Sonderforschungsbereich 1277

Emergent Relativistic Effects in Condensed Matter -
From Fundamental Aspects to Electronic Functionality

SFB – Colloquium

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Topic: Stability of Magnetic Quantum States in Rare-Earth Adatoms

Abstract:

Magnetic quantum states in single surface adsorbed atoms or in single ion molecules have in general very short relaxation and coherence times. This is due to the relaxation of the magnetization by quantum mechanical tunneling that can be promoted by electron and phonon scattering. The most stable magnetic quantum sates can be achieved in rare-earth atoms in certain crystal field environments created by organic ligands in molecules and in surface adsorbed atoms by the underlying atoms. The crystal field stabilizes certain orientations of the orbital moments. Rare-earth atoms have very strong spin-orbit coupling, which is a relativistic effect, stabilizing orientations of the spin magnetic moment of the 4*f* electrons. These electrons are strongly localized and thereby well protected.

We report on a combination of ensemble XMCD and single atom STM measurements investigating the stability of the magnetic quantum states of single surface adsorbed rare-earth atoms leading in some systems to magnetic hysteresis in single adatoms up to relatively high temperatures and with large coercitive fields [1–4]. We call these systems single atom magnets (SAMs).

An important and often neglected ingredient in their spin dynamics are the spin-polarized valence electrons. There is a strong intra-atomic exchange coupling between them and the 4*f* electrons creating an effective total angular moment of $J_{4f} + S_{5d6s}$. The spin-dynamics of Dy on graphene shows clear signatures of this.

All known SAMs are rare-earth (RE) elements. Optical spectroscopy measurements reveal very long coherence times of RE ions dilutely dissolved into solids. The present record is 6 ± 1 hours for $^{151}Eu^{3+}$ ions in yttrium orthosilicate [5]. From these studies we conclude that SAMs can also be single atom quantum bits, with coherence times potentially outperforming present solid-state realizations of qubits.

[1] F. Donati *et al.,* Science **352**, 318 (2016).
[2] R. Baltic *et al.*, Nano Lett. **16**, 7610 (2016).
[3] F. Donati *et al.*, Nano Lett. **19**, 8266 (2021).
[4] A. Singha *et al.*, Nat. Commun. **12**, 4179 (2021).
[5] M. Zhong *et al.* Nature **517**, 177 (2015).

Host: Prof. Dr. Franz J. Gießibl