Ultracold elastic and inelastic collision: probing and controlling of two-body and many-body physics

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We report our recent works in which ultracold elastic and inelastic collisions probe novel atomic properties in the ground and metastable states of ultracold atoms. First, we experimentally explore the collision physics between non-S-state atoms (ytterbium (Yb), effectively a two-electron system, in the metastable $^3P_2$ state) and S-state atoms (lithium (Li), an alkali metal, in the ground state) [1]. By investigating inelastic interspecies collisional losses in the double quantum degenerate mixture we reveal the dependence of the inelastic losses on the internal spin states of both species. As a result, we discover two very distinct regimes: in collisions with Li in the F = 1/2 hyperfine state overall constant inelastic collision rates are found. These results are in agreement with our previous report [2]. The collisional system with Li in the F = 3/2 state, however, exhibits a quite different behavior. Now the magnetic sublevel of Yb matters and we observe suppressed losses for stretched state configurations and up to 40-times increased relaxation rates in the other cases. Our results demonstrate for the first time the interplay between external, anisotropy induced interaction (special to systems involving non-S-state particles) and internal, isotropic effects (common to all alkali systems) in an ultracold system involving a metastable state. The detailed understanding of those anisotropy induced behaviors and their possible suppression play a crucial role in future efforts to create and cool collisionally stable molecular states. We also show that in certain spin combinations of the Yb($^3P_2$)-Li system an efficient suppression of inelastic collisional decay is possible. This thus provides a significant step forward towards controllable impurity physics realized in the Yb-Li ultracold mixture system.

In addition, we discuss the effect of ultracold inelastic collision on the quantum many-body state. In particular, we study the Bose-Hubbard system subjected to the dissipation introduced by photo-associative inelastic two-body collision [3] or by intrinsic one in the metastable electronic state [4]. We find that the strong inelastic collision introduces a quantum Zeno effect and favors the formation of the Mott insulating state: the melting of the Mott insulator is delayed and the growth of the phase coherence is suppressed. The effect of the engineered two-body inelastic collision on the Fermi Hubbard system is also studied, revealing the temperature dependent behavior of atom loss. This suggests that two-body inelastic collision rate could be a nice probe for the quantum many-body state.

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[3] T. Tomita, *et al.,* 2017 *Sci. Adv.* **3**, e1701513.
[4] T. Tomita, *et al.,* 2019 *Phys. Rev. A.* **99**, 031601(R).