Multi-nucleon transfer in super-heavy systems at sub- and near barrier energies

S.Heinz[1,2], V. Comas[1], C. Golabek[3], S.Hofmann[1,4], W. Mittig[3], F. Rejmund[3], A.C.C. Villari[3]
D.Ackermann[1], J. Heredia[1], F.P. Heßberger[1], J. Khuyagbaatar[1], B. Kindler[1], B. Lommel[1] and R. Mann[1]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany*
[2] *Justus-Liebig-Universität Gießen, 35392 Gießen, Germany*
[3] *GANIL (IN2P3/CNRS – CSM/ CEA) B.P. 55027 14076 Caen Cedex 5, France*
[4] *Institut für Physik, Goethe-Universität Frankdurt, 60054 Frankfurt, Germany*

We investigated multi-nucleon transfer reactions at beam energies below and slightly above the Coulomb barrier in superheavy systems like $^{58,64}Ni + ^{207}Pb$ ($Z_1 + Z_2 = 110$), $^{48}Ca + ^{248}Cm$ ($Z_1 + Z_2 = 116$) or $^{238}U + ^{238}U$ ($Z_1 + Z_2 = 184$). The experiments with medium heavy projectiles were performed at the velocity filter SHIP at GSI. SHIP accepts reaction products which are emitted into forward angles of (0 ± 2) degrees and is therefore especially suitable for nuclear reaction studies at low energies. The setup allows for strong background suppression which enables to reach cross-section limits of 10 pb within one day of beam time. This is due to the efficient separation of the primary beam and the possibility to identify the target-like reaction products via their radioactive decays during beam-off periods. We measured excitation functions for target-like transfer products starting at beam energies of ~10% below the barrier up to ~15% above the barrier. With all projectile / target combinations we observed a massive transfer of neutrons and protons, which was mostly accompanied by strong dissipation of kinetic energy. Mostly, the transfer products appeared with total kinetic energies which were independent of the bombarding energy and had values slightly below the Viola energy [1]
The transfer reactions in $^{238}U + ^{238}U$ have been studied at the VAMOS spectrometer at GANIL, also at beam energies below and slightly above the barrier [2]. The identification of A and Z of the reaction products was made via E, ΔE, TOF measurements, which lead to a sensitivity limit of ~1 μb. As a consequence, we observed only transfer products with A and Z lower than uranium, while the transfer products beyond uranium appear mostly with cross-sections significantly lower than 1 μb due to their higher fissility. Also in the U +U system we found a strong nucleon exchange of up to ~20 protons as well as neutrons already at energies very close to the barrier. For a transfer of more than ~10 nucleons we observed the same behavior than for the above described lighter systems: the total kinetic energy of the products became independent of the bombarding energy and was significantly lower than the Coulomb barrier for spherical nuclei. This reflects that a massive nucleon exchange is only starting when the underlying di-nuclear system reaches a certain deformation and provides a sufficiently strong neck.
The observation of massive transfer at near-barrier energies indicates also an applicatory aspect. The low reaction energies lead to transfer products with low excitation energies. This increases their survival probability against particle evaporation and fission, so that such reactions could be especially applied to create new, relatively neutron-rich isotopes of heavy and superheavy nuclei.

[1] S. Heinz et al., Eur. Phys. J. A **43**, 181 – 184 (2010).
[2] C. Golabek et al., Eur. Phys. J. A **43**, 251 – 259 (2010).