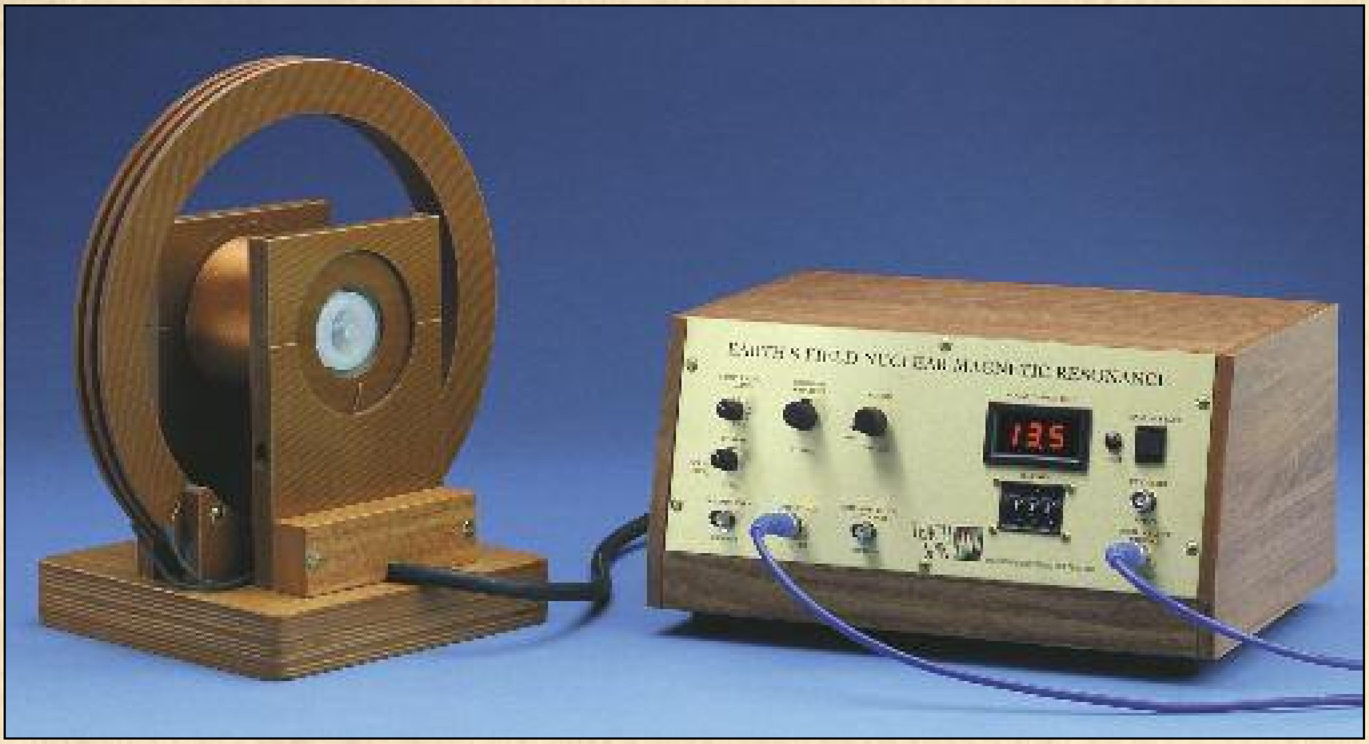
EARTH'S FIELD NMR



A Conceptual Introduction to NMR

- Observe both Proton and Fluorine Free Precession
- Discover both the Curie Law and Spin-Lattice Relaxation
- Measure Spin-Lattice Relaxation as a Function of:
    - Paramagnetic Ion Concentration
    - Viscosity
    - Temperature
- Observe and Measure Proton-Fluorine J-Coupling
- Measure Absolute Value of $g_{proton}/g_{fluorine}$
- Precisely Measure Earth's Magnetic Field
- Hear the Precessions on Built-In Audio System
- Study Bucking Coils for Enhancing Signal-to-Noise
- Examine Effects of Tuning on Signal-to-Noise

Instruments Designed For Teaching

TEACH SPIN

MAGNETIC RESONANCE IN EARTH'S MAGNETIC FIELD

It is hard to imagine a college physics or chemistry major graduating without having performed some kind of magnetic resonance experiment. Magnetic resonance has been, and clearly will continue to be, an important experimental tool in the arsenal of physicists, chemists, biologists and medical diagnosticians. Recent developments in quantum computing seem to indicate that magnetic resonance might become the basic platform of computer science hardware. Science majors surely should have a basic understanding of this type of spectroscopy.

