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Summary of the thesis "Quantum control of collisional properties of ultracold atoms and molecules"

The main subject of the present thesis is theoretical description of cold and ultracold collisions of atoms and molecules. Its most important goal is to develop a possibly simple model capable of capturing the underlying physics in a wide range of systems. This includes ultracold chemical reactions, collisions affected by one or more Feshbach resonances and scattering taking place in tight traps of various shape. Quantum defect theory provides an ideal framework for constructing such a general model.

A brief introduction to the latest achievements in the physics of ultracold atomic and molecular gases is given in the beginning. Then in the first chapter, the quantum defect formalism is introduced and applied to inelastic scattering of particles interacting via isotropic power-law potential at long range. Analytical formulas for the elastic and reactive rate constants are derived in the low energy limit, parametrized in terms of short-range reaction probability and phase shift. At finite energies shape resonances can occur, which may bring the reaction rates far above the classical estimates.

The second chapter introduces the concept of Feshbach resonances which result from the coupling with closed scattering channels. While most studies of Feshbach resonances to date were only considering a single isolated closed channel, here it is shown how to describe many overlapping resonances using quantum defect theory. In the next part it is discussed how the presence of external trap influences the Feshbach resonance, in particular when the trap shape does not allow for separation of center of mass and relative motion anymore.

The third chapter continues the investigation of collisions in traps. It focuses on chemical reactions taking place in the presence of strong confinement which reduces the dimensionality of the system. Separation of the length scales associated with the interaction and with the external trap allows to use the results from the first chapter to obtain collision rates in quasi-1D and quasi-2D geometry. A recent experiment which studied reactive collisions of Rb_2 molecules in a tight anisotropic trap is analyzed using the developed formalism. In the last part it is discussed how to extend the model to include dipole-dipole interactions. In this case analytic treatment is not possible anymore. However, the numerical results can be partially understood in terms of simple approximations, such as distorted wave Born approximation (for elastic scattering) and taking asymptotically lowest adiabatic potential (for reactive one).

The last two chapters are dedicated to practical application of the obtained results. Chapter 4 provides an analysis of experimental data from merged beam experiments in light of the reaction model from Chapter 1. It is shown how to adjust the model to account for multiple product channels and include additional terms in the interaction potential.

Chapter 5 presents a practical application of some of the results in implementing quantum gates. A novel gate scheme is proposed, basing on using two fermions in an extremely tight trap, which can be realized using nanoplasmonic structures. In such a trap, individual control of the qubits is not possible with current techniques. Instead, Feshbach resonance is used as a control source. It allows to decouple unwanted states from

the dynamics. Using optimal control methods it is then possible to perform a quantum gate with neutral atoms with operation time much shorter than in the schemes using optical lattices.