Detection of Hyperpolarized Xenon-129 Through Titanium Shielding

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Purpose:

- To test the depolarizing characteristics of titanium with a hyperpolarized gas.
- Titanium tubing is required for the design of the Helium polarizer in development by Xemed and UNH.
- Detection of spin polarization uses Nuclear Magnetic Resonance (NMR).

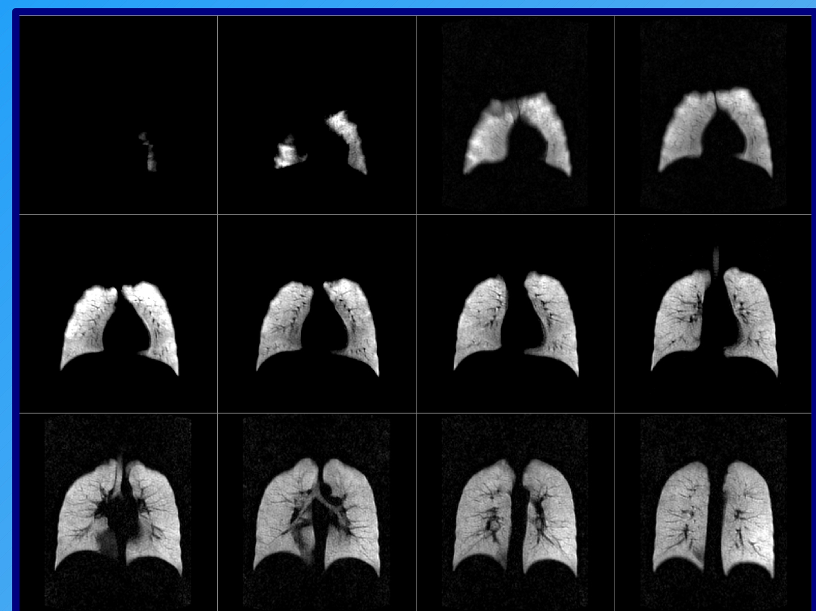

Figure 1: Magnetic Resonance Imaging (MRI) is the most common example of NMR. Xemed uses polarized Xenon-129 and NMR to create an image of lungs based on saturation of polarized Xenon-129 breathed into the lungs. To create an image, the sources of the NMR signals are tracked and plotted, creating a 3D map of the properly functioning areas of a pair of lungs.

How NMR Works:

- Nuclei with an even number of protons and neutrons have neither spin nor magnetism.
- Xenon-129 has an odd number of neutrons, giving it spin ½ and a magnetic moment.
- Polarization occurs when Xenon-129 acquires an excess of its spins aligned to an external magnetic field.
- A quantized photon is absorbed or emitted during transitions between spin states.
- Depolarization occurs in the following ways:
  - Natural relaxation, measured by T_1.
  - Collisions with other atoms, including the container's.
  - The physical act of NMR measurement.

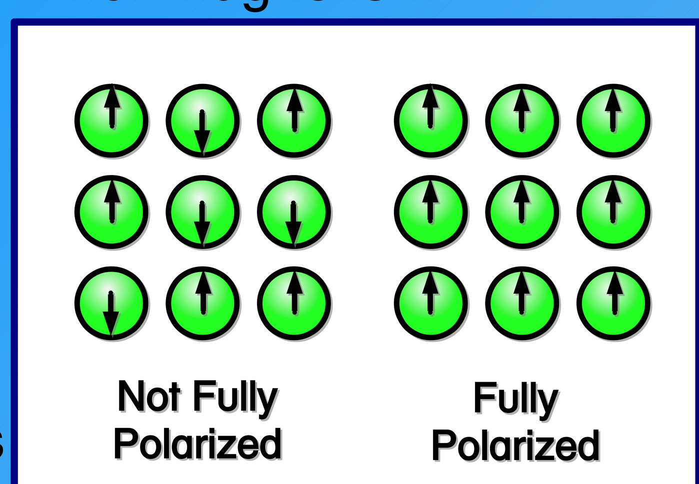

Figure 2: A graphical interpretation of spin polarization. When the atom is not fully polarized, the spins are not uniformly oriented. For 100% polarized atoms, all of their spins point uniformly along the external magnetic field, either parallel or anti-parallel. After relaxing, the atoms align randomly.