TeachSpin, in collaboration with Professor Bill Melton of the University of North Carolina at Charlotte, has developed THE experiment to introduce sophomore, junior or even senior physics majors to the exciting field of magnetic resonance. Students with a basic understanding of gyroscopic motion and electromagnetic induction can perform experiments with this apparatus that naturally lead to an understanding of precession, Curie's Law of paramagnetism, spin-lattice relaxation, and even spin-spin coupling. The apparatus lends itself to inquiry based explorations. Essential experimental parameters all appear on a human scale. That is, the polarization times are in seconds, and the precession frequencies are in the audio range. We are confident that this instrument will become a "new classic" replacing the old, enigmatic marginal oscillator.

THE INSTRUMENT

The best way to explain our apparatus EFNMR1-A is to examine the simplified block diagram in Figure 1.

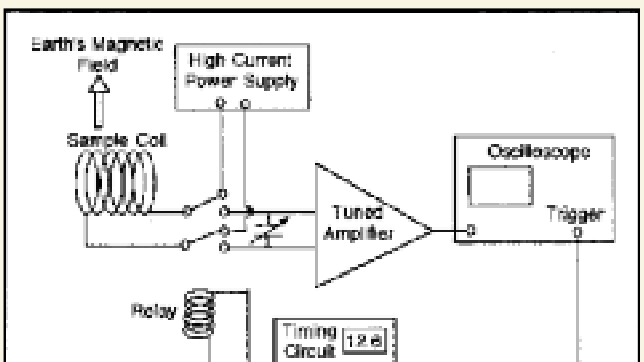


Figure 1

The high Q sample coil surrounds a 125 ml plastic bottle containing a liquid rich in either hydrogen or fluorine nuclei. The sample is placed in a uniform part of the earth's magnetic field with the coil's axis aligned perpendicular to this field. The sample coil is connected first to a current regulated dc power supply and then to a high-gain, low-noise, tuned amplifier, with the switching electronically controlled. The output of the tuned amplifier is presented on a storage oscilloscope for observation and measurement.

To begin an experiment, the sample coil is connected to the dc power supply. This supplies a maximum of 3 amperes for a predetermined length of time. The electronic circuit then disconnects the supply, quickly dissipates the stored energy, and connects the coil to the tuned amplifier.

The sample's nuclei (usually protons), having been polarized in a large magnetic field created by the power supply, find themselves oriented with their net magnetization perpendicular to the Earth's field. With the polarizing field now off, this magnetization precesses in the Earth's field, producing a time varying magnetic flux through the sample coil. The time varying flux creates an emf at the coil's terminals, which is magnified by the tuned amplifier.

STUDENT EXPERIMENTS

1. Tuning the Receiver

The student must first find the precession signal by adjusting the coil's tuning capacitor and tuning the amplifier to maximize the signal of either protons or fluorine nuclei. Figure 2 shows a signal from a water sample doped with $CuSO_4$.

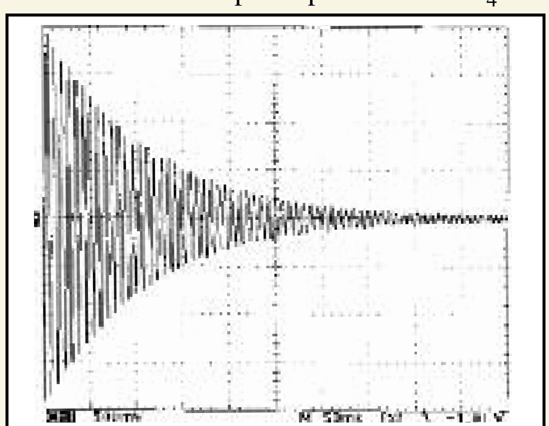


Figure 2

2. Magnetization Depends Linearly on the Magnitude of the Polarizing Field

For a fixed polarization time, students can quickly discover the linear relation between the maximum signal amplitude (which is proportional to the net magnetization) and the polarization current (which is proportional to the polarizing field). They have "discovered" Curie's Law. A graph of student data is shown in Figure 3.

