Award Abstract #0855482

Hyperpolarized 129Xe: Physics and Applications

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Sponsor:	University of Utah 75 S 2000 E SALT LAKE CITY, UT 84112-8930 (801)581-6903
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ABSTRACT

This award is funded under the American Recovery and Reinvestment Act of 2009 (Public Law 111-5).

The inert (or 'noble') gases are so named because they generally do not interact much with other materials. Like many other elements, however, certain of these gases possess a property called 'spin,' that is, the nucleus at the center of each atom behaves like a very tiny spinning magnet. The presence of these spinning magnets can be detected, because when acting in concert, they can produce a detectable electrical current in a coil of wire by a technique is known as nuclear magnetic resonance (NMR). In this project, a laser technique known as 'spin-exchange optical pumping' is used to generate an extraordinary alignment ('polarization') of the spins in the isotope Xe-129, which is stable (non-radioactive) and is abundant in naturally occurring xenon. This so-called 'hyperpolarization' of xenon gas enhances its sensitivity to NMR by a factor of 10,000 or more, making possible a wide variety of both fundamental and applied magnetic resonance experiments.

There are two main thrusts to the project. The first is to improve and optimize the state-of-the-art method for generating large quantities of hyperpolarized xenon. In this method, the gas flows through a long glass cell through which the laser light also travels. The laser light is absorbed by a vapor of alkali metal (usually rubidium). The single valence electron of the alkali-metal atom also possesses spin and is aligned or polarized by the light. The alkali-metal atoms then collide with the

xenon atoms and the spin polarization is transferred to the xenon nuclei. Several techniques based on magnetic resonance of the alkali-metal electron are applied to quantitatively assess both the degree of alkali-metal polarization and the degree of xenon polarization. These are crucial diagnostics for optimizing performance of the system. The second main thrust of this project applies hyperpolarized xenon to a long standing problem in fundamental physics: the ability to predict how a large system of mutually interacting particles will behave. In this case, the large system is 1020 or so Xe-129 nuclei, frozen in place at -200 °C with their nuclear spins interacting magnetically with each other. This is an ideal system in which to study the effects of chaos on the NMR signal generated by all of these nuclei. It is an especially compelling system from a fundamental perspective, since chaotic effects are only understood for so-called classical systems, whereby one can in principle know simultaneously each of the positions and velocities of the interacting particles. The system of interacting Xe-129 nuclei is clearly governed by quantum mechanical theory, whereby such precise knowledge of each particle is forbidden. Despite this seeming paradox, a collaborator predicted a universal NMR signal behavior that is remarkably matched by experiments using a mathematical analog of classical chaos in the quantum realm.

It is nearly impossible to overstate the multidisciplinary reach of research into hyperpolarized noble gases. In additional to fundamental physics, they are applied in medical imaging, biochemistry and molecular imaging, and surface science. All of these applications depend on an understanding of the basic physics of the spin-exchange optical pumping process in order to optimize the polarization and production rate. The medical imaging application is perhaps most compelling: hyperpolarized noble gases are ideal because they are non-toxic and can be inhaled to produce beautiful magnetic resonance images (MRI) of animal and human lungs. Physicians studying lung disease and drug companies studying potential treatments are all keenly interested in this technology. Research previous to this award has already produced a patent on storage cells for hyperpolarized xenon that are quite relevant to both of these companies. Hence, the project reaches across disciplines within physics (from AMO to condensed matter, to the relationship between quantum mechanics and chaos), impacts commercial development of hyperpolarized Xe-129 for medical imaging and other applications, and involves students at all levels. In particular, a track record of involving undergraduates, especially women, in this research program is well established and will continue.

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