Evidence for the Role of Proton Shell Closure in Quasifission Reactions from X-Ray Fluorescence of Mass-Identified Fragments

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The atomic numbers and the masses of fragments formed in quasifission reactions are simultaneously measured at scission in $^{48}\mathrm{Ti} + ^{238}\mathrm{U}$ reactions at a laboratory energy of 286 MeV. The atomic numbers are determined from measured characteristic fluorescence x rays, whereas the masses are obtained from the emission angles and times of flight of the two emerging fragments. For the first time, thanks to this full identification of the quasifission fragments on a broad angular range, the important role of the proton shell closure at $Z = 82$ is evidenced by the associated maximum production yield, a maximum predicted by time-dependent Hartree-Fock calculations. This new experimental approach gives now access to precise studies of the time dependence of the N/Z (neutron over proton ratios of the fragments) evolution in quasifission reactions.

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Since the mid-1970s, it has been known that the formation of superheavy nuclei by fusion is hindered by out-of-equilibrium mechanisms [1–3]. In these mechanisms, the available kinetic energy can be totally dissipated, and large mass transfers between the projectile and the target can occur, leading to emerging fragments quite difficult to distinguish from fragments arising from fusion followed by fission (that might be mass symmetric or asymmetric) [4–7]. Because of these characteristics, the generic name quasifission (QF) is nowadays often used for all these mechanisms. Since the pioneering works, many experimental aspects of QF have been explored [8–17], and dynamical models, macroscopic or microscopic, have been developed in order to reproduce cross sections, distributions of mass, angle, kinetic or excitation energy, and some of the correlations between these observables [15,18–25]. Considering the huge experimental difficulties to extract in a nonarbitrary way small cross sections of fusion followed by fission from dominant quasifission cross sections, a key issue for superheavy nucleus formation studies, it is now essential to get a very good understanding of the QF mechanisms and to confront and improve the models with unambiguous exclusive data in order to reach reliable predictive capacities.

A simultaneous determination of the fragment atomic number (Z) and mass (A) formed in QF or in fission processes remains nowadays a challenge [26–30], especially difficult because these quantities are most of the time measured after particle evaporation. In this Letter, an experimental approach giving access for QF fragments to A and Z at scission will be presented and the data compared with predictions of a microscopic time-dependent Hartree-Fock (TDHF) model [22]. The atomic number was determined from the coincident characteristic fluorescence x rays, as already attempted for fission fragments [31], whereas the mass was determined from the velocities of the emerging fragments.

A $^{48}\mathrm{Ti}^{19+}$ beam was accelerated at 5.75 MeV/nucleon by the Australian National University electrostatic accelerator followed by its LINAC postaccelerator. It bombarded UF_4 targets highly enriched in $^{238}\mathrm{U}$ on thin carbon or aluminum backings. Because of damage resulting from the beam impact, the targets were rapidly drilled, and different sample thicknesses, ranging from 340 up to 940 $\mu\mathrm{g/cm}^2$, have been used during 3 days of data acquisition with a beam intensity $I \approx 12$ nA. For binary reactions, a very large range of folding angles between the two emerging fragments was covered by two large area position-sensitive multiwire proportional counters ($280 \times 360\ \mathrm{mm}^2$), MWPC1 and MWPC2. They were positioned on opposite sides of the beam at $d_1 = 195$ and $d_2 = 180$ mm from the target, covering the angular ranges $53° \leq \theta_1 \leq 124°$ and $20° \leq \theta_2 \leq 80°$, respectively. Coincident photons were detected by three planar germanium detectors (500 mm^2, 1 cm thick each) located at 6 cm from the target. These detectors were positioned at the same polar angle $\theta = 143°$