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Towards Quantum Magnetism with Ultracold Quantum Gases in Optical Lattices

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Quantum mechanical superexchange interactions form the basis of quantum magnetism in strongly correlated electronic media and are believed to play a major role in high-Tc superconducting materials. We report on the first direct measurement of such superexchange interactions with ultracold atoms in optical lattices. After preparing a spin-mixture of ultracold atoms with the help of optical superlattices in an antiferromagnetically ordered state, we are able to observe a coherent superexchange mediated spin dynamics down to coupling energies as low as 5 Hz. Furthermore, it is shown how these superexchange interactions can be fully controlled in magnitude and sign. The prospects of using such superexchange interactions for the investigation of dynamical behaviour in quantum spin systems and for quantum information processing will be outlined in the talk. In addition we present results on the dynamical resolved co-tunnelling of repulsively bound atom pairs in optical superlattices and show how by using "Coulomb-blockade" type tunnelling resonance one can count atoms one by one to determine their number statistics in the lattice potential. Finally, latest results on ultracold Fermions and Bose-Fermi mixtures in optical lattices will be presented.