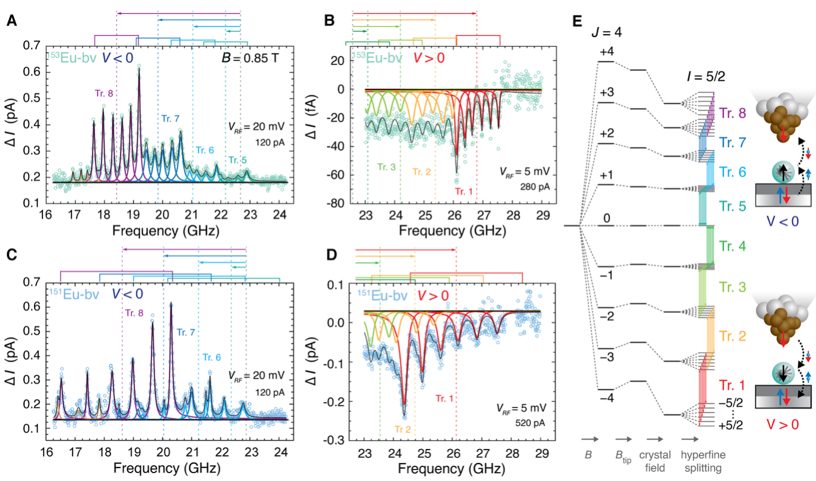
Magnetism of Adatoms – from Storage to Qubits

Harald Brune
Institute of Physics, École Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne,
harald.brune@epfl.ch

The ultimate size limit of a magnetic memory is a single atom. Richard Feynman expressed the vision that mankind might one day be able to store information in the smallest unit of matter. In 2016 we presented 2 systems where the magnetic quantum states of individual surface adsorbed atoms are stable [1,2]. We describe the Physis underlying bistability in magnetic quantum systems and summarize the systems known today where magnetic information storage in single atoms is possible. To chemically protect these atoms, we developed a method for transfer of one monolayer graphene on entire 7 mm diameter single crystal surfaces under ultra-high vacuum conditions [3]. This effectively seals the surface, moreover, this enables the growth of magnetic nanostructures into the 3rd dimension, namely, to create pillars of single atom magnets. One promising example is Dy atoms on MgO(100) that have a magnetic anisotropy energy of $K = 250$ meV [4]. Piling up 4 or 5 such atoms, vertically separated by graphene or h-BN layers, is expected to give rise to systems that can potentially be stable up to room temperature, still having laterally the size of a single atom.

We end by describing our efforts to find single atoms with long-lived magnetic superposition states that could lend themselves as single atom magnetic qubits. Encouraged by lanthanide atoms in bulk insulators, having exceptionally long coherence time [5], we performed electron spin resonance (ESR) measurements on single lanthanide atoms adsorbed at surfaces, see the Figure below for Eu/MgO [6]. ESR-STM contrast needs spin-polarized valence electrons that we obtain by stabilizing a mono-valent $6s^1$ state of the lanthanide adatoms. This allows to access the $4f$ states and the nuclear magnetic states, however, it also makes the atoms magnetic quantum states more vulnerable for electron and phonon scattering.



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