Interactions and collisions in ultracold mixtures of highly magnetic lanthanide atoms with open-shell atoms and ions

The last two decades have brought significant progress in laser techniques of atom trapping and cooling to low and ultralow temperatures. At ultralow temperatures, that is, temperatures below 1 milikelvin, quantum properties of matter emerge, and for that reason, studies of ultracold systems enable better understanding of quantum phenomena. Moreover, such systems can be prepared, controlled, and measured with great precision, which opens possibilities to, for example, simulate complex many-body effects and understand them at microscopic level, or to track the dynamics of chemical reactions.

Thereby, the attainment of the first atomic Bose-Einstein condensate in 1995 has opened a new chapter in modern physics and chemistry. Subsequent years have seen ground-breaking experiments involving ultracold quantum gases (Bose-Einstein condensates and degenerate Fermi gases) of atoms and molecules with more and more complex internal structure, encompassing, among others, quantum simulations of condensed matter physics, ultracold controlled chemistry, or precision tests of fundamental laws of physics.

In recent years, researchers‘ attention has been attracted by ultracold gases of highly magnetic atoms from the lanthanide group, because strong anisotropic dipole-dipole interactions present in such systems allow for the observation of fascinating phenomena and novel quantum phases. Strong anisotropy of interactions in such systems results from the atoms‘ complex internal structure.

The aim of this project is to investigate interactions and collisions in ultracold mixtures of highly magnetic lanthanide atoms with open-shell atoms and ions, that is, ones whose valence shell is not completely filled with electrons. The research will have theoretical character and will comprise calculations of interaction potentials of the considered systems with the use of quantum chemistry methods, and next, calculations of ultracold collisions in magnetic field and analysis of prospects for the formation of heteronuclear molecules and molecular ions in the analyzed mixtures by magnetoassociation. At the same time, we will be considering multielectron systems with complex internal structure, hence the aforementioned calculations will be challenging even with the use of state-of-the-art quantum chemistry and molecular physics methods.

The results of the project will allow for theoretical explanation of the results of the experiment recently realized by an experimental group in Innsbruck. We will also analyze prospects for the application of the considered systems in quantum computation and quantum simulations, or precise measurements aiming to test fundamental physical laws and search for physics beyond Standard Model.