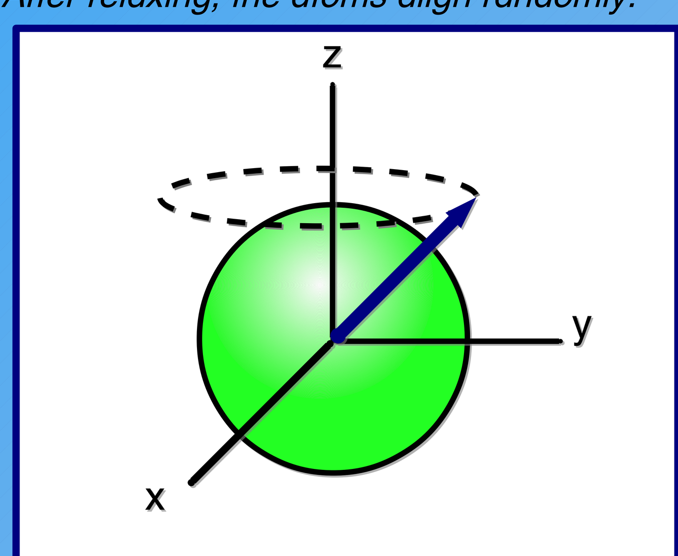

Figure 3: The spin of polarized atoms will precess, under the influence of a magnetic field, with a specific frequency.

Design:

- Probe circuit was designed as a narrow bandpass using an inductor and capacitor.
- Inductor was designed and wound by hand in a solenoid shape to the desired inductance given by equation {1}.

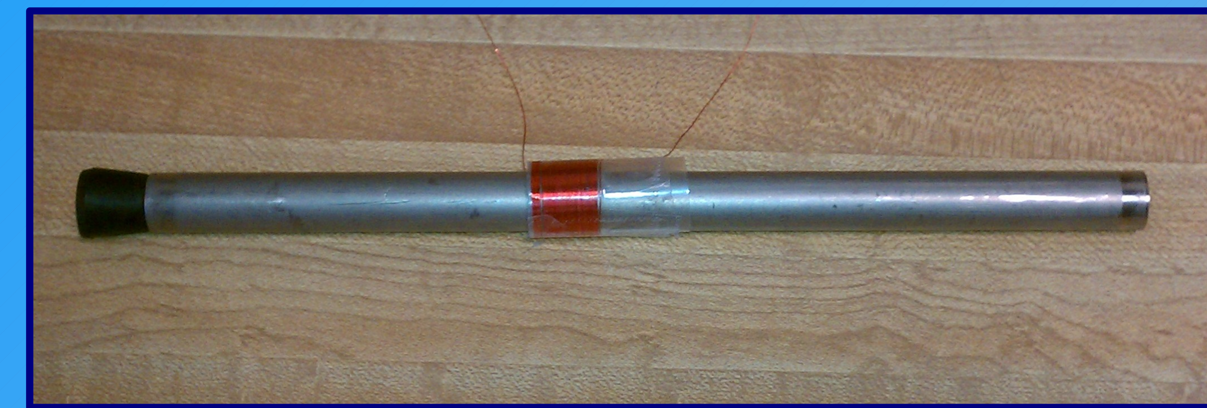

Figure 4: A solenoid shape is used as the probe to allow sensitivity to changes in magnetic flux, converting the photons emitted during state transitions into a current. This coil was physically wound by hand, requiring small changes to tune inductance. The probe may send and receive signals.