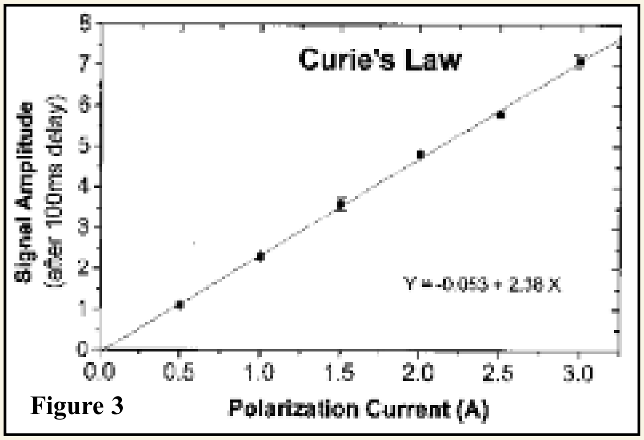


Figure 3

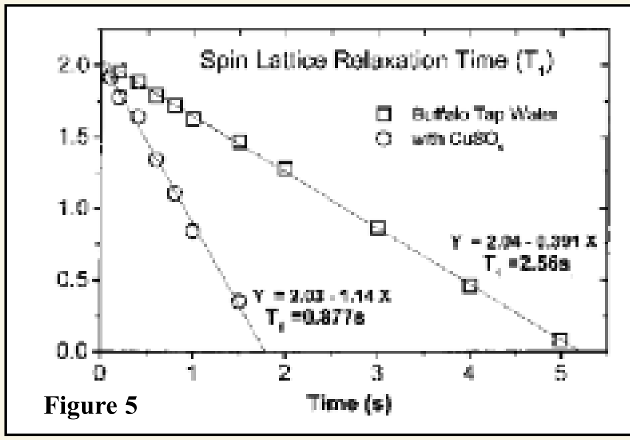


Figure 5

3. Magnetization Depends Exponentially on Polarizing Time

Examination of the maximum signal amplitude as a function of polarization time, for a fixed polarization field, yields surprising and important data. For times longer than about ten seconds, the signal from water does not change with increasing polarization time; saturated magnetization. For shorter times, the signal decreases, but obviously not linearly. A graph for Buffalo tap water is shown below.

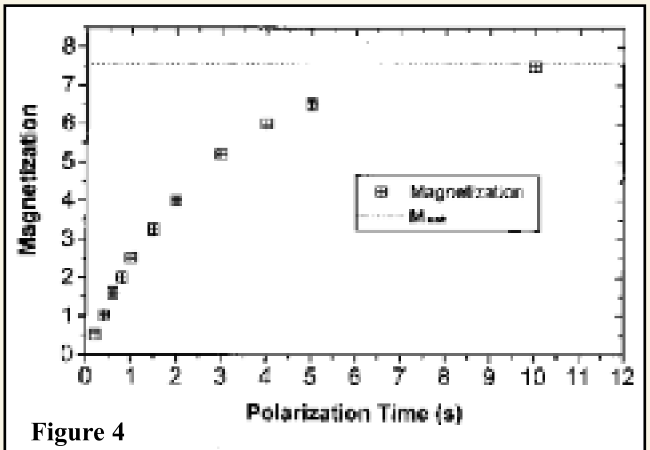


Figure 4

Analysis shows that the data is mathematically described by the equation:

$$M(t) = M_{sat}(1 - e^{-\alpha t}) \quad \text{or} \quad \ln(M_{sat} - M(t)) = -\alpha t + \ln M_{sat}$$

A plot of the natural log of the difference between the saturation magnetization and the magnetization at time t, versus the polarization time yields a straight line of slope α. Alpha is the reciprocal of the spin-lattice relaxation time T_1.

Students can discover that table salt does not affect relaxation time while, as shown in Figure 5, miniscule amounts of copper sulfate affect it dramatically. Concentration and temperature effects can also be studied.

4. For a Fixed Magnetic Field, Precession Frequency is Characteristic of the Nucleus

This apparatus is also capable of detecting fluorine nuclear precession. Students quickly discover that the precession frequencies for protons and fluorine nuclei are indeed different, but are independent of the particular solution. The ratio of the precession frequencies gives the absolute ratio: $g_{proton}/g_{fluorine}$.

TeachSpin offers three non-toxic fluorine oils with which students can study the relation of viscosity and spin-lattice relaxation time.

5. J-Coupling

A particularly interesting sample of fluorobenzene (usually available from your chemistry department) exhibits a pronounced beat signal on the proton's free precession. The beats, shown in Figure 6, are due to the proton-fluorine spin-spin coupling. A measure of the beat frequency accurately determines the J-coupling between the proton and fluorine spins.

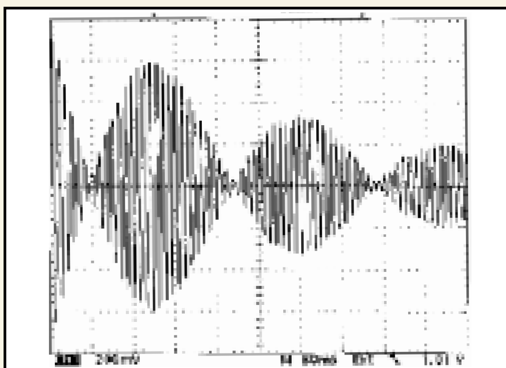


Figure 6

6. Precession Frequency Gives Local Magnetic Field

Using the gyromagnetic ratio γ of either the proton or fluorine nucleus, students use $\Omega = \gamma B$ to find the magnitude of the local magnetic field.

