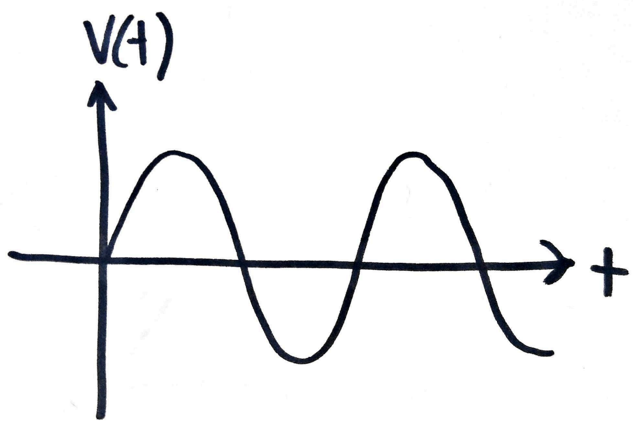
Module 5 Student Questions

Faraday's Law - Guided Inquiry Questions

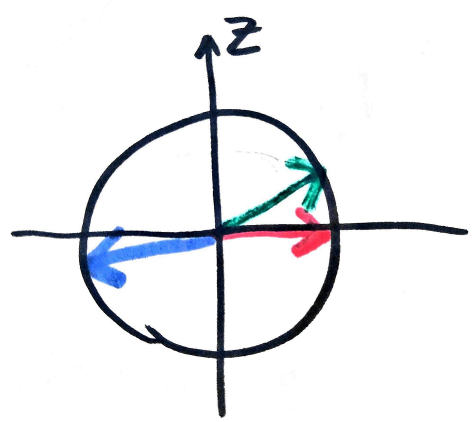
1. Sketch an example of what the voltage versus time data might look like for the experiment performed in the video when the magnet is being rotated on the central platform. (A rough sketch will do!) If the quantum spins are precessing at the Larmor frequency, what might be a reasonable guess for the frequency of the fluctuating voltage we will be detecting?

   The fluctuating voltage detected will presumably be at the Larmor frequency.



2. We need spins to be precessing in order to induce any voltage and measure NMR signal. Draw a picture in the Bloch representation of possible quantum states to put the spins in. Explain your choice.

   Any superposition state would be precessing and thus induce a fluctuating voltage that can be measured.



3.

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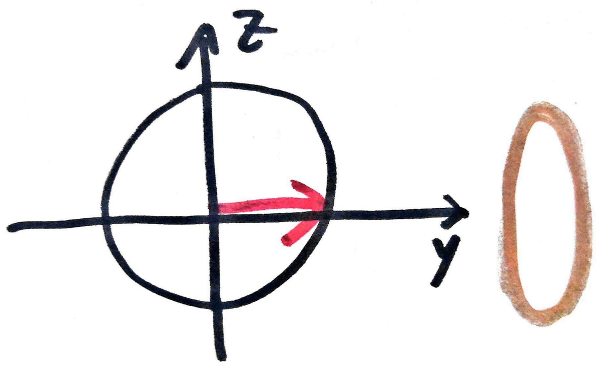
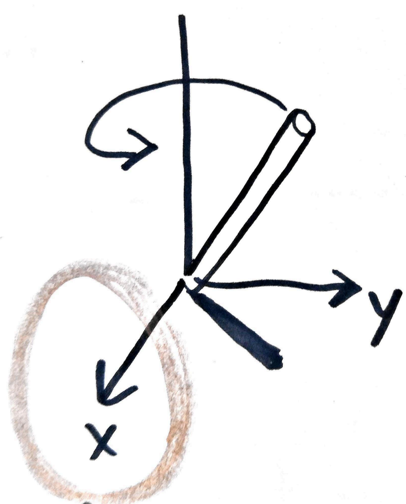
4. Look closely at the video of the wire loop and the rotating bar magnet in the video above. Everything in the experimental setup was oriented to maximize the signal being measured according to Faraday's law of induction. Using this video as a guide, draw a possible orientation of the loop of wire we could use to detect the NMR signal next to your Bloch sphere.

