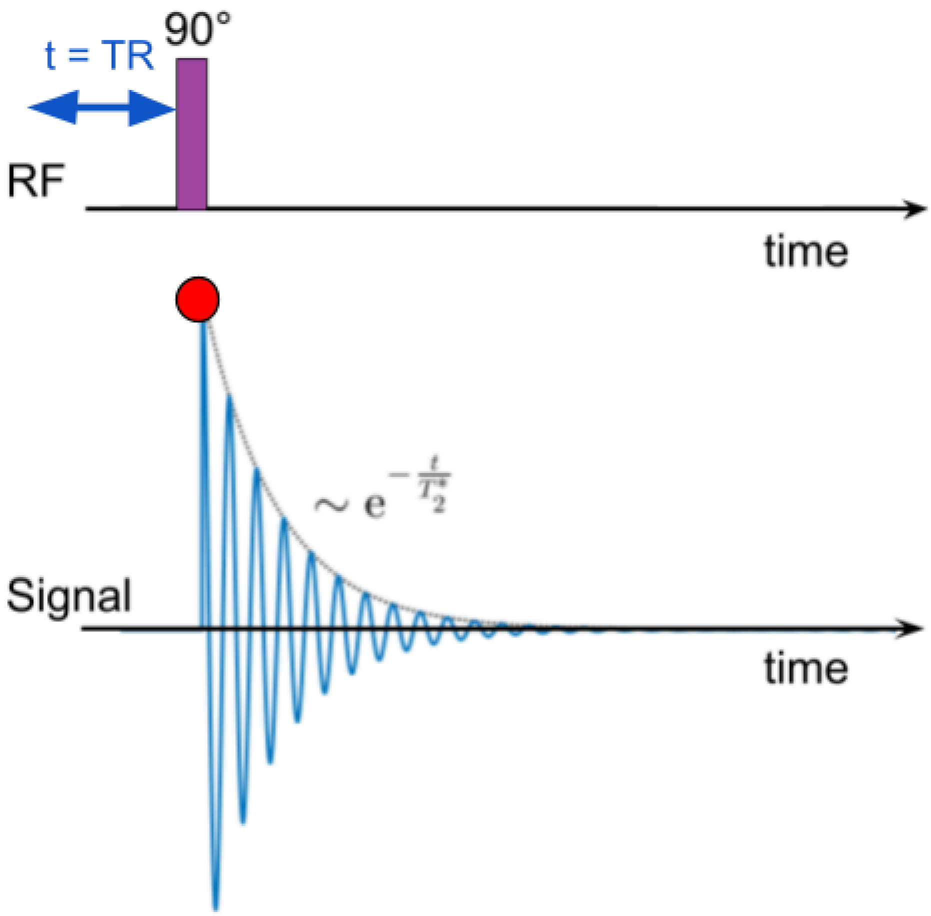
This material is based upon work supported by the National Science Foundation under award DUE-2120545. Making Nuclear Magnetic Resonance Resonate With Students: Integrating NMR Into the Undergraduate Science Curriculum,

The longer the repetition time, the larger the amplitude of the FID. The sample with a *shorter* T_1 time would have the largest change in amplitude when going from short TR to slightly longer TR times.



15. Describe an experimental procedure you can use to compare the T_1 times of two samples. Include a pulse sequence for your experiment/s.

This material is based upon work supported by the National Science Foundation under award DUE-2120545. Making Nuclear Magnetic Resonance Resonate With Students: Integrating NMR Into the Undergraduate Science Curriculum,



To compare the T_1 times for the two samples, we can take two data points with two different short TR values to compare the slope of Mz versus time. The sample that has the largest slope must have the smaller T_1.

Here are my measurements:

Sample A: Heavy Mineral Oil
TR = 0.02 s, Mz = 2.35 V
TR = 0.04 s, Mz = 3.26 V

Sample B: Silicone (Ultra Soft)
TR = 0.02 s, Mz = 0.24 V
TR = 0.04 s, Mz = 0.32 V

This material is based upon work supported by the National Science Foundation under award DUE-2120545. Making Nuclear Magnetic Resonance Resonate With Students: Integrating NMR Into the Undergraduate Science Curriculum,

Sample A has a slope of 0.91 V / 0.02 s ~ 45.5 V/s
Sample B has a slop of 0.08 V / 0.02 s ~ 0.4 V/s

Sample B (Silicone - Ultra Soft) must have a longer T1 time. This makes sense because I could see the silicone signal was still changing noticeably with TR times around 1 second, which led me to increase the TR time from 1 second to 3 seconds instead.

