Abstract

This dissertation presents the development of experimental tools enabling precision studies of ultracold atoms and molecules. It builds on the foundations of laser cooling and trapping, laser frequency stabilization, and optical frequency combs, which together define the modern landscape of precision spectroscopy and time metrology.

This work addresses several key components required for stable and scalable measurement environments: advanced laser systems with offset locking and frequency comb referencing, coherent optical frequency transfer with residual noise suppression, and precise control of magnetic fields in ultracold atom experiments.

Beyond atomic systems, the dissertation explores pathways toward ultracold molecules, motivated by their rich internal structure, strong dipolar interactions, and potential applications in many-body physics. Particular attention is given to alkali–silver dimers, such as KAg and CsAg, predicted to possess exceptionally large permanent dipole moments. As a step toward their production, the photoionization cross sections of excited states of cesium and potassium at 328 nm are measured and analyzed, providing crucial input for molecule-formation strategies.

The work integrates these advances into a coherent experimental "toolbox": fast magnetic field switching, autonomous frequency-tunable spectroscopy lasers, fiber-based optical frequency distribution with digital noise cancellation, and photoionization studies. Together, these developments establish a robust platform for next-generation precision measurements on ultracold molecules.