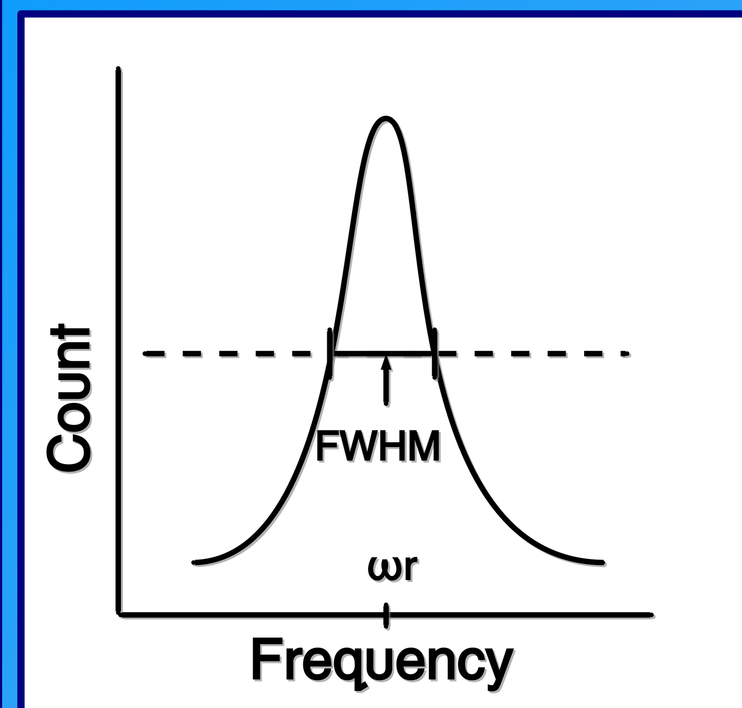

Figure 5: This is the post FFT form of a narrow bandpass, which magnifies certain frequencies nearby the resonant frequency, ω_r. Full Width Half Max (FWHM), a measure of spread, is noted as the width of the curve at half of the height.

- The resonant frequency of the bandpass was chosen to be 83 kHz based on the magnetic field possible, the gyromagnetic ratio of Xenon-129, and the preset capacitance in the circuit.
- Frequency was tuned in the circuit according to equation {2}.
- The Q, or quality value, of the circuit affects the spread of the bandpass, with a higher Q magnifying the signal better.
- Q is controlled with the resonant frequency and resistance of the circuit, making a large resonant frequency and low resistance more desirable for a better signal-to-noise ratio.
- Total wire length of the probe had to be minimized in an attempt to lower the resistance, thus raising Q.
- The probe was connected to an analog-to-digital converter (ADC) using custom, non-ferrous BNC connectors and wires.

Procedure:

- The probe must be calibrated using water to determine a voltage to set the transmitted signal to which corresponds to the 90° flip angle.
- Magnetic field, and the transmitted signal's frequency, must be tuned to the quantum spin frequency, specific of the polarized atom's gyromagnetic ratio.
- Titanium tube chamber was evacuated of all previous gas, to avoid depolarizing collisions, using a pressure controller, plastic tubing, and valves.
- The received signal is interpreted through an ADC, then sent to a computer.
- A Fast Fourier Transform Analysis of the current through the probe gives information on the relaxation time and absolute polarization.

Figure 6: Experimental set-up of NMR water calibration. The probe sits in the middle of large copper coils which generate a uniform magnetic field required for Nuclear Magnetic Resonance. The magnetic field is controlled with the current created by a power supply.

Equations:

{1}

$$L = \frac{\mu_0 N^2 A}{l}$$

L is the Inductance (H), μ_0 is the Permeability of Free Space ($H \cdot m^{-1}$), N is the Number of Turns, A is the Cross Sectional Area (m^2), and l is Length (m).

{2}

$$\omega_r = \frac{1}{\sqrt{(LC)}}$$

ω_r is the Resonant Frequency (in Hz), L is the Inductance (H), and C is the Capacitance (F).

Results:

- NMR Peak was successfully observed at the predicted frequency, indicating that polarization was detected.
- T_1, was measured to be 7.4 minutes, compared to the same volume of Xenon-129 in a specially designed, clean Tedlar bag with a T_1 of 12.9 minutes.
- NMR peak was confirmed in four different measurements.
- A control test was done, ensuring that when the chamber is evacuated of polarized Xenon-129 gas, no peak is observed.

