Module 9 - How Does the Phase of Matter Affect MR Signal?
Instructor's Manual

Suggested Prior Modules

Modules 6, 7, and 8 (for Reflection Questions 1 & 2).

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

- Basic understanding of T_1 and T_2 relaxation times.

The entirety of Module 6 could be done as a longer, interactive pre-reading assignment for Module 9. It is estimated to take about 2 hours for students to complete asynchronously.

Particular prior knowledge from Module 7 that students are expected to have already learned:

- Use of the Hahn echo or CPMG pulse sequence to measure T_2 relaxation times.

If you do not have time to do the entirety of Module 7, the Hahn Echo Theory and Can We Find T_2 Using a Single Experiment and More Pulses? sections should suffice as preparation for this module and could be done as a pre-reading assignment.

Particular prior knowledge from Module 8 that students are expected to have already learned:

- How peak width in the frequency spectrum corresponds to T_2 relaxation times.

Note: This is only necessary if you want students to be able to answer Reflection Questions 1 & 2. *If you do not have time to do the entirety of Module 8, the What Information Does the Fourier Transform Provide? section should suffice as preparation for this module and could be done as a pre-reading assignment.*

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.

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,

Expected Learning Outcomes

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

1. *Explain the ways that molecular motion affects the resulting NMR spectra (Scientific Ability A1)*
2. *Predict and test how the NMR signal and frequency spectrum will differ from liquid and soft-solid samples (Scientific Abilities C4 and C8)*
3. *Identify the challenges of solid-state NMR compared with liquid-state NMR (Scientific Ability A2)*

Background Information

(10 minutes)

Suggested activity: Have students take turns reading aloud the text, along with the information in the margin. You can have the class do an open brainstorming session on the discussion questions. These open-ended questions serve as a good icebreaker to get students ready to engage with the rest of the material.

Some key points that you should make sure come up in the discussion are: (1) the ordered structure of solids versus liquids/gases, (2) the different densities of the different phases (whether they fill their containers or not), and, *most importantly*, (3) the relative motion of the molecules in the three different states, with molecules/atoms in a solid remaining in the same place on average and molecules/atoms in a liquid or gas diffusing around randomly within the volume of the sample.

Observation Experiments: Magnetic Moment Motion Impact on Local Magnetic Environment

(30 minutes)

Suggested activity: This section is best done in small groups (if you have enough compasses and magnets for each group), but can also be done as a class if you are able to project the experiments with the magnets and compasses so everyone can see what happens. You can do a quick check-in with the groups or class after each experiment to go over their responses to the guided inquiry questions.

Testing Experiment: Molecular Motion Effect On T_2

(30 minutes or 45 minutes if doing the experiment as a class)

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Suggested activity: This section is best done in small groups and has students design an experiment to test a given hypothesis and then make a prediction of what they would expect to see if they performed their experiment and the hypothesis is true. Students will then either look at the provided experimental data or (if you have access to a benchtop NMR system) perform their experiments to make a reasonable judgment about the validity of the hypothesis.

How Does Molecular Motion Impact Relaxation Time Constants?

(10 minutes)

Suggested activity: This section is best done in small groups or by doing think-pair-share as a class. These questions allow for multiple explanations, so they serve as a good way to have students explain their responses and listen to other students' explanations to help clarify their understanding of the impacts of molecular motion on T_1 and T_2 time constants.

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. Ofte,n 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.

Note: Reflection Questions 1 & 2 are the only questions that require some prior knowledge from Module 8 (the effects of relaxation times on peak widths in the frequency spectrum). If you do not plan on covering that, then you can skip these questions.

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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Follow this rubric to assess your work for this module:

Scientific Ability	Adequate	Needs improvement	Inadequate	Missing
Is able to explain the ways that molecular motion affects the resulting NMR spectra	All necessary ways that which molecular motion affects NMR spectra have been explained and written in a comprehensible way.	Some of the ways that molecular motion affects NMR spectra have been explained, but not all.	Some of the explanations contain errors or are incorrect.	No attempt is made to explain the ways that molecular motion affects NMR spectra.
Is able to predict and test how the NMR signal and frequency spectrum will differ from liquid and soft-solid samples	A prediction is made that * follows from the hypothesis, * is distinct from the hypothesis, * accurately describes the expected outcome of the experiment A judgment is made, consistent with the experimental outcome, and assumptions are taken into account.	Prediction follows from the hypothesis, but is flawed, OR a judgment is made that is consistent with the outcome of the experiment, but assumptions are not taken into account.	A prediction is made, but it is identical to the hypothesis, OR a judgment is made but is not consistent with the outcome of the experiment.	No prediction or test is given.
Is able to identify the challenges of solid-state NMR compared with liquid-state NMR	Challenges are identified from all given (or understood) information and contains no major flaws.	Challenges are identified correctly, but there is information missing.	An attempt is made to identify the challenges, but it uses incorrect information or does not agree with the information used.	No attempt is made to identify the challenges of solid-state NMR compared with liquid-state NMR.

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