Investigation of Ion-Atom Collision Dynamics using X-ray Spectroscopy Technique and its Implications in Physical Processes

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The study of ion-atom collisions and their associated dynamic charge changing processes are vital in various fields of fundamental science, including plasma physics, material science, nuclear astrophysics, etc. Experimentally, the projectile charge state evolution during the passage from the matter is studied using the conventional electromagnetic (EM) techniques. However, in various studies, the shortcomings of the EM techniques, e.g., the contribution from post-atomic processes, electron capture in Rydberg states, etc., have been highlighted. In this connection, extensive work is carried out in our laboratory to explore the new insights of interactions using the x-ray spectroscopy technique [1]. The charge state variation of the projectile ions (^{56}Fe, ^{58}Ni and ^{63}Cu) during the passage from thin carbon foils has been explored in the 1.51-2.69 MeV/u energy range. Using characteristic and radiative electron capture (REC) x-ray emissions, charge state distribution and its various parameters like mean charge state (MCS), distribution width, etc., have been measured. Interestingly, an unusual Lorentzian CSD is observed in contrast to the Gaussian distribution as found in the theoretical predictions [2,3] and the measurements using EM techniques [4,5], shown in Fig. 1(b). The appearance of the Lorentzian CSD is analogous to the ionic CSD observed in any partially ionized plasma environment. The important aspect of this collisionally produced plasma, called beam-foil plasma is the high density and localized nature. The variation found between shapes of the observed and ETACHA [2] predicted CSDs are attributed to the plasma coupling interactions that are not considered yet in the theoretical codes and formalisms. Whereas, deviation from the experimentally measured CSD using the EM technique is due to the contribution from the multi-electron capture from the exit surface of the target [6]. It can be easily verified through the observed difference between the measured and calculated MCSs in the present work and from the semi-empirical formalism [3], respectively, shown in Fig. 1(c). Thus, the charge changing processes, leading to the CSD in the bulk of the solid, prominently influence due to the creation of localized beam-foil plasma environment. This laboratory high-density beam-foil plasma can simulate the characteristics of the high-density plasma as seen in the stellar interior. It will also be interesting to check the projectile energy ranges that can result in the beam-foil plasma. Present work suggests further modification in the theoretical CSD calculations by incorporating the plasma coupling interactions during the ion-atom collisions.

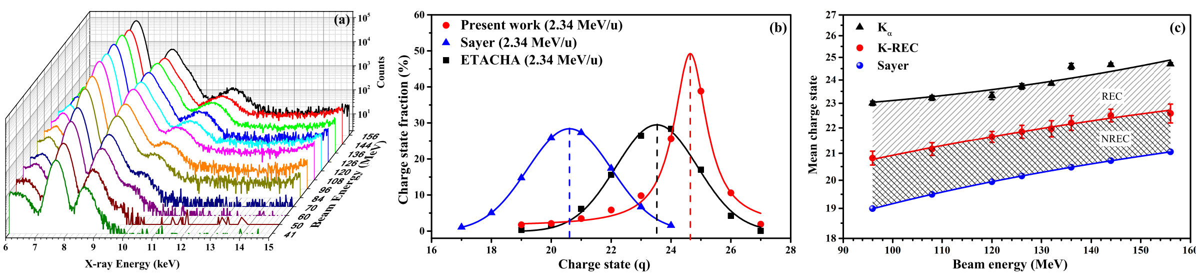

Figure 1: (a) The x-ray spectra for ^{58}Ni on ^{12}C for different beam energies. (b) For a typical case of 136 MeV ^{58}Ni on ^{12}C, a comparison between measurements and theoretical predictions of CSD and the mean charge states. The figures show Lorentzian fit to the data of present work and Gaussian fit to all others. The vertical dashed lines mark the mean charge states. (c) Comparison between mean charge state measurements using x-rays (K_α and K-REC x-rays) and theoretical predictions for various beam energies. Errors are embedded in the symbols itself.

References

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