Studies of single- and double-electron capture by highly charged ions isolated at very low energy in a Penning trap

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Synopsis We report on experiments investigating the charge exchange of highly charged ions with various target background gases. This work focuses on two cases: Ne^{10+} and Kr^{17+} projectile ions that are captured and stored in a Penning trap. The charge state evolution derived from time-of-flight data allows the determination of the ratio of double- to single-electron capture rates. Comparison with an extended classical over-barrier model is discussed. Progress with a refined computation based on CTMC simulation coupled with collisional-radiative modeling is also presented.

An improved understanding of electron capture processes by highly charged ions (HCIs) in collisions with neutral atoms, also known as charge exchange, has important applications in many areas including the study of comets [1], controlled fusion energy [2], and ongoing experiments to form one-electron ions in Rydberg states [3]. Although charge exchange has been investigated over a wide energy range, few studies have been performed in the regime of very low thermal energies (velocities << 0.01 atomic units), which are of interest in recently proposed experiments [4].

The electron beam ion trap (EBIT) at the National Institute of Standards and Technology is used to produce highly charged ions, which can be extracted from the EBIT as an ion bunch. A specific charge state in the ion bunch is separated and captured in a unitary Penning trap [5]. Here, the isolated ions are held for varying lengths of time at thermal energies of ~5 eV. During their dwell time in the trap, the ions interact with controlled amounts of injected background gases from which they can capture electrons. The ions are then ejected from the trap to a time-of-flight (TOF) detector to quantify the evolution of the population of each charge state.

A systematic study was performed using Ne^{10+} and Kr^{17+} ion projectiles. Measurements were completed for a variety of background gases injected into the Penning trap region over a range of pressures. By fitting the observed TOF peaks as a function of storage time to a set of linear differential equations, the rates of electron capture are determined. We observe that the ratio of stabilized double- to single-electron capture rates differ significantly from the predictions of an extended classical over-barrier (COB) model.

Efforts are underway to refine predictions for electron capture rates by HCIs in this very low energy regime. We discuss a combination of classical trajectory Monte Carlo (CTMC) simulation and collisional-radiative modeling which is being used to determine the electron capture by a Ne^{10+} projectile ion from a Ne target atom, accounting for the subsequent auto-ionization, thereby predicting the rates of stabilized electron capture.

References

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