Module 7 - How Do We Improve Our NMR Signal?
Instructor's Manual

Suggested Prior Modules

Module 6.

Particular prior knowledge from Module 6 that students are expected to have already learned:

- Familiarity with the Bloch simulator.
- Basic understanding of T_1 and T_2 relaxation times.
- Interpreting and drawing simple pulse sequences.

The entirety of Module 6 could be done as a longer, interactive pre-reading assignment for Module 7. It is estimated to take about 2 hours for students to complete asynchronously. You may want to have students complete a short assessment to verify they have the necessary prior knowledge listed above.

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

Expected Learning Outcomes

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

1. *Use Bloch simulator and a physical model to answer questions about the spin dynamics resulting from a given pulse sequence (Scientific Ability A4)*
2. *Extract information from provided NMR experimental data (Scientific Ability A1)*
3. *Choose correct experimental parameters to optimize T_2 contrast for different samples (Scientific Ability A4)*

Background Information

(15 minutes)

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,

Suggested activity: Have students take turns reading aloud the text, along with 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.

Observation Experiments: Spin Echoes

(30 minutes)

Suggested activity: Students can pair up with one person running the simulator and one recording their answers to the guided inquiry questions. (The instructor can clarify that it is fine if students have the same answers for these questions, but also encourage students to write down who they were working with to give proper attribution that it was a shared effort.)

Hahn Echo Theory

(20 minutes)

Suggested activity: Have students take turns reading aloud the text, along with the information in the margin. Pull up the online module so you can have the entire class view the Hahn echo animations. You can have students do a think-pair-share of the discussion questions. The ‘challenge’ question is a nice one to have students practice their experimental design skills. This is a fairly easy experiment to perform, either by purposefully applying a magnetic field gradient while doing a Hahn echo experiment or displacing the sample somewhat so that it is no longer within the most homogeneous region of the field. Using the CPMG pulse sequence provides even clearer results, as this sequence also corrects for pulse errors. Students can look at the provided experiment and data in the answers to see experimental evidence supporting this hypothesis.

Can We Find T_2 Using a Single Experiment and More Pulses?

(10 minutes)

Suggested activity: Have students take a few minutes to read the short text and look at the image of the Carr, Purcell, Meiboom, and Gill (CPMG) sequence. You can have the entire class do a think-pair-share of the discussion questions.

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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.

The fourth reflection question is the basis of the example experiment for this module, and you can see the experiment designed, the data collected, and the conclusions in the 'Module 7 - Example Experiment' document.

The last two reflection questions are challenge questions that provide a nice opportunity for students to try coming up with their own hypothesis and experimental procedure to explain a mysterious signal. (These questions are based on an observation that an undergraduate student made in the first implementation of this module and ultimately turned into a fruitful student-led experimental exploration!)

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 that is found on the next page).

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Scientific Ability	Adequate	Needs improvement	Inadequate	Missing
Is able to use the Bloch simulator and a physical model to answer questions about the spin dynamics resulting from a given pulse sequence	The questions are correctly answered using both the Bloch simulator and a physical model.	The questions are correctly answered, but only using one of the two representations - Bloch simulator or physical model.	The questions are incorrectly answered or correctly answered without reference to either of the two representations.	No attempt is made to answer the questions.
Is able to extract information from the provided NMR experimental data	All necessary information has been extracted correctly, and written with correct units.	Some of the information is extracted correctly, but not all of the information.	Information that is extracted contains errors, such as labeling quantities incorrectly, not taking into account timescale or vertical scale information on plots, etc.	No visible attempt is made to extract information from the provided NMR experimental data.
Is able to choose the correct experimental parameters to optimize T_2 contrast for different samples	All experimental parameters to optimize T_2 contrast for different samples are correctly identified.	Most of the experimental parameters to optimize T_2 contrast for different samples are correctly identified.	An attempt is made, but most of the experimental parameters to optimize T_2 contrast for different samples are incorrectly identified.	No attempt is made to identify the experimental parameters to optimize T_2 contrast for different samples.

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