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Ultracold Quantum Gases –
A Fascinating Playground for Basic Research in Physics

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The talk provides an introduction into ultracold dilute atomic gases and discusses several illustrative examples where this emerging field allows important insights into basic research in physics.

We start with reviewing the properties of Bose-Einstein condensates (BECs) with the anisotropic and long-range dipole-dipole interaction. To this end we investigate the influence of quantum fluctuations upon the equilibrium configuration and the time-of-flight dynamics. We find that both atomic magnetic and molecular electric dipolar BECs offer promising scenarios for detecting beyond mean-field effects.

Furthermore, we report on recent progress in understanding the properties of ultracold bosonic atoms in potentials with quenched disorder. This notoriously difficult dirty boson problem is experimentally relevant for the miniaturization of BECs on chips and can also be studied by tailoring disorder potentials via laser speckle fields. Theoretically it is challenging because of the competition of localization and interaction as well as of disorder and superfluidity.

Finally, we consider systems of ultracold bosonic gases in optical lattices, which have recently become a popular research topic as they represent model systems for quantum phase transitions in solid-state physics with a yet unprecedented level of control. In order to determine the location of the quantum phase transition from the superfluid to the Mott phase we work out a Ginzburg-Landau theory for the underlying Bose-Hubbard model. Furthermore, we elucidate several intriguing examples where this quantum phase transition can be tuned by suitable system parameters.