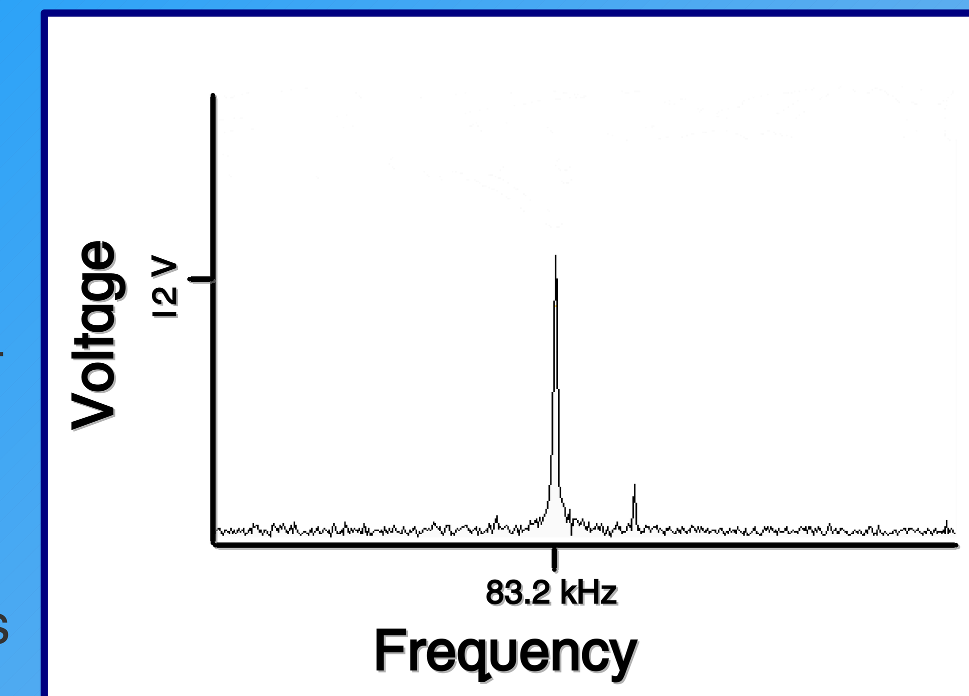

Figure 7: Post Fast Fourier Analysis data of the polarized Xenon-129 within a titanium tube shield. This shows that polarized gas can be detected through titanium. The resonant frequency of 83.2 kHz was expected from the circuit design.

Aspirations:

- A Helium-3 polarizer and circulation unit is slated to be finished by Xemed within the next month.
- Helium-3 is used commonly in medical imaging, neutron scattering, and particle beam experiments.

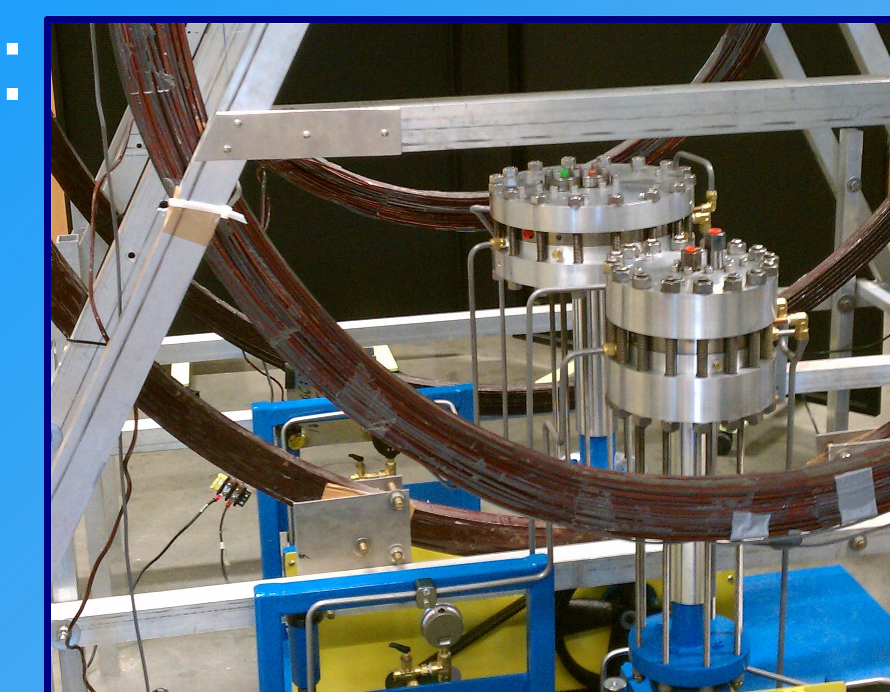

Figure 8: Two compressors use thin metal membranes to pressurize the polarized Helium-3 gas and then circulate it through a series of titanium tubes. This increases the relaxation time, prolonging polarization of Helium-3 gas.

- The machine will be placed at various labs, allowing a cheaper, more highly polarized Helium-3, which would shorten beam times at accelerator labs and lower noise levels, allowing more precise data.

Acknowledgments:

Xemed — Images from the air we breathe
University of New Hampshire