4 - 10 Energy-loss Enhancement and Charge-equilibration Time for Highly Charged Xenon ions at Near-Bohr Velocity in Solids

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For highly charged ions traveling through solids, the power of the solids to stop the ions is known to be dependent on the charge state of the projectiles. An equilibrium charge state is to be established after the ions traveling a particular distance called the charge equilibrium length. In this pre-equilibrium regime, the stopping power of the solids to the ions has been proven to have an enhanced behavior as compared to the charge equilibration cases.

In laboratory researches usually measure the time-of-flight (TOF) of the ions travelling through a thin foil to obtain the energy-loss and the charge-equilibrium time of the ions in the target. In a recent paper[1], we proposed to explore the energy loss and the charge-equilibration time of highly charged ions in materials by measuring the characteristic X-ray yield of projectiles, rather than the TOF method. We reported on the experimental evidence that core-electron ionization of projectiles is indeed involved in the energy loss of ions in the near-Bohr velocity region. The principle for our X-ray-yield method is shown schematically in Fig. 1.

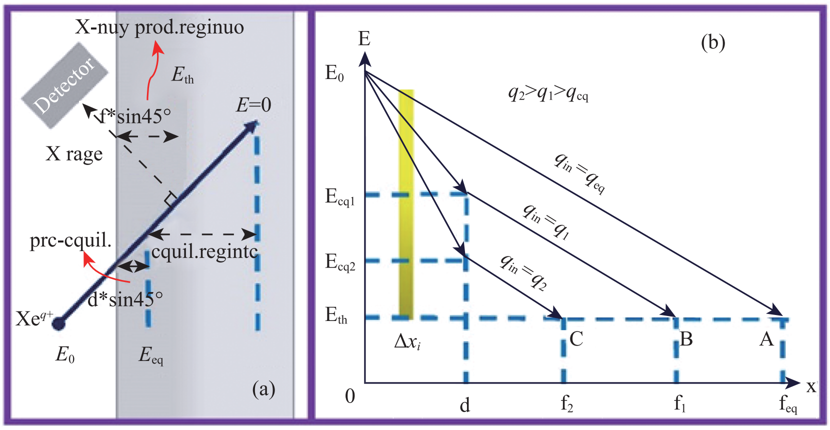

Fig. 1 (color online) The principle of X-ray yield for determining the energy-loss enhancement and charge-equilibrium time.

As shown schematically in Fig. 1, as projectile ions such as Xe^{q+} with near-Bohr velocity enter into the target at an incident angle of 45 $^\circ$, inner-shell (core) electrons of the projectile would be ionized by collisions as long as its kinetic energy is greater than the ionization threshold energies (Fig. 1(a)). In the case that the initial charge state of the projectile ions is larger than q_{eq}, the ions lose their kinetic energy at a faster rate and reach the equilibration charge state on a femtosecond timescale, and then the energy loss proceeds at the rate of the equilibration state (Fig. 1(b)). The total inner-shell X-ray yield over this timescale can be expressed approximately as $\sum_i N\sigma_X \Delta x_i$, with N and σ_X being the target atomic density and the X-ray emission cross section, respectively, and Δx_i being the i-th increment of depth. As can be seen from Fig. 1(b), the area surrounded by the three points E_0, E_{th}, and A (or B and C) for collisions at q_{eq} (or q_1 and q_2) reads $\sum_i (E_i - E_{\mathrm{th}})\Delta x_i$, which is proportional to Δx_i and decreases with the increase of the initial charge state of the ions. Therefore, the X-ray yield will decrease gradually with the increase of the initial charge state of the projectile if its initial kinetic energy remains unchanged.

Reference

[1] Z. Y. Song, Phys. Rev. A, 106, 6(2022)062817.