Multinucleon transfer reactions – A new way to exotic nuclei?

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In recent years, intense discussions were initiated by new theoretical model calculations (see e.g. [1, 2]) to produce new neutron-rich heavy and superheavy nuclei in multinucleon transfer reactions. One region of interest concerns nuclei around the closed neutron shell N = 126 which are of relevance for the astrophysical r-process. These isotopes are presently produced in fragmentation reactions at relativistic energies with heavy projectiles and light target nuclei. However, the new calculations in macroscopic-microscopic models predict larger cross-sections for these isotopes in multinucleon transfer reactions at Coulomb barrier energies. Another region of interest is neutron-rich transuranium isotopes which are not reachable in fragmentation reactions or in fusion reactions with stable beams. Only few experimental data exist on transfer products in these regions. The most sensitive previous experiments reached limit cross-sections of 50 nb. However, the expected cross-sections for new neutron-rich transfer products are very small. Model predictions result in values of $\sigma < 1$ μb for isotopes around $N = 126$ and in $\sigma < 1$ nb for new neutron-rich isotopes with $Z \geq 102$. As a consequence, similarly efficient separation and detection techniques have to be applied like have been developed for the identification of single atoms in superheavy element experiments.

At GSI Darmstadt we performed first studies of multinucleon transfer reactions applying the velocity filter SHIP for separation of deep inelastic transfer products from background events. The isotopic identification was performed via alpha or gamma decay spectroscopy. This method turned out to be two orders of magnitude more sensitive than the techniques applied in previous experiments. We reached total cross-section limits of (0.1 – 1) nb which would already allow to access new neutron-rich nuclei in the above named regions.
Among other, we studied transfer reactions in ^{64}Ni + ^{207}Pb and ^{48}Ca + ^{238}U. We identified nuclei in the region of $Z \approx 76 - 93$ with neutron-numbers up to the limits of the presently known nuclear chart and the trend of the production cross-sections as a function of neutron-number strongly indicates that also *new* isotopes must have been populated. The latter point is presently under investigation. Further, our analysis revealed for which region of isotopes fragmentation reactions are still preferable and for which regions transfer reactions are more promising. We also found that the non-observation of new isotopes is not predominantly a matter of small cross-sections but is limited by the presently available techniques for A and Z identification of very heavy and low-energetic ions.
In addition, our measured cross-sections for transfer products from different collision systems are about one order of magnitude larger than predicted by theoretical models. If this trend also persists in the region of more exotic nuclei it would be very beneficial for the production of new isotopes.

[1] G.G. Adamian et al., Phys. Rev. C 81, 057602 (2010).
[2] V. Zagrebaev and W. Greiner, Phys. Rev. Lett. 101, 122701 (2008).