Reflection Questions

1. What will happen to your MR signal if you choose a repetition time (TR) that is much shorter than the T_1 time for your sample?

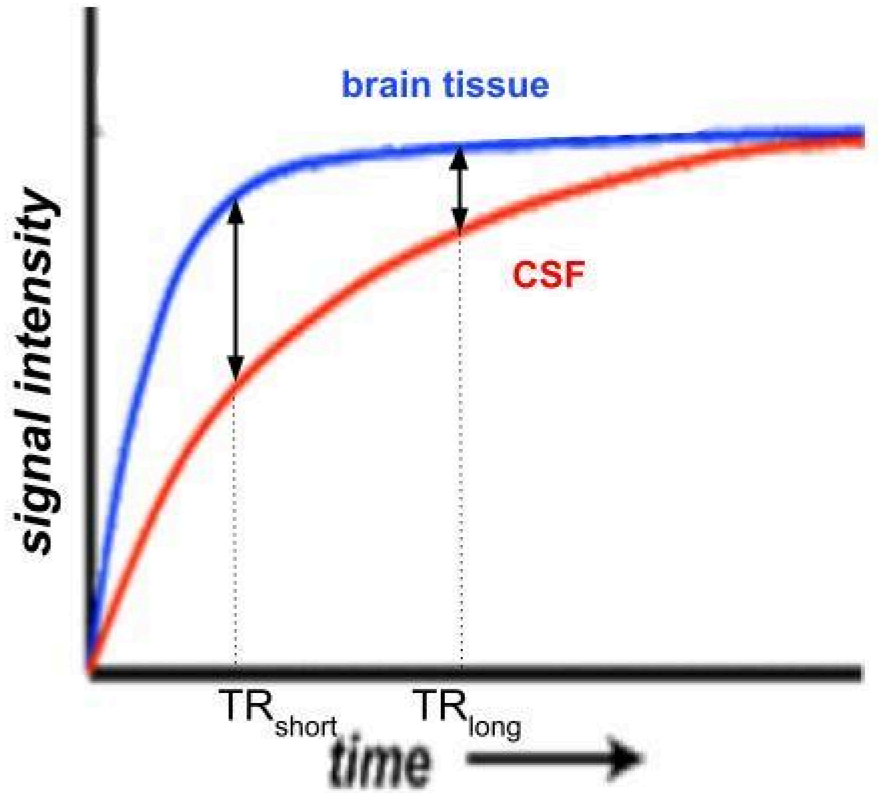
   If you choose a repetition time that is much shorter than the T_1 time for your sample, then our model of what is happening to the spin dynamics breaks down because a majority of the spins may not be aligned with the magnetic field and starting at equilibrium. The resulting signal will be very small because the net magnetization vector magnitude will be close to zero.

2. Will using a TR time that is too short impact the measured T_2 time?

   The short TR time would not impact the measured T_2 time because that is a measure of the transverse relaxation (dephasing in the xy-plane), whereas a short TR time impacts the amplitude of the MR signal since not all the spins have realigned along the z-axis via the longitudinal relaxation.

   Below is a plot of the T_1 curves for brain tissue compared with cerebrospinal fluid (CSF). You should use this plot to answer the following questions.

This material is based upon work supported by the National Science Foundation under award DUE-2120545. Making Nuclear Magnetic Resonance Resonate With Students: Integrating NMR Into the Undergraduate Science Curriculum,



3. Which has the longer T_1 time, brain tissue or cerebrospinal fluid?

   Cerebrospinal fluid has a longer T_1 time because it takes longer for the signal to recover (realign with the magnetic field).

4. You are designing a T_1-weighted MRI pulse sequence that needs to highlight brain tissue from the surrounding cerebrospinal fluid. Looking at the T_1 curves provided, which of the TR times (TR_{short} or TR_{long}) would be a better choice? Why?

   Using TR_{short} would be the better choice because at that TR value, you have the largest difference between the two signals with the brain signal having more signal than the cerebrospinal fluid because the brain has a shorter T1 time and so more signal has recovered for short TR times compared with the cerebrospinal fluid.

This material is based upon work supported by the National Science Foundation under award DUE-2120545. Making Nuclear Magnetic Resonance Resonate With Students: Integrating NMR Into the Undergraduate Science Curriculum,