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Trap-assisted bound states and emergence of chaos in ultracold atom-ion collisions

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A hybrid system combining ultracold atoms and ions can be a valuable tool for studying the properties of atom-ion collisions in the ultracold regime. In free space, atoms and ions cannot be bound in an elastic binary collision due to energy and momentum conservation. However, since the ion is strongly trapped, the trap can couple the center-of-mass and relative motion and lead to a short-lived bound state. By measuring the spin-exchange of Sr^+ and Rb as a function of energy and magnetic field, we estimate the binding energy and lifetime of the bound state and compare it to a classical molecular dynamics simulation. Numerical simulations also suggest that the bound states would appear both in harmonic and time-dependent ion traps.
In addition, our simulations show that in collisions of Rb and harmonically trapped Sr^+ ion, the lifetime of the bound state has a significant sensitivity to the initial conditions. A closer look shows self-similarity on different scales and fractal behavior. This chaotic behavior persists when the ion is in a Paul trap under experimental parameters. Further, Chaos leads to a molecular lifetime distribution that has a power-law tail of long-lived events, which might be observed experimentally. The emergence of chaos in the classical description of atom-trapped-ion collisions suggests that chaos might also be visible in the quantum limit, for example, as a Wigner-Dyson distribution of resonances.

Primary author: PINKAS, Meirav (Department of Physics of Complex Systems and AMOS, Weizmann Institute of Science, Israel)

Co-authors: Dr KATZ, Or (Department of Physics of Complex Systems and AMOS, Weizmann Institute of Science, Israel); Mr WENGROWICZ, Jonathan (Department of Physics of Complex Systems and AMOS, Weizmann Institute of Science, Israel); Dr AKERMAN, Nitzan (Department of Physics of Complex Systems and AMOS, Weizmann Institute of Science, Israel); Prof. OZERI, Roee (Department of Physics of Complex Systems and AMOS, Weizmann Institute of Science, Israel)

Presenter: PINKAS, Meirav (Department of Physics of Complex Systems and AMOS, Weizmann Institute of Science, Israel)

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