# Module 5 - How Do We Measure NMR Signal?
## ***Instructor's Manual***

## Suggested Prior Modules

Modules 3 and 4.

Particular prior knowledge from Module 3 that students are expected to have already learned:

- Quantum spins have magnetic moments aligned or anti-aligned with their spin angular momentum
- Quantum spins precess in the presence of a magnetic field.

*If you do not have time to do the entirety of Module 3, the Spin Magnetic Moment and Larmor Precession sections should suffice as preparation for this module and could potentially be done as a pre-reading assignment for Module 5. You may want to have students complete a short assessment to verify they have the necessary prior knowledge listed above.*

Particular prior knowledge from Module 4 that students are expected to have already learned:

- The Bloch sphere representation of spin-½ quantum states.
- Some familiarity with the Bloch simulator.

*If you do not have time to do the entirety of Module 4, the Bloch Sphere Representation and Getting Started with the Bloch Simulator sections should suffice as preparation for this module and could potentially be done as a pre-reading assignment for Module 5. You may want to have students complete a short assessment to verify they have the necessary prior knowledge listed above.*

Particular prior knowledge from other courses that students are expected to have seen already:

- Vectors (basics, no need to know *how* to break them up into components, just that they *can* be broken up into components)

If students have *not seen* vectors before or need a refresher, this Khan Academy lesson on vectors or pre-reading from any introductory physics textbook should suffice.

### Suggested Use:

The instructions below are suggestions to help students engage with the material in class and were implementations of the materials that the developers used in their classes. However, all sections and questions in this module can successfully be done

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asynchronously online to serve as a pre-reading assignment in preparation for class or lab.

This module uses the [TeachSpin Pulsed NMR spectrometer] to highlight the various parts that *all* NMR spectrometers will have - though they are hidden away inside the box for most spectrometers. If you have access to an NMR spectrometer at your institution, this is a great module to use before teaching students how to run a simple 1D spectrum (which is the free induction decay experiment) on your NMR system.

## Expected Learning Outcomes

At the end of this module, students should be able to...

1. identify what physical quantities are being measured and describe how to acquire magnetic resonance (MR) signal using an NMR spectrometer (Scientific Ability B4)
2. extract information and interpret MR signal from oscilloscope correctly (Scientific Ability A1)
3. identify which experimental parameters can cause observed changes in MR signal (Scientific Ability G5)

## (Optional ) Introductory Activity

*(20 - 30 minutes depending on whether you are cycling students through stations or not)*

**Suggested activity: Introduction to Oscilloscope Activity**
We highly suggest this activity to teach oscilloscope basics if students have not used an oscilloscope before.

## Background Information

*(10 minutes)*

**Suggested activity:** Have students take turns reading aloud the text, as well as the information in the margin. You can have students do a think-pair-share of the discussion questions, and this is a good opportunity to have them practice explaining the reasoning behind their answers.

## What are we directly measuring?

*(10 minutes)*

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**Suggested activity:** Have students take turns reading aloud the text and watch the Faraday's Law Demonstration video. If you have some other favorite Faraday's Law demos, feel free to include them here, especially if your students haven't seen them before. The main point students need to understand is that you need a changing magnetic field through the loop in order to induce a voltage. You can have students do a think-pair-share of the guided inquiry questions, and this is another good opportunity to have them practice explaining the reasoning behind their answers.

## NMR Signal

*(10 minutes)*

**Suggested activity:** Have students take turns reading aloud the text and explaining what they are seeing in the figure. Then students can work in pairs using the Bloch simulator to answer the guided inquiry questions (one can be the simulation driver and the other can be the recorder). Pairs can check their work with the instructor and then move on to the next section when they are ready.

## More Realistic NMR Signal

*(15 minutes)*

**Suggested activity:** Students can individually do an interrogative reading of the text and then continue working in pairs using the Bloch simulator to answer the guided inquiry questions after swapping roles as recorder versus simulator driver. When nearly everyone is done with the section, bring the class together to have some pairs share their responses to the guided inquiry questions. Encourage students rewrite their responses, if necessary, to make use of the new vocabulary introduced in this section - inhomogeneities and dephasing. Then read aloud to the class the paragraph about the free induction decay signal and have students verify that the figure matches what they observed in the Bloch simulator.

## Guided Tour of the Different Components of NMR Spectrometer

*(15 minutes or longer if cycling students to learn how to run an FID experiment on your NMR spectrometer)*

**Suggested activity:** Students can individually do an interrogative reading of the text and work on the guided inquiry questions. If you have your own benchtop NMR system, this is a good time to cycle students through in groups of 2-3 to get hands-on access to the NMR spectrometer and learn how to set up and run an FID experiment. (Any sample that provides lots of signal works - like a mineral oil or water.)

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## Reflection Questions

*(Any Remaining Time)*

**Suggested activity:** In any remaining time you can choose some or all of the questions as a small group or individual reflection activity. Often these are good open questions that provide an opportunity for students to reflect on everything they have learned in this module. These questions can be completed outside of class as homework and used to assess students' comprehension of the material.

**In the last 5 minutes of class:** Give the students some time in class to assess themselves on the learning objectives using the provided rubric in the student worksheet and copied below.

| Scientific Ability | Adequate | Needs improvement | Inadequate | Missing |
|---|---|---|---|---|
| **Is able to identify what physical quantities are being measured and describe how to acquire magnetic resonance (MR) signal using an NMR spectrometer** | All measured quantities are correctly identified and the description of how MR signal is acquired is accurate and clear. | All measured quantities are correctly identified but the description of how MR signal is acquired is vague or incomplete. | Not all measured quantities are correctly identified OR no description of how MR signal is acquired is provided. | Measured quantities are incorrect and no description of how MR signal is acquired is provided. |
| **Is able to extract information and interpret MR signal from oscilloscope correctly** | All necessary information has been extracted correctly, and written in a comprehensible way. | Some of the information is extracted correctly, but not all of the information (e.g. missing units). | Information that is extracted is incorrect or contains errors such as labeling quantities incorrectly. | No visible attempt is made to extract information. |
| **Is able to identify which experimental parameters can cause observed changes in MR signal** | All experimental parameters and the resulting changes they make to the MR signal are correctly identified. | Most of the experimental parameters and the resulting changes they make to the MR signal are correctly identified. | An attempt is made, but most of the experimental parameters and the resulting changes they make to the MR signal are incorrectly identified. | No attempt is made to identify the experimental parameters that can cause the observed changes in MR signal. |

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