A method for imaging and spectroscopy using γ-rays and magnetic resonance

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Abstract

Background: Magnetic resonance imaging and Nuclear imaging have been essential to the modern lineup of diagnostic medicine since their inception, but there are downsides to both approaches. **Purpose:** Polarized nuclear imaging serves as a novel methodology that serves as a best of both worlds approach. **Methods:** Using spin-exchange optical pumping, ^{131m}Xe is polarized and aligned in a magnetic field to align nuclear spins. Once an RF pulse or magnetic field gradient is applied to upset alignment, anisotropic γ-rays are acquired by a γ-ray detector in order to form an image. **Results:** Compared to traditional MRI imaging of a test glass cell requiring 10^{24} water molecules, only 4×10^{13} atoms of ^{131m}Xe were used to create a high resolution image. **Conclusion:** Establishing the potency of polarized nuclear imaging widens the applicable scope of magnetic resonance, and initializes the search for the most suitable candidates for a new class of radioactive tracers that could possibly find use in diagnostic medicine.

Magnetic resonance imaging and nuclear imaging are at the forefront of the modern lineup of diagnostic medicine, but scientists are never complacent with the norm. Zheng et al, developed a novel technique which seems to form the basis of a new imaging modality, polarized nuclear imaging (PNI). Magnetic resonance imaging arises from the principles of nuclear magnetic resonance, originally demonstrated by Rabi. In a magnetic field, odd numbered atoms, such as such as hydrogen, intrinsic nuclear spins are aligned in one direction, applying resonant radio-frequency pulses to the system will manipulate the orientation of the nuclear spins. Extracting data such as the various spatial relaxation rates, allows for contrasting images to be made due to the inherent rate at which different atoms relax back into the external magnetic field induced equilibrium. The downside of this imaging technique is that is requires an abundance of atoms with significantly large magnetic moments, on the order of 1×10^1 moles per liter.

In contrast, with nuclear imaging, radioactive tracers emit γ-rays which are captured by a so-called "γ-ray camera" that captures the image through flashes of light in a scintillator. This targeted radioactive tracer is effective in minuscule concentrations in comparison to magnetic resonance imaging, on the order of picomoles per liter, however, with it accompanies a certain uncertainty in detection that ultimately limits the spatial resolution. Knowing the advantages and drawbacks of both methodologies, this is where polarized nuclear imaging comes into play. Exploiting the anisotropic property of γ-ray emission in certain nuclei with a spin greater than 1/2, Zheng et al. found, by highly polarizing a sample of ^{131m}Xe through optical pumping and aligning it in a magnetic field, that a significantly reduced amount of γ-rays are emitted in the direction spin orientation. What this means, looking at figure 1, image **c**, the rotating sample has an oscillating γ-ray count rate that provides insight into its nuclear-spin dynamics.

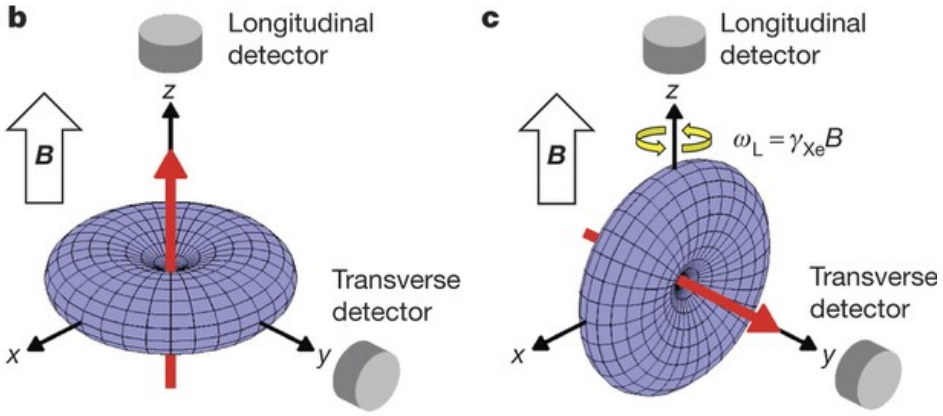

Figure 1: Image **b** is a fully polarized sample of ^{131m}Xe aligned with the magnetic field, and the counts are minimized in the longitudinal detector, and maximized in the transverse detector. Image **c** is the same sample but a pulse has been applied so it is oriented in the xy plane. It has a maximized count rate in the longitudinal detector, and consequently, rotating at the Larmor frequency as it returns to the state of image **b**, the count rate fluctuates between minimum and maximum [2].

