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Ultracold Quantum Gases in Hexagonal Optical Lattices

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Hexagonal structures occur in a vast variety of systems, ranging from honeycombs of bees in life sciences to carbon nanotubes in material sciences. The latter, in particular its unfolded two-dimensional layer – Graphene – has rapidly grown to one of the most discussed topics in condensed-matter physics. Not only does it show proximity to various carbon-based materials but also exceptional properties owing to its unusual energy spectrum. In quantum optics, ultracold quantum gases confined in periodic light fields have shown to be very general and versatile instruments to mimic solid state systems. However, so far nearly all experiments were performed in cubic lattice geometries only. Here we report on the first experimental realization of ultracold quantum gases in a state-dependent, two-dimensional, Graphene-like optical lattice with hexagonal symmetry. The lattice is realized via a spin-dependent optical lattice structure with alternating σ^+ and σ^- -sites and thus constitutes a so called 'magnetic'-lattice with 'antiferromagnetic'-structure. Atoms with different spin orientation can be loaded to specific lattice sites or – depending on the parameters – to the whole lattice. As a consequence e.g. superpositions of a superfluid spin component with a different spin component in the Mott-insulating phase can be realized as well as spin-dependent transport properties, disorder etc. After preparing an antiferromagnetically ordered state we e.g. measure sustainable changes of the transport properties of the atoms. This manifests in a significant reduction of the tunneling as compared to a single-component system. We attribute this observation to a partial tunneling blockade for one spin component induced by population in another spin component localized at alternating lattice sites. Within a Gutzwiller-Ansatz we calculate the phase diagrams for the mixed spin-states and find very good agreement with our experimental results. Moreover, by state-resolved recording of the position of the atoms we observe a profound redistribution of the atoms in the lattice due to interstate interactions.