Particles in new clothes: From Quasiparticles to flat worlds

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When particles are part of a many-body system, they can change their properties due to their interaction with the surrounding medium. The particles become dressed by excitations of the medium and new collective states of matter are formed. In this state of matter, the particles turn into quasiparticles, sometimes called polarons, that can share much similarity with the original particles. In this colloquium, I will review the remarkable progress achieved over the last decade in the research of quasiparticles, in particular so-called polarons, and I will show how universality can be leveraged to connect the fields of material science, ultracold atoms and quantum chemistry. After introducing the idea of polaron formation, I will discuss a striking connection between the physics of cold atoms and novel atomically thin semiconductors. In these ultraflat materials electrons interacting with excitons feature a remarkable similarity with cold atomic Bose-Fermi mixtures as realized experimentally here in Heidelberg. This unique connection opens up exciting perspectives for the applied quantum simulation of two-dimensional materials using the quantum optical tools available in cold atoms. I will discuss recent results on the quantum simulation of emergent optical attractive and repulsive polaron resonances in cold atoms and their subsequent first observation in atomically thin materials. Finally, I will explain how these new observations lay the foundation to explore exciting applications of polaron physics to quantum sensing in material science or the realization of novel forms of light-induced superconductivity.