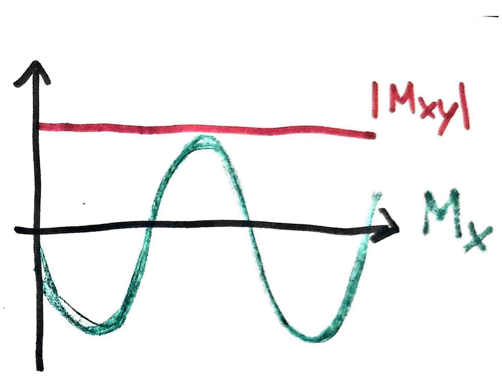


Loop would need to be oriented along xz-plane to maximize signal being produced by precessing spins in the xy-plane.

NMR Signal - Guided Inquiry Questions

5. Open the Bloch simulator and, without clicking on anything, draw a sketch of the motion of the net nuclear magnetization vector, $\vec{M}$, and copy down the plot of $|M_{xy}|$ and M_x in the upper-right corner. Does this match with our description of the NMR signal described in the previous paragraph? How so?





Yes, this does appear to match with our description of NMR signal as being voltage induced by the Mx and My components of the net nuclear magnetization vector.

6. In your sketch, draw the orientation of the wire loop that is collecting the red (M_x) NMR signal. *Hint: It may be helpful to add some x- and y-axes to your sketch!*

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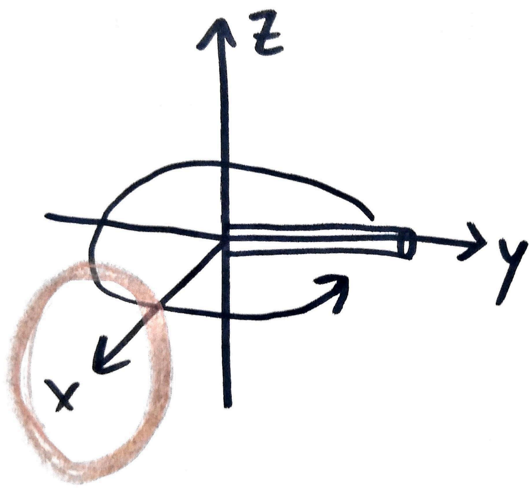
Added the orientation of the wire loop in my sketch above!

7. Draw a sketch of how the net nuclear magnetization vector should be oriented in order to maximize the red (M_x) NMR signal.



More Realistic NMR Signal - Guided Inquiry Questions

8. Open the Bloch simulator, select "Inhomogeneity" instead of "Equilibrium" in the drop-down menu, and then click on "90°_x hard". Describe what you are seeing.
I see 9 cylinders that all initially start with the same orientation, but start 'fanning out' or dephasing, as described in the text. As this happens, the plot of $|M_{xy}|$ versus time is slowly going down along with the amplitude of the sinusoidal M_x versus time.

9. Copy down the plot of $|M_{xy}|$ and M_x and explain why it looks that way. Try to make use of *inhomogeneities* and *dephasing* in your explanation.
Hint: think of what the net nuclear magnetization vector would be doing in this experiment.

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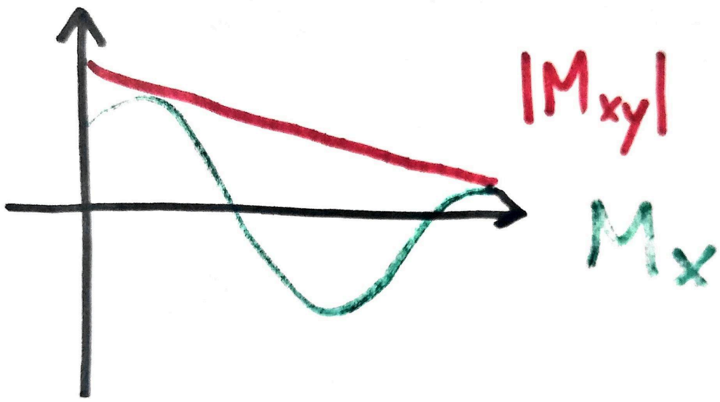

Presumably, the different cylinders fan out because they all have slightly different precession frequencies (due to *inhomogeneities* in the applied magnetic field over the sample). Since the signal is showing the x- and y- components of the net nuclear magnetization vector, as these vectors get more and more out of alignment (*dephasing*), then the overall magnitude of the net nuclear magnetization vector is decreasing, so both the amplitude of M_x and $|M_{xy}|$ is decreasing.

