Electronic read-out of a single nuclear spin

Spin is one of the intrinsic quantum properties of particles. The spin of the electrons orbiting an atom has many significant consequences, in particular it determines the magnetic properties of materials. At the present time, electronic spins have been favoured candidates as carrier of quantum information in studies of potential devices for quantum computing. However, electronic spin states are subject to strong environmental influences, resulting in very short relaxation and coherence times. In alternative concepts, atomic nuclei, which can also have spin, have been proposed as the building blocks for quantum computing, since nuclear spin states are much less strongly coupled to the environment. However, weak coupling comes at a price: it remains challenging to address and manipulate individual nuclear spins.

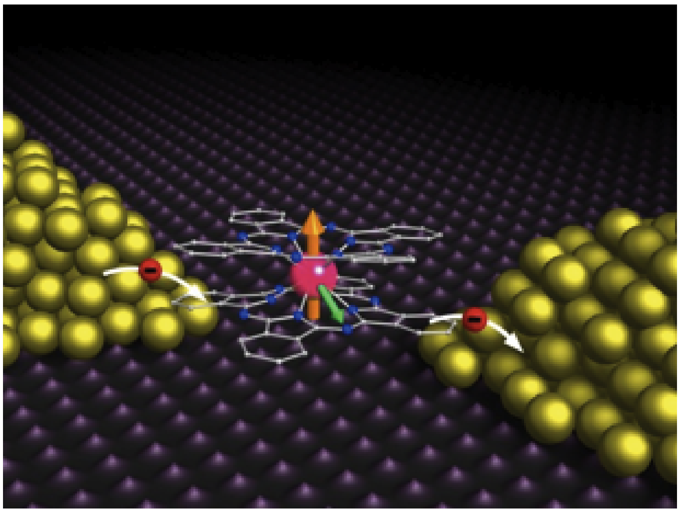

Fig. 1 : Artist's impression of a spin transistor based on a Single Molecule Magnet. The Terbium ion (red) is sandwiched between two organic molecules (grey and blue) to form the Single Molecule Magnet. The orange and green arrows represent the orientation of the electronic spin and nuclear spin carried by the Tb^{3+} ion. Yellow spheres are gold atoms: the molecular magnet is situated in a break in a gold nanowire above a gate electrode (dark background). By monitoring the current (white arrows) flowing from source to drain through the organic molecule, the four possible nuclear spin states of the Tb^{3+} ion can be detected electrically.

The magnetic moment of a nucleus is several orders of magnitude smaller than that of an electron, hence the relative difficulty of reading out the spin state of a single nucleus. To meet this challenge, there have been various proposals to measure instead the state of an electronic spin that is correlated to the nuclear spin state, in order to obtain an indirect and non-destructive measurement of the nuclear spin's state. Towards this goal, at the Institut NEEL, in collaboration with chemists of the Karlsruhe Institute of Technology, Germany, we have demonstrated the ability to perform electrical detection of the state of a single nuclear spin using a spin transistor based on a "Single-Molecule Magnet".

The advantage of molecular materials is that they can be chemically "tailored" for the active operations that process the spin quantum state, yet integrated with existing electronics technologies. Our technique involves the use of a bi-molecule of $TbPc_2$ (Terbium Pthalocyanine). As depicted in Fig. 1, The electronic spin (red in the Figure) and the nuclear spin (green) are carried by a Terbium 3+ ion sandwiched between the two complex organic molecules (the pthalocyanines). We integrate this Single-Molecule Magnet in a three-terminal transistor geometry (source, gate and drain), using an electromigration technique.

By sweeping an external magnetic field, we can find four field values where the electronic spin can switch from a "spin-up" to a "spin-down" configuration, without changing the nuclear spin state. This occurs via a process called Quantum Tunneling of Magnetization QTM (at the "anticrossing" points in the graphs of spin-state energy levels versus field). These four field values can be identified with the four possible spin states of the Terbium I = 3/2 nucleus.

While sweeping the magnetic field, we use the transistor device to monitor the flow of electrons through the two pthalocyanines in the vicinity of the Terbium. Because there is a ferromagnetic coupling between these flowing electrons and the Terbium ion, the current is sensitive to the Tb^{3+} electronic spin state. In this way, we have been able to detect the Quantum Tunneling of Magnetization for a single electronic spin, and thus perform a non-destructive electronic read-out of the state of a single nuclear spin.

These experiments have demonstrated the possibility of addressing and detecting the spin state of a single nucleus using Quantum Tunneling of Magnetization in a Single-Molecule Magnet. In combination with the long lifetimes (tens of seconds) that we measure for the nuclear spin states, this provides a pathway towards nanospintronics devices with integrated memory, logic and possibly quantum logic functions.

CONTACTS
Franck BALESTRO
franck.balestro@neel.cnrs.fr
Wolfgang WERNSDORFER
wolfgang.wernsdorfer@neel.cnrs.fr

Ph.D STUDENT
Romain VINCENT

FURTHER READING
ELECTRONIC READ-OUT OF A SINGLE NUCLEAR SPIN USING A MOLECULAR SPIN-TRANSISTOR
R. Vincent, S. Klyatskaya, M. Ruben, W. Wernsdorfer & F. Balestro
Nature, 488, 357 (2012)