Search for super-heavy nuclei beyond Z = 130 using X-Ray Spectroscopy: Molecular Orbital Approach

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Introduction

The key goal of studying heavy ion-heavy atom collisions has been to approach super-heavy nuclei with united atomic numbers far beyond existing matter, with $Z_{UA}=Z_P+Z_T>100$ (Z_P and Z_T are the atomic numbers of the projectile and target respectively). Populating such nuclei in lab still remains a challenge for nuclear as well as atomic physicists. Beyond Z_{UA} =137 the normal Dirac equation for a point charge cannot be solved. For $Z_{UA}>160$ the innermost electron levels even dive into the negative continuum due to tremendous relativistic effects.

Such nuclei may be investigated through super-heavy quasi-atoms or quasi-molecules. which are formed transiently during relatively slow heavy ion-heavy atom collisions where the velocity of the ion (V_{ion}) is much slower than the orbital velocities (v_{Ts}) of the K, L, or M shell electrons of the target i.e., ($V_{ion} < v_{Ts}$), V_{ion} being the velocity of the heavy ion. In order to probe the inner shell levels of these quasi-molecules, vacancies have to be provided there and their decay by X-Ray emission in the separated partners or in the quasi-molecule itself has to be studied.

Probing the quasi-molecules through M-shell X-Rays is a further daunting task. Heavy-ion impact noticeably affects the various radiative and non-radiative processes which occur following the ionization of the M-shell. This affects the sub-shell fluorescence yield, Coster-Kronig transition probabilities, and X-Ray emission rates, thus altering the ionization cross-sections drastically as compared to light ion impact. The inability to execute an accurate efficiency calibration of the X-Ray detectors has continued to be a significant barrier to the expansion of the M-shell database since it makes it challenging to measure cross-sections for M-shell X-rays below 3 keV [2].

Due to this, the M-shell X-Ray based investigations involving high Z targets and very low-energy (few keV/u) high Z projectiles are limited. The objective of the current work is to investigate these super-heavy systems quasi-molecules and the role of kinetic energy as well as the charge state of the projectile ion in vacancy transfer mechanisms of such heavy systems through M Shell X-Rays.

Experimental Details

In this experiment, Xenon ions with energies of 2–5 MeV and charge states of $q^{(10-14)+}$ were obtained from the 10 GHz ECR ion source at the Low Energy Ion Beam Facility (LEIBF) at Inter University Accelerator Center (IUAC), New Delhi. Accelerated ion beams were focused by a series of multiple quadrupole lenses and directed onto targets retained inside the experimental chamber after selecting a charge state in the analysing magnet. The ion beams collimated to a 3- mm diameter, having intensities 0.5–60 nA, generate the M X-rays of thin metallic targets of Pt, Au, Pb and Bi with different thicknesses. Thin foils of different thicknesses ~ 100, 250, 350 $\mu g/cm^2$ of Pt; ~ 135, 508 $\mu g/cm^2$ of Au, ~ 107, 157, 390 $\mu g/cm^2$ of Pb and ~ 120, 293, 431 $\mu g/cm^2$ of Bi evaporated onto ~ 25 $\mu g/cm^2$ carbon backing were used and their thickness was confirmed by RBS method and is discussed elsewhere [3]. These targets were mounted on stainless steel target ladder at an angle 45° with respect to the forwarding beam direction. The ion-beam current for normalization was monitored through the collection of charge using a penetrable Faraday cup placed in front of the target ladder and a Faraday cup placed behind the target ladder as dis- cussed by Zhou et al. [4]. A silicon drift X-Ray detector (SDD) with a resolution of 120 eV at 5.9 keV was mounted at 90° with respect to targets. The efficiency (ϵ_X) of the SDD was calculated both experimentally as well as the- theoretically. Experimental efficiency was determined using standard calibrated radioactive sources of ^{55}Fe and ^{241}Am and through proton beam bombarded on low Z targets of Al and Ni for measuring their K X-ray yields through a method reported by Lennard [5].

Results and discussion

The multiple ionizations of the target and the projectile itself is observed through the measured energy shifts of the characteristics X-rays and reduced intensity ratios. Additionally, we observed that there is a clear discrepancy between the experimental cross-sections and those estimated using the theoretical PWBA and ECPSSR models [7]. The results of this study show that the framework and theories for ion-atom collision systems now in use are insufficient to explain the collision processes at very low scaled velocities and must be significantly modified. The enlarged cross-sections demonstrate that the transfer of vacancies to the inner shell of the collision partners involves a different process from direct Coulomb interaction. The level diagram that correlates the binding energies of the separated atoms with the united atoms/quasimolecules generated during the collision and the molecular orbital picture give a qualitative explanation of the vacancy transfer mechanism.

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