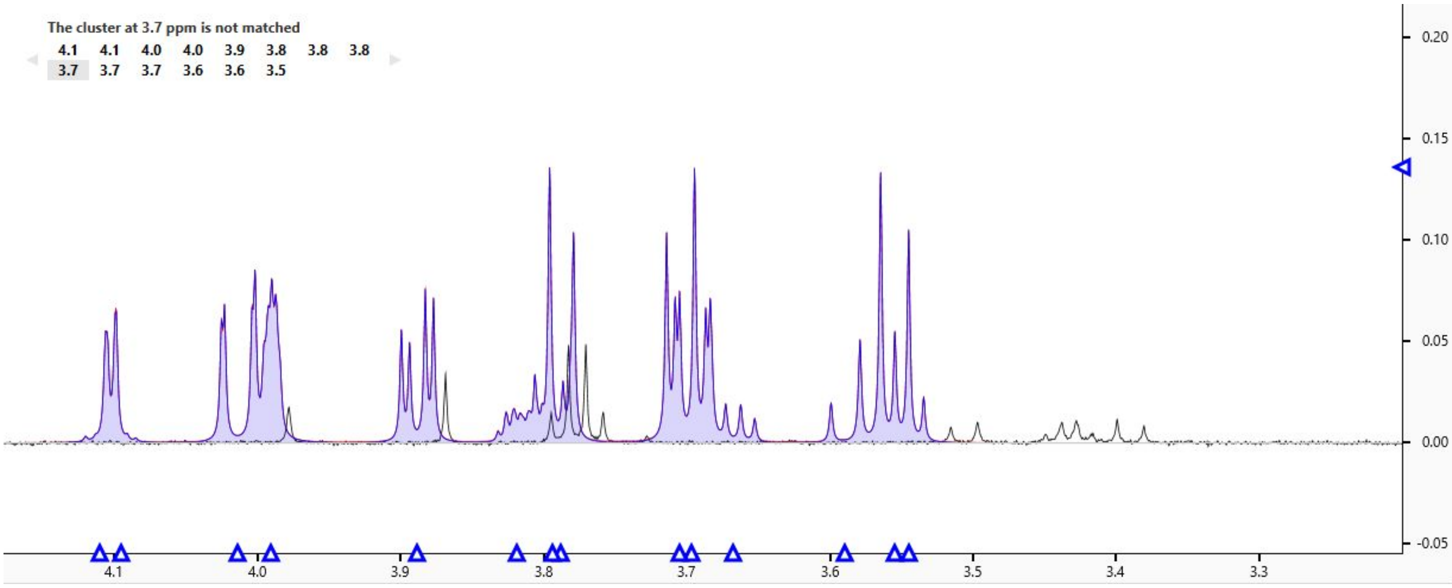
KENAN FELLOWS PROGRAM
FOR TEACHER LEADERSHIP



Spinning around: How does a NMR spectrometer work?

OVERVIEW

Students will explore angular momentum and precession with an engineering challenge. This is followed by a deeper exploration in how precession is used in NMR spectroscopy.

AUTHOR	GRADE LEVEL	CONTENT AREA
Megan Alvord	11-12th grade	AP Physics

ESSENTIAL QUESTIONS

Students will be able to answer:

What factors determine spin time for a spinning top?

Define precession and identify three objects that precess.

How does precession help us collect data in an NMR?

TIME NEEDED

Time needed to prepare or gather and set up materials - 1 hour

Time needed to facilitate the activity - 150 minutes

Time needed to wrap up/ review activity - 30 minutes

STANDARDS

Plan a data-collection and analysis strategy to determine the change in angular momentum of a system and relate it to interactions with other objects and systems.

Making **Connections**

Students may be familiar with the big idea behind this activity: precession. Precession is often taught in Earth Science as planet Earth wobbles along its axis. The same principle that governs the wobble of the Earth is also seen in a spinning top that starts to wobble, or precess, before falling over. Next, precession is also found in spinning atoms. But what makes an atom spin and why would we want to do that anyway?

Background

Students start with an engineering design challenge where they build a spinning top out of given materials in order to spin the longest. Characteristics of the best spinning tops are analyzed and recorded. The term precession is introduced and related back to the wobble of the Earth, followed by an introduction to a simulation of nuclear magnetic resonance where students can simulate the same precession as their spinning tops and the Earth, but with atoms. Students explore the characteristics that determine precession of an atom and the causes of this wobble. Then, students can dive deeper into the "why" behind the uses of atomic precession and explore how it is used in MRIs.

