Physics of nuclear spins in quantum dots

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Electronic and optoelectronic semiconductor devices rely, as the name suggests, on the use of electrons. In classical devices, it is the electric charge of the electron that plays a key role. More recent efforts in the field of semiconductor physics were focused on trying to exploit a different property of the electron – its mechanical moment (spin) and magnetic moment associated with it. In particular, the concept of Quantum Information Processing (QIP) seeks to use the spin wavefunction of the electron to store and process information.

However, quantum states are very fragile and sensitive to interaction with external environment. As a result, the attempts to use the spins of electrons in semiconductors encounter issues completely unknown in classical electronic devices. One of those issues arises from the fact that protons and neutrons also possess spin, so that atomic nuclei of many semiconductors have non-zero magnetic moments [1]. Nuclear magnetic moments (associated with nuclear spins) are small, but their interaction with electron magnetisation (known as hyperfine interaction) means that electron spin is no longer an isolated two-level quantum mechanical system. This presents a number of challenges and opportunities on the way to practical use of semiconductors in QIP devices.

In this lecture, I will discuss the most important aspects of the electron and hole hyperfine interaction in the context of the applications of few-spin solid-state systems for QIP. I will start by reviewing the background physics of the nuclear spins and hyperfine interaction. I will then go through the milestones of the research done on nuclear spins in semiconductors in the last two decades [2, 3]. I will particularly focus on the role of the hyperfine interaction in semiconductor quantum dots, since they are the most promising candidates for scalable solid-state QIP devices. In the last part of my lecture, I will present the most up-to-date results of the experimental work carried out at the University of Sheffield. In particular, I will demonstrate how nuclear magnetic resonance (NMR) techniques can be used to study the physics of nuclear spins in quantum dots and the properties of quantum dots in general [4 – 6].

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[4] E. A. Chekhovich, et al., ”Structural analysis of strained quantum dots using nuclear magnetic resonance”. Nature Nanotechnology **7**, 646 (2012).
[5] E. A. Chekhovich, et al., ”Element-sensitive measurement of the hole–nuclear spin interaction in quantum dots”. Nature Physics **9**, 74 (2013).
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