7. Bucking Coils Enhance Signal-to-Noise

Advanced students can examine the workings of the instrument itself as described in the Hardware Section.

HARDWARE

Although the fundamental ideas behind the instrument are simple, the actual design of the apparatus has important subtleties. As the cover photo shows, there are actually two coils around the sample. The outer or "halo" coil is a bucking coil, designed to significantly reduce random noise pickup from the always present stray electromagnetic fields. The bucking coil has the same turns-area as the inner sample coil. The coils are connected in series but in opposition. The output of the two coils is connected to the receiver. Since the two coils are in opposition, local noise fields produce equal and opposite emf in each coil and the net noise emf at the receiver is theoretically zero. *Because the precessing magnetization is a dipole field, it couples primarily to the sample coil.* This common mode rejection is essential to the outstanding signal-to-noise ratio of the apparatus. Advanced students can study this system by rearranging the bucking coil connections.

It is essential that the sample be located in a region where the Earth's magnetic field is uniform. This requires that there be no ferromagnetic materials nearby. TeachSpin has built a special stand for the coils (Figure 7) made of wood and brass. The stand allows the coils to be moved vertically as well as horizontally. Students can observe that moving the coils to areas of greater field gradients signifigantly decreases the duration of the free precession.

The apparatus also allows the experimenter to listen to the precessing nuclei. The nuclear precession signals are amplified and fed into an internal loud speaker. If the local magnetic field is reasonably uniform, the "ping" can be heard for several seconds. External speakers can be added for classroom demonstrations.

The instrument uses a linear full-wave rectifier and low-pass filter as an amplitude detector. Its output is proportional to the maximum amplitude of the precession signal. This detector is particularly useful for signal averaging weak signals to enhance the signal-to-noise ratio.

Turning off the polarization field with different damping configurations has some subtle yet interesting physics for advanced students to consider. Various damping resistors can be added and both the current and voltage in the sample coil can be monitored during the entire cycle of the experiment.

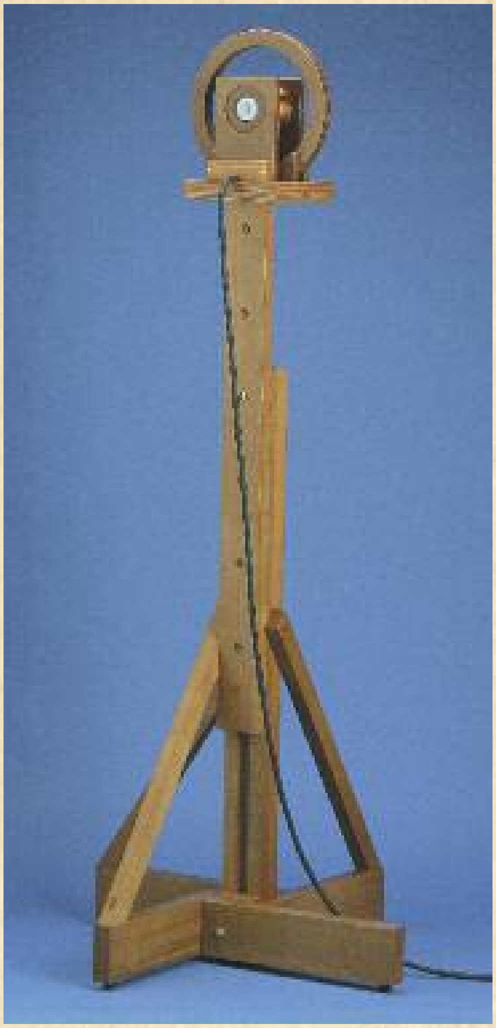


Figure 7

SPECIFICATIONS

Accessible Nuclei: H^1 protons, F^{19} fluorine
Frequency range: 1.6 - 2.7 kHz
Bandwidth: 33 Hz at 2.1 kHz
Sample: Vol. 125 ml, Diameter 5.1 cm
Polarizing times: 0.1 to 99.9 s
in increments of 0.1 s
Dead Time: 100 ms
Signal-to-Noise for $H_2$0: Nom. 200:1
Optimum 700:1
Non-Magnetic pedestal support included
Polarizing Power Supply Required
Current Regulated.: 0.5-3.0 A, 36 V
(Available from TeachSpin)

AVAILABLE ACCESSORIES

Dummy Calibration Sample Holder
Extra Sample Holders
Fluorine Liquid Samples

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