Materials

- Cardboard to cut into circles of 12-15 cm diameter, to serve as the spinning top. *These can be pre-cut if you are working with younger children. Note: if all students have the same diameter, then the groups can be directly compared. Or, opt for a more true engineering approach and let the students decide the diameter.*
- Weights (pennies and washers work well)
- Tape (to secure weights. Hot glue is an option for more advanced prototypes, but not recommended for a short challenge. Glue dots are awesome for those with sufficient financial resources)
- Rotating device (sharpened pencils or wooden skewers work well and punch fairly easily through the cardboard)
- Rubber bands (recommended to have below the cardboard disk to prevent sliding)
- Student laptops

Teacher **Tips**

For my class, I elected to pre-cut the cardboard in order to maximize the time that students had to build and test their prototype. If you have your students cut out their own circles, I would recommend having circular shaped items (cups, pots, cookie cutters) of various sizes available as templates. If you desire to teach your students how to use a compass, this would be an excellent activity to use to teach that skill.

If you have adventurous groups of students, allow them to be creative as much as possible with materials.

Group size is recommended to be 2-3 persons. Groups of four can be used if materials are limited, but typically not all hands can be placed on the prototype as in groups of two or three.

The simulation that will be used is a Java-based simulation and will not work on phones and certain devices. Check compatibility of devices before beginning this lesson.

The **Activity**

Day 1

Part 1: Opener (time suggestion: 15-20 minutes)

- Teacher spins a top in front of the class. The top may be homemade or a store-bought metal one. The teacher asks students to make observations. These observations should be written down by students, either on their individual paper or on a group white board. Either way, have the students share their observations with one other person or group.
- Have a student from each pair or group share out common observations. The teacher may elect to write these for all to see on a large whiteboard, poster paper, or on a word document projected over-head.
- Next, ask students to infer what they could do to change the top so that it could spin longer. Once again, have students write these down, share with someone else, and report their inferences. The teacher may elect to write these for all to see.

Part 2: Engineering Challenge (time suggestions: 20-30 minutes for prototyping and 10 minutes for official timing)

- Teacher shows students available materials.
- Using the given materials, students should explore and determine the factors so that the top will spin as long as possible.
- Give students a set amount of time to prototype and test.
- Once the given time is complete, have each group spin their top in front of the class and record their official time. The teacher should write these times down and the longest time announced.

Part 3: Challenge Review

- Each group, now having seen all of the tops and recorded times, should return together as a group and list the factors that they found to keep the top spinning longest. Have students report out this list. The teacher can place talley marks next to repeated factors.
- Expected factors: added mass to the cardboard, mass further from rotation axis, and a faster initial spin.

- Have students complete the reflection questions in the "Student Pages" portion below. Finish for homework if needed.

Day 2

Part 1: Review Student reflection questions and mini lecture on precession (10 minutes)

- Review student reflection questions (5 minutes)
- Mini lecture on precession (5 minutes) - See appendix for information to consider including in your own presentation

Part 2: Simulation Introduction (15 minutes)

- Have students use the following Phet Simulation https://phet.colorado.edu/en/simulation/legacy/mri
- Direct students to the simple NMR. Assign one of the six known atoms to each group. Turn the power slider to 100%. Encourage students to manipulate the simulation for a little bit (5 minutes) and choose "wave view" or "photo view". Point out that there are two models occurring simultaneously: the big center photo and the middle right photo. Observe both while answering the questions found in the "Student Pages" portion below.

Part 2: Simulation Lab (20-30 minutes)

- Have students complete the following steps:
- Collect data to relate the value of the magnetic field to the frequency required to release the maximum number of photons. Ideally 6-10 different magnetic field values and their resulting frequencies.
- Graph your data points. Plot a line of best fit in Excel/Google Sheets/Desmos and use the program to determine the equation of the line.
- Research what your slope represents for your atom. Hint: Use the units of your slope in your research.

Part 2: Simulation Review and Mini Lecture (15 minutes)

- See notes in the appendix for information on magnetic moment and videos to help with visualization.

WRAP UP AND ACTION

Part 1 (15 minutes): Using the same PhET simulation on the simplified NMR tab, determine the Larmor frequency of the unknown atom (marked "???") by collecting data and graphing as before. Using your knowledge of the relationship and this table of elements, determine the unknown element.

Follow with one of the Extension activities.

Extensions

Extensions for this activity go into the "why" of nuclear precession, which in research are chiefly Nuclear Magnetic Resonance (NMR) of substances and Magnetic Resonance Imaging (MRI) of humans and animals for medical purposes.

For NMR: Is it honey?

Show the following videos on the research done to explore whether bottled honey is as pure as it says it is.

1. https://www.youtube.com/watch?v=xaSdEqkV0Z4 and Is it Honey? Using NMR in Food Testing Episode 2 (Food Analysis)
2. NMR in Honey Testing The New Standard and NMR in Honey Testing The New Standard Part 2

Extend this by having students research further on the properties of honey and how they are copied by common additives.

