Module 2 - What Quantum Particles Can We Use for Magnetic Resonance?
Instructor's Manual

Suggested Prior Modules

There are no suggested prior modules, nor required prior knowledge. This module provides the first introduction to quantum spin and its properties and ultimately helps students learn how to determine which nuclear isotopes are useful for NMR.

Particular prior knowledge from other courses that is helpful for students to have seen already:

- Electrons filling atomic orbitals

If students have *not seen* this material before, then instructors can skip over the electrons filling the atomic orbitals of oxygen example in the final paragraph of [Spin-½ Particles and Their Properties](), and also skip Guided Inquiry Question 5. These are simply there to connect to some chemistry topics some students may have seen before, but not necessary for achieving the learning objectives of the module. Fortunately, students who had not taken general chemistry nor seen how atomic orbitals were filled before were still able to answer the rest of the questions and use the rules to determine the total nuclear spin for different isotopes.

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. calculate the number of spin states and the possible m_s values for a given spin quantum number, s

2. determine whether a nuclear spin will be zero, integer, or half-integer

3. identify and explain the reasons certain isotopes are most useful for NMR

This material is based upon work supported by the National Science Foundation under award DUE-2120545.

(Optional) Introductory Activity

(20 minutes)

Suggested activity: [Introduction to the Elementary Particles]()

We highly suggest this fun group activity to help students understand the importance of spin in the realm of particle physics. This activity does require some prior prep work initially, but the supplies can be re-used for any future implementations.

Optional Prior Reading Resource (*NOTE: only available on mobile phones*): https://m.particleadventure.org/standard-model/eternal-questions.html

Background Information

(5 minutes)

Suggested activity: Read aloud the short text - which essentially summarizes the aims of this module - and then go through the *Class-Wide Discussion* questions as a class. Encourage everyone to contribute something to the discussion, since there are plenty of answers to go around. The whole class together can certainly come up with more than a single person!

Discovery of Quantum Spin

(15 minutes)

Suggested activity: Have students take turns reading aloud this section. Feel free to pause to explain further the different boldfaced words that may require more clarification.

Before viewing the Stern-Gerlach Experiment video, have the students do a think-pair-share for answers to the following questions (which are also in the module text):

- If there is NO intrinsic magnetic moment that allows electrically neutral atoms to interact with a magnetic field, what would you expect to see on the screen?
- If there IS an intrinsic magnetic moment that allows electrically neutral atoms to interact with a magnetic field AND the atoms in the atomic beam have random

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orientations of that magnetic moment with respect to the magnetic field, what would you expect to see on the screen?

If you use small whiteboards, students can draw what they expect to see in the two situations on whiteboards. Help students understand that there should be a single undeflected beam in the first case and a vertical smear in the second case (some who have seen statistics may even suggest a normal distribution). In the second case, the magnetic moments of the individual atoms are randomly oriented and those more aligned with the inhomogeneous magnetic field will move toward the stronger field at the top, those less aligned with the inhomogeneous magnetic field will move away from the stronger field at the top, and those oriented nearly perpendicular to the magnetic field will not be deflected much at all.

Once predictions are made, view the video with students and finish reading the text. You can encourage students to check out the paper referenced in the *FURTHER STUDY* in the margin if they want to learn more about the efforts of many scientists to interpret the results correctly from the experiment and ultimately come to an understanding that the results were due to the unpaired electron of the silver atoms.

Spin Quantum Numbers

(20 minutes)

Suggested activity: Have students take turns reading aloud this section. Feel free to pause to explain further the different boldfaced words that may require more clarification.

Then allow about 10 minutes for students to go through the *Exploration Activity* in pairs. Once they have developed possible rules to follow to get the allowed m_s values for a given s value and the total number of allowed spin states. Students can read the following section which essentially provides the rules physicists developed.

Have students work in small groups answering the applications questions using the provided information for about 5 minutes. Then you can quickly go over the right answers to ensure students understand how to apply these rules.

Potential Sources for Magnetic Resonance

(10 minutes)

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Suggested activity: Have students take turns reading aloud this section. Feel free to pause to explain further the different boldfaced words that may require more clarification. Then have students work in small groups to answer the two guided inquiry questions using the provided information for no more than 5 minutes. Briefly have students share their responses with the rest of the class (2 minutes).

Nuclear Spin

(20 minutes)

Suggested activity: Read aloud the text for the section and you can use carbon-14 as an example isotope that is NOT a good candidate for NMR because it has an even number of both neutrons and protons, so has zero spin. You can comment that it is also not very naturally abundant due to its instability (radioactivity), which are other factors to consider when looking for good NMR candidates.

Then have students work in small groups to check out the PhET simulation and answer the guided inquiry questions using the provided information. Students can complete these at different rates depending on how comfortable they are with the periodic table and isotopes. You can go around the groups to check answers and help out those who are unsure.

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 often good questions that can be completed outside of class as homework.

Some of these questions do not necessarily have correct answers but provide an opportunity for students to reflect on everything they have learned in this module. Reflection question number 3 provides a good assessment of the third learning outcome.

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.

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Follow this rubric to assess your work for this module:

Learning Outcome	Adequate	Needs improvement	Inadequate	Missing
Is able to calculate the number of spin states and the possible m_s values for a given spin quantum number, s	Can easily calculate the number of spins states and possible m_s values without referencing the text.	Can easily calculate the number of spins states and possible m_s values if referencing the text.	Struggles to calculate the number of spin states and possible m_s values.	Does not demonstrate any understanding of what is meant by spin states and m_s values.
Is able to determine whether a nuclear spin will be zero, integer, or half-integer	Can easily determine whether a nuclear spin will be zero, integer, or half-integer without referencing the text.	Can easily determine whether a nuclear spin will be zero, integer, or half-integer if referencing the text.	Struggles to determine whether a nuclear spin will be zero, integer, or half-integer.	Does not demonstrate any understanding of what is meant by nuclear spin being zero, integer, or half-integer
Is able to identify and explain the reasons certain isotopes are most useful for NMR	Can accurately describe at least 3 reasons certain isotopes are most useful for NMR.	Can accurately describe at least 2 reasons certain isotopes are most useful for NMR.	Can roughly describe at least 1 reason certain isotopes are most useful for NMR.	Cannot accurately describe any reasons certain isotopes are most useful for NMR.

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