By combining the NMR pulsing techniques with γ-ray detection, Zheng et al, were able to translate this γ-ray flux at the γ-ray detectors into spatial frequencies. The trick here, is implementing the Fourier transform to translate these spatial frequencies into the actual shape of the sample. This trick is the basis for how magnetic resonance imaging works, albeit with spatial relaxation rates. The experimental setup for performing PNI is located in Figure 2, wherein all of the components fit together in order to make this hybrid imaging method work.

The result is shown in figure 3. What makes this an astounding result, is the fact that only 4×10^{13} atoms of ^{131m}Xe are contained within the cell. In a comparable MRI, the cell would have to have been filled with at least 10^{24} water molecules. This is a significant margin, roughly 50 billion times less nuclei are involved with PNI than with MRI. This means that PNI is clearly a highly sensitive imaging technique.

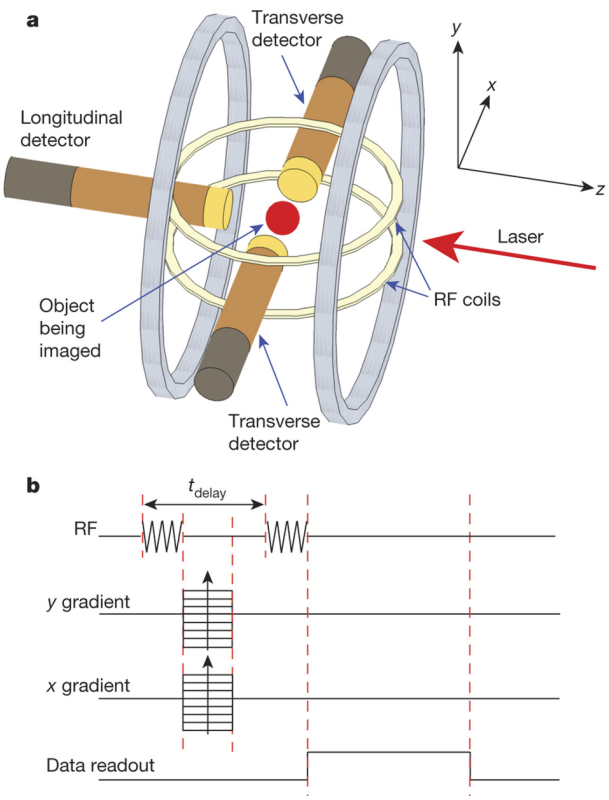

Figure 2: Image **a** is a cartoon of the experimental setup. You can see the detectors, and the laser which provides the polarization of the sample, as well as the magnetic field coils and the RF coils for providing the NMR backbone. Image **b** is the pulse sequence involved with making the image in figure 3 [2]

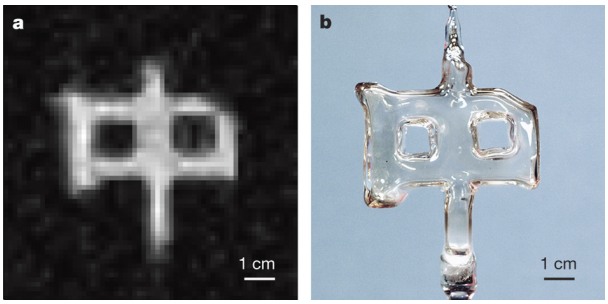

Figure 3: Image **a** is a fully polarized sample of ^{131m}Xe of roughly 1 mCi inside a sealed glass cell. Fully exemplifying the combination of techniques in polarized nuclear imaging to create a 2D image. Image **b** is a photograph of the same sample in the same cell, providing reference for the clarity of PNI.[2]

The demonstrated potency of polarized nuclear imaging certainly widens the applicable scope of magnetic resonance research. While PNI does indeed provide a superior resolution, the truth of the matter is that there are a few problems that need to be addressed. The time scale of PNI with ^{131m}Xe is just not feasible for use with in vivo systems, with the time taking theoretically 200 minutes for a hyper-polarized sample to 60 hours for the sample obtained in figure 3 without an optimized process[1]. Another issue is that nuclear polarization for the nuclei suitable for PNI maintains polarization for less than one second in the liquid state, in general. This means that there will be difficulties keeping the tracer polarized as it travels from the injection site to the site of interest within the body. These issues, while certainly ruling out ^{131m}Xe as a major player in wide application and diagnostic radioactive tracers, the truth is that this only initializes the search for the most suitable candidates. Already, Zheng et al. believe that isotopes such as ^{127m}Xe,^{79m}Kr, and of notable use for in vivo, ^{129}Xe, provide a better platform for polarized nuclear imaging.

References

[1] Bowtell, R. Imaging techniques: Mri illuminated by γ-rays. *Nature 537* (Sept 2016), 621–622.

[2] Yuan, Zheng, e. a. A method for imaging and spectroscopy using γ-rays and magnetic resonance. *Nature 537* (Apr 2016), 652–655.