MRI: Simulation or Videos

Simulation: PhET also has a simplified MRI simulation that works very similarly to the NMR (because both use the same science!). Challenge your students to find the tumor using their new found knowledge: Simplified MRI

Videos are numerous exploring MRIs. Some favorites are:

1. How does an MRI machine work?
2. See-Thru Science: How MRI Machines Work
3. MRI basics: part 1: Nuclear spin (5 part series)

Resources

NCSU METRIC (see more information in "About Fellowship") is a great resource for schools in the Triangle for learning more about NMR and spectroscopy in general. The researchers here are more than willing to talk with students about their research and the science behind it.

Many universities with chemistry departments also have access to NMR, such as:

- Appalachian State University
- UNC - Asheville
- UNC - Charlotte
- UNC - Greensboro
- North Carolina A&T
- UNC - Chapel Hill
- North Carolina Central University
- Fayetteville State University
- UNC - Pembroke
- UNC Wilmington

The engineering design challenge was adapted from College Board AP Central Curriculum Modules. YouTube is such a great resource for learning not only about precession, but also how it applies to NMR and MRI. Because these ideas are abstract, the animations shown through video are helpful for students to visualize the process that is occuring.

Bruker Corporation is a great resource for learning about the research and processes of the NRM machinery.

About the **Author**

Megan Alvord is a high school physics teacher in Wake County and is a 2019-2020 Kenan Fellow. She is a total physics nerd and loves sharing how the foundational physics she gets to teach directly connects with modern physics research. When not teaching, Megan is reading, walking her dog, and planning her next jet setting journey.

About the **Fellowship**

The Molecular Education, Technology and Research Innovation Center (METRIC) provides North Carolina State University researchers and partners with world-class state-of-the-art measurement science facilities across four buildings throughout campus, encompassing three key molecular characterization technologies including mass spectrometry, magnetic resonance (NMR and EPR), and X-Ray Crystallography (small molecule and macromolecular). METRIC is directed by Dr. David Muddiman. Megan specifically worked with Dr. Peter Thompson and the NMR machines in Polk Hall on a project designed by primary investigator Arion Kennedy. Megan assisted Dr. Thompson in sample collection, preparation, and analysis for the selected project. The goal of the project is, long term, to determine if non-alcoholic fatty liver disease is affected by glucose and fructose levels in diets. Megan got to see first hand the beginning steps of this long term project by focusing on sample preparation techniques and identifying how the data would be analyzed to produce meaningful results. Megan enjoyed seeing the dividers between physics, chemistry, and biology disappear in this Fellowship, which while working with a biochemistry focus, inspired her to construct a primarily physics lesson.

Student Pages

Engineering Challenge Reflection questions

What were the characteristics of the best spinning tops?

Relate the aspects of your design that led to success to angular momentum. (AP Physics only)

What aspects of your design could be improved? Why? How would you make those modifications on a future top?

What causes the top to wobble?

Research this “wobble”

What other objects have this same wobble?

Finish these questions for homework if not complete in class.

Further extension questions

- What aspects of engineering did you learn during this challenge?
- What made your group successful?
- What limits did your group run into?
- What would you do differently if you had $1000 to spend?

Simulation introduction questions

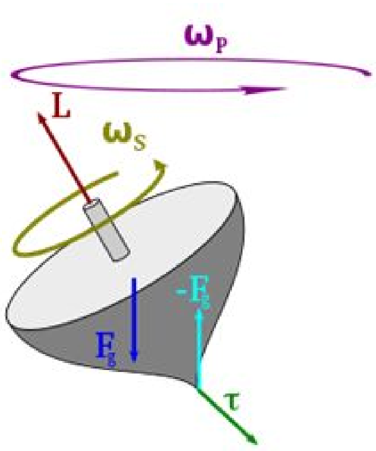
1. What does changing the magnetic field do in the simulation?

2. What does changing the frequency do in the simulation?

3. Describe the conditions for photons to be emitted.

Appendix For Teachers

Information on precession:

- Torque causes a change in the angular momentum in the direction of that torque which causes the top to precess. Review how the Earth also precesses.
- 

Information for lecture on magnetic moment

- Any free system with a constant gyromagnetic ratio, such as a rigid system of charges, a nucleus, or an electron, when placed in an external magnetic field B (measured in teslas) that is not aligned with its magnetic moment, will precess at a frequency f (measured in hertz), that is proportional to the external field (Wikipedia). This frequency is called the Larmor frequency.
- Alignment of magnetic forces creates a torque on the spinning nucleus. This torque causes a change in angular momentum. The changing angular momentum produces the EM wave signal.
- The EM wave signal can also be produced when the nucleus transitions between spin levels (show where this occurs in the simulation).
- Magnetic moment is the strength and orientation of a magnetic (or any other object that produces a magnetic field). Moving charged particles produce a magnetic field.
- Videos to help with visualization:
- Nuclear transitions between spin levels: https://www.youtube.com/watch?v=ASuK9fG6wEU (time 1:44)
- Precession of atomic nuclei: https://www.youtube.com/watch?v=2XO_NHHn6Eg or https://www.youtube.com/watch?v=p3WnFYBnghU