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# Many-electron phenomena in the ionization of ions

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**Abstract**

This brief review of many-electron phenomena in the single and multiple ionization of ions tries to elucidate connections between ion–atom collisions and interactions of single free electrons and photons with neutral or charged atomic species. With the capability of using multiply charged ions in collisions with charged particles or photons, conventional studies on neutral targets can be extended to a new dimension: the target charge state. This is especially interesting for studies of selected effects along specific isoelectronic sequences, i.e. of n-electron atoms with variable nuclear charge. The necessary colliding-beams and merged-beams techniques are technically demanding but can provide access, for example, to electron correlation effects in collisions under the influence of increasingly strong electron–nucleus interactions.


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## 1. Introduction

For probing the structure and the dynamics of microscopic systems at the atomic or subatomic level, scattering experiments with energetic particles or photons are the generally accepted method of choice. Collisions involving molecular species for studying chemical reactions would typically require thermal energies of the collision partners while investigating the structure of nucleons requires the highest-energy accelerators presently available. The generic scattering scenario for binary collisions is sketched in Fig. 1. Particles A and B in given quantum mechanical states characterized by all their quantum numbers enter the interaction region with momenta $\vec{p}_A$ and $\vec{p}_B$. From the interaction region, which is characterized by the black box, secondary particles emerge, for example C, D, and E, with their associated

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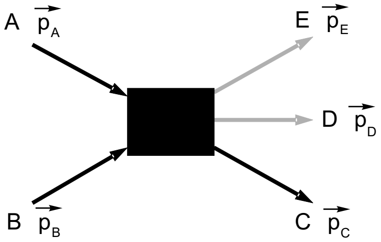


Fig. 1. Generic scattering scheme of collisions $A + B \rightarrow C + D + E$ with the particles in states each characterized by a complete set of quantum numbers and by the particle's linear momentum.

momenta and quantum numbers. In kinematically complete experiments the momenta of the different outgoing particles are determined while it is often not possible to also identify all the quantum numbers. In ionizing ion–atom collisions frequently only the final state of the projectile, e.g. characterized by the emerging particle C, is observed, thus leaving ambiguity of what has really happened in the collision. In the theoretical treatment the time dependent Schrödinger equation has to be propagated in the box, and is projected afterwards to obtain observable quantities. For numerical calculations the black box may be represented by a grid composed of small volume elements that cover the interaction region.

Single and multiple ionization processes in ion–atom collisions involve a multitude of complex interactions between the electrons and the nuclei of projectile and target. If we imagine just a collision of a one-electron atom (or ion) with a two-electron atom (or ion) there are already 10 different electromagnetic pair interactions to be considered (see Fig. 2). In an experiment that observes ionization of A, i.e. in the example of Fig. 2 the removal of the electron from A, there are several possible classes of processes and associated final states. The electron of A can be released to the continuum or it can be captured by particle B. At the same time, the two-electron atom B can loose one or both of its electrons to the continuum. A full theoretical treatment of this (still quite simple) example with all its electron-electron, electron–nucleus and nucleus-nucleus interactions is not possible. Approximations are required to make the problem tractable.

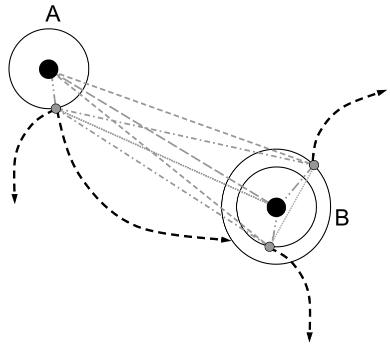


Fig. 2. Pair interactions and electron pathways to be considered in ionization processes where a one-electron atom A is ionized in a collision with a two-electron atom B.

Some of the complexity is avoided in studies of fast collisions when the impulse approximation can be applied and the electrons can be described as independent quasi-free particles with a known momentum distribution. Under such conditions investigations of electron–ion collision phenomena become possible. The resulting simplification of interpreting experiments has been exploited very successfully by a number of groups (e.g. [1,2] and references therein).

For the detailed investigation of ionization mechanisms that can occur in fast ion–atom collisions, it is illuminating to consider collisions of ions (or atoms) with really free electrons or completely stripped nuclei. For that purpose, electron–ion and ion–ion experiments with well prepared beams of free particles provide favorable conditions. The resulting requirement of employing colliding-beams techniques is associated with low densities of the interacting particles and hence often poses problems with low signal and high background rates. The scheme shown in Fig. 1 can alternatively represent the principle arrangement of a crossed-beams experiment where beams of particle species A and B meet in the interaction region and the outgoing particles have to be analyzed. Different from the previous quantum-mechanical meaning, the black box plotted in Fig. 1 is now interpreted as a classical macroscopic interaction volume. The experimentalist has to enter this crossing region with his instrumentation and determine the overlap of the two intersecting