A single ion in an ultracold gas is a versatile experimental platform to study interactions between charged and neutral particles in a controllable manner. When the gas density is large enough, a single ion can be viewed as an impurity in a sea of ultracold atoms or molecules. On the other hand, that single ion can also undergo a chemical reaction with atoms or molecules in the gas. This article discusses the dynamics of a charged impurity in an ultracold bath and the interplay between cold chemistry and impurity physics.
An ion interacting with a molecule could react to form a molecular ion, as depicted in panel (I) of Fig.3. Furthermore, at energies above the binding energy of the molecule, the ion may dissociate the molecule, as depicted in panel (II) of Fig.3. Finally, the ion may induce a change in the internal state of the molecule, known as vibrational quenching, as shown in panel (III) of Fig.3. However, at temperatures $\lesssim 1\text{ mK}$, vibrational reaction products.

In many-body systems, reactive channels due to few-body processes may be considered decay channels when the particle treated as an impurity changes its nature as a result of the reaction, as is the case for ion-atom-atom three-body recombination. Every decay process has a characteristic lifetime, i.e., the typical time-scale for the process to occur. In particular, the collision time gives the lifetime of the many-body decay channel: the typical time it takes the colliding bodies to reach the short-range region to react. For example, it is $\sim 100\mu$s for typical experimental conditions in atom-ion hybrid trap experiments [9].

A single ion in an ultracold molecular bath

When a single ion is brought into contact with an ultracold gas of molecules, the ion can be considered an impurity in a bath with internal degrees of freedom. As a result, new and intriguing many-body phenomena may occur. Nevertheless, very little has been developed in this direction. On the contrary, such a scenario has been studied theoretically and recently experimentally from a few-body perspective [11].
quenching is negligible due to the dominant nature of charged-neutral interactions. Therefore, there are only two possible outcomes: a molecular ion or two atoms and one free ion.

The relevance of each of these reaction products for a given collision energy depends on the molecular binding energy, as shown in panel (b) of Fig.3 for Yb⁺-Li₂ collisions. In particular, the dominant reaction channel is molecular ion formation for deeply bound molecules (in comparison to the collision energy), whereas for weakly bound molecules molecular dissociation is the most relevant reaction channel [10]. Furthermore, the molecular ion formation rate saturates to the Langevin rate (the maximum possible rate for a charged-neutral interaction), which has been experimentally confirmed [11]. Therefore, by tuning the binding energy of the ultracold molecular gas, it is possible to control whether the ion reacts to form a molecular ion or, on the contrary, stays unchanged.

Feshbach molecules are weakly bound molecules whose binding energy depends on the applied external magnetic field, as shown in panel (a) of Fig. 4 for the Li₂ molecules. Therefore, controlling the collision energy and the external magnetic field, it is possible to draw a phase diagram for a charged impurity in an ultracold molecular gas, as shown in panel (b) of Fig.4 for the particular...
As a result, to preserve the charged impurity, we need to have a gas of weakly bound molecules and as large collision energies as possible.

**Outlook**

A single ion in an ultracold gas is a platform to study many-body systems such as charged polarons and mesoscopic molecular ions. However, due to the very reactive nature of ion-atom interactions, it is required to approach the same system from a few-body physics standpoint. Therefore, it is necessary to work synergistically between many-body and few-body physics to reveal the true nature of many-body processes in atom-ion hybrid traps.

**About the author**

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**References**