First report of real-time manipulation and control of nuclear spin noise

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Basel Physicists in collaboration with Dutch researchers have demonstrated a new method for polarizing nuclear spins in extremely small samples. By Monitoring and controlling spin fluctuations, the method may provide a route for enhancing the resolution of magnetic resonance imaging (MRI) on the nanometer-scale, allowing researchers to make 3D images of smaller objects than ever before. The results have been published in the journal *Nature Physics*.

Many of the elements that make up the matter around us, such as hydrogen or phosphorus, contain a magnetic nucleus at the center of each atom. This nucleus acts like a tiny magnet with a north and south pole. By applying a large magnetic field, the poles of these nuclei align along the magnetic field, producing a so-called nuclear spin polarization.

When the nuclei are irradiated with electromagnetic impulses (radio waves) at a very specific frequency, they change their direction away from the magnetic field. Because they are magnetic, the nuclei then start turning back. As they do so, they emit the energy they had previously absorbed through the radio waves. With a special antenna these signals can be detected.

This method is called nuclear magnetic resonance (NMR) and can provide very useful information about a sample, such as its chemical composition or structure. The method also forms the basis of magnetic resonance imaging (MRI), which can make 3D images of the density of an object and is often used on patients in hospitals.

However, for very small objects (i.e. smaller than a single cell) containing a small number of nuclei, the natural fluctuations of the nuclear spin polarization actually become larger than the polarization produced by a large magnetic field. These deviations are known as "spin noise". The fact that spin noise is so dominant at small scales is one of the reasons why measuring NMR and MRI in very small objects is so difficult.

Monitoring, controlling and capturing

The team led by Prof. Martino Poggio from the University of Basel in Switzerland has now demonstrated, together with scientists from Eindhoven University of Technology and Delft University of Technology in the Netherlands, a method for creating polarization order from such random fluctuations. By monitoring, controlling, and capturing statistical spin fluctuations, the team produced polarizations that were much larger than what can be created by applying a magnetic field.

This is the first report of the real-time manipulation, control, and capture of fluctuations arising from nuclear spin noise. The results are immediately relevant to recent technical advances that have dramatically reduced the possible detection volumes of NMR measurements. "Improved understanding of these phenomena may lead to new high resolution nano- and atomic-scale imaging techniques", explains Poggio. The Basel method may provide a route for enhancing the sensitivity of nanometer-scale magnetic resonance imaging (MRI) or possibly for the implementation of solid-state quantum computers.

Further Implications

The method's ability to reduce nuclear spin polarization fluctuations may also be useful to enhance the coherence time of solid-state qubits. Qubits are units of quantum information used in quantum computers. Qubits implemented in the solid-state – especially in structures called quantum dots – are very susceptible to fluctuations in nuclear polarization: even tiny variations in the nuclear polarization destroy a qubit's coherence. Therefore, the ability to control these fluctuations may extend qubit coherence times and thus help in the on-going development of solid-state quantum computers. Poggio points out that his "approach to capture and store spin fluctuations is generally applicable to any technique capable of detecting and addressing nanometer-scale volumes of nuclear spins in real-time".

More information: Peddibhotla, P. et al. Harnessing nuclear spin polarization fluctuations in a semiconductor nanowire, *Nature Physics* (2013). DOI: 10.1038/nphys2731