Different Components of NMR Spectrometer - Guided Inquiry Questions

The videos below show NMR signal from the TeachSpin benchtop NMR spectrometer as shown on an oscilloscope. The yellow trace corresponds to $|M_{xy}|$ and the blue trace corresponds to M_x after subtracting out the input frequency of ~21 MHz.

10. Check out this YouTube video (https://www.youtube.com/watch?v=SayyvFx6L1I). Which of the three primary spectrometer settings is being changed during the course of this video? Explain how you arrive at your conclusion.

    The knob that is being changed is the pulse length, as the frequency of the MR signal never changes, but the amplitude in changing in a cyclic way. First the amplitude increases, reaches a maximum (around the 90-degree pulse length) and then decreases and the signal disappears (presumably around the 180-degree pulse length), and then increases again but the blue trace has with a 180-degree phase shift suggesting now the pulse length is approaching 270-degrees rotation, and finally the amplitude decreases back to zero, presumably getting to a pulse length that causes a full 360-degree rotation.

11. Check out this YouTube video (https://www.youtube.com/watch?v=5VK8XQ2z_qM). Which of the three primary

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spectrometer settings is being changed during the course of this video? Explain how you arrive at your conclusion.

Changing the frequency, as the oscillations in the blue trace change significantly, while the yellow trace 'envelope' doesn't change.

12. Check out this YouTube video (https://www.youtube.com/watch?v=L7wS_iK9yqE). Which of the three primary spectrometer settings is being changed during the course of this video? Explain how you arrive at your conclusion.

    Decreasing the period or repetition time (TR), as the frequency of the blue trace doesn't change, but the amplitude slowly decreases and eventually you see the repeated pulses get closer together, suggesting this isn't just a pulse length change but a change in the overall repetition time.

Reflection Questions

1. Explain how the free induction decay experiment is designed to maximize NMR signal. *Hint: Consider why a 90-degree pulse is used and why this generates the most signal given what you have learned about Faraday's law and ways to orient the receiver coil relative to the rotating bar magnet in order to maximize the voltage induced.*
   The FID experiment first initializes the spins by waiting for them to return to the equilibrium state (by having a long enough TR time), and then the 90-degree pulse brings all the spins into the xy-plane, maximizing the M_x and M_y components of the net nuclear magnetization vector so that the voltage induced being picked up by the coil that is oriented perpendicular to the magnetic field will be maximized.

2. All three primary spectrometer settings can effect the size of the NMR signal (the overall maximum voltage of the signal as observed on the oscilloscope). If you observe the amplitude changing in the signal, how can you differentiate whether it is the frequency being changed as opposed to either the pulse length or the repetition time?

   Only the frequency being changed will change the frequency of oscillations observed in the M_x trace.

3. You are unsure if the signal you are seeing is coming from the sample or from leakage coming from the transmitted pulse. (This can occur since we acquire

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signal right after the pulse and are using the same coil for both transmitting and receiving!) What are some things you can try to do to verify if the signal is indeed coming from the sample?

Probably the easiest thing to do is take out the sample and see if you still observe a signal. If you do still see the signal, then that signal must not be coming from the sample itself and it suggests it might be due to the experimental apparatus. (Sometimes you can still see some very small MR signal due to the protons in the epoxy resin used to keep the detection coil in place!) To really test if this 'signal' without the sample is leakage from the pulse and not some other signal source (like the epoxy resin) you can try changing the frequency so it is off-resonance with the protons. Any MR signal should die down, but leakage from the pulse would still remain pretty constant (as long as you are not completely out of the range of the frequencies that the electronics are designed to detect.)

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