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SPARC – Environment for Atomic Collision Physics at FAIR

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The new facility at GSI (FAIR) will have key features that offer a range of new research opportunities, among others, in atomic physics and related fields. In recent years, SPARC (Stored Particles Atomic Physics Research Collaboration) is grown up to more than 300 physicists from all over the world. The lecture will give a survey of selected atomic physics topics which form a motivation of the SPARC activities concerning future collision experiments at FAIR.
One of the actual frontiers in atomic physics is the study of matter exposed to extremely strong electromagnetic fields. In particular, highly charged ions form unique laboratories where such conditions are largely fulfilled. These species can be stored in form of intense beams and used in collision experiments. For such investigations, precise spectroscopy of photons emitted in collisions of heavy ions with atoms is required. This emission gives details of the specific electronic transition mechanisms operating in strong fields as well as information on electronic structure of the exotic atomic systems (e.g. H- and He-like uranium). Accurate measurements of electron binding energies are very well suited to deduce characteristic quantum electrodynamics (QED) phenomena in strong fields. QED, the basis and cornerstone of all present field theories, is the best confirmed theory in physics, however, precise tests in the strong-field limit are still pending. Moreover, details concerning photoionization of very heavy atoms can be revealed in such experiments when observing radiative electron capture (REC). Here, angular distribution of REC photons sensitively proves the rigorous relativistic treatment of the process, even at relatively low ion velocities.
In addition, in the discussed slow ion-atom collisions the electronic clouds of the collision partners adjust their motion to the Coulomb field of the nuclei and form molecular orbitals (MO's). Electron vacancy production in such collisions was commonly discussed as a manifestation of mechanisms transporting electrons out of these transiently formed MO's. Vacancies produced in the quasi-molecular levels may become inner-shell vacancies in one of the collision partners and finally decay via characteristic x-ray emission. First fingerprints of this scenario were observed as early as 1965. Over the years many intriguing details in the inner-shell ionization data have been discussed and explained within the MO picture. Simultaneously, probing of extremely strong fields via the innermost molecular levels (e.g. 1sσ or 2sσ) of the exotic quasi-atoms with the united charge Z » 100, revealed many puzzles which couldn't be solved with the available generation of accelerators. In particular, the very fundamental question whether the 1sσ-level becomes a resonance in the negative energy continuum remained without answer. An implication of the molecular model is possibility of observing x-rays in a form of continua (MO x-ray radiation) created during collisions. These continua have been observed for the first time in 1972, followed by basic proofs of their quasi-molecular origin. Molecular x-ray radiation has been studied extensively over next two decades. Many aspects concerning production mechanisms, angular distribution, impact parameter dependencies or energy distribution of MO x-ray radiation have been successfully investigated. However, one of the main goals, estimation of the electron binding energies in the vicinity of the united atom limit for Z » 100, is still open for further experiments.
Many of the research topics mentioned – from collision dynamics to spectroscopy – that were started successfully at GSI, will be expanded into new regimes and under much better and advanced experimental conditions at FAIR. The new facility ensures that the unprecedented feasibilities concerning beam energy, intensity, experimental tools can be reached. In particular, an option for merged or crossed beams would provide possibilities to study electron binding energies in supercritical electromagnetic fields using quasi-molecular radiation.

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