Ion-Matter Collisions: new challenges

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Synopsis The objective of this tutorial is to underpin the role of fundamental processes that are involved from the first moments of the interaction between highly charged ions and matter. When they are well known, the knowledge and mastery of these processes allow to probe and/or modify matter in a controlled manner, and even to highlight specific phenomena. We will also discuss what can be learned from ion-ion collisions in a regime where the ion energy loss is maximal.

When multicharged ions interact with matter, the latter is subjected to strong fields (which can reach up to 10^9 V/cm), often for extremely short durations (from femtoseconds to a few attoseconds) inducing electronic dynamics that are more or less understood. In ion-matter collisions, different "velocity" regimes are usually defined but to distinguish them, a collision strength parameter need to be introduced since the ion velocity is not the only relevant parameter.

In the "low velocity regime", typically at center-of-mass energies of a few keV to a few 100 keV, the ion captures target electrons in highly excited states, which is by far the dominant process. On the contrary, in the "high velocity regime", the so-called perturbative regime, the ion mainly loses its electrons (ionization) or they are promoted in excited states (excitation). For those collision regimes, the cross sections of the electronic processes are fairly well reproduced by existing theories. From there, we will wonder if we can use this knowledge to probe, for instance, the magnetic order of a sample surface [1] or to modify/optimize a given ion charge state at the exit of a target [2]. With these two examples we will take the opportunity to give an overview of the experimental techniques implemented at heavy-ion accelerators.

A third collision regime is one in which the ion stopping power is maximum, resulting in the most significant effects on material modifications (including biological material [3]). At the atomic level, there, all the primary electronic processes reach their optimum probability and are of the same order of magnitude. Consequently, the experimental determination of the effective cross section of a single elementary collision process becomes extremely difficult even when dealing with a "simple" ion-atom collision (beyond proton - hydrogen atom collision). In this regime, available theoretical calculations are at their limit of validity and there is a crucial lack of measurements. In other words, this regime corresponds to a real 'terra incognita' for atomic physics of collisions. So how to unravel such complex electronic dynamics? This is only possible if the presence of many electrons can be avoided and/or controlled on each of the collision partners, i.e. the projectile and the target, but the development of an ion-ion collider in this velocity regime remained a real challenge!

In this tutorial, we will see how we can not only investigate the pure 3-body problem (bare heavy ion on hydrogenic target) but also study the role of additional electrons - one by one- bounded to the projectile and/or the target. Beyond the 3-body problem that will serve as a benchmark for theories, we will explore how to quantify a whole series of effects that will be tackled during the presentation. We will also discuss the technical obstacles that need to be overcome, as well as the possibility of using state-of-the-art accelerators available today to perform those hyper-demanding and challenging experiments [4].

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References

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