ID contributo: **48** Tipo: **Presentazione orale**

Production of neutron-rich nuclei of the terra incognita

martedì 15 novembre 2016 11:50 (12 minuti)

Summary

Multi-nucleon transfer reactions are the only known mean to produce neutron-rich nuclei of the Terra Incognita. In particular, the closed-shell region N=126 plays a central role for studying shell quenching in neutron-rich nuclei and for astrophysical interest being the last ”waiting-point”of the r-process. The choice of suitable reactions is challenging. A favorable case is the reaction 136Xe+208Pb, around the Coulomb barrier, because the neutron shell-closures of 136Xe and 208Pb play a stabilizing role which favors the proton-transfer from lead to xenon leading to neutron-rich osmium fragments. TOF-TOF data were analyzed to reconstruct the mass-energy distribution of the primary fragments. The results of a recent experiment held at Laboratori Nazionali di Legnaro with the PRISMA setup, aimed at identifying the charge and the mass of the produced neutron-rich nuclei, will be shown.

The production and study of heavy and super-heavy neutron-rich nuclei represent, nowadays, one of the most interesting challenges in nuclear physics and astrophysics. It is the only way to explore the unknown regions of the Segré map and to proceed towards the potential discover of the predicted Island of Stability centered at N = 184, Z = 114-120. Furthermore, quantities such as half-lives and masses (binding energies) are extremely important also for nuclear astrophysics investigations and for the understanding of the r-process: the last "waiting point" of the rapid neutron capture process, corresponding to the closed neutron shell N = 126, lies indeed deeply in the Terra Incognita. Aside from the astrophysical interest, the study of the structural properties of exotic neutron-rich nuclei would also contribute to the discussion of the quenching of shell effects in nuclei with large neutron excess.
Concerning their production, heavy neutron-rich nuclei are obtained in fusion reactions with neutron-rich radioactive (exotic) nuclei, neutron capture or multinucleon transfer reactions at energies near the Coulomb barrier. The first two methods look unfeasible because of the low intensity of the currently available Radioactive Ion Beams (RIBs) and the insufficient neutron fluxes from existing working nuclear reactors. Multinucleon transfer reactions, along with the quasi-fission process, offer a more feasible ground for the production of neutron-rich nuclei in this scarcely known region of the nuclear map, by means of stable beams, even though the cross sections are of the order of mb or µb.
Emblematic is the collision 136Xe + 208Pb at energies close to the Coulomb barrier. In this case, both nuclei have a closed neutron shell, N = 82 and N = 126; because of this, proton transfer from Pb to Xe might be favorable, allowing the exploration of the closed shell N = 126. Another advantage is the Q-value around zero for such transfer. Consequently, the products would be only slightly excited. In other words, the neutron shell closures plays a stabilizing role, which may increase the probability of proton transfers and fragment survival against neutron evaporation.
Mass-TKE and angular distributions of the products can be measured using just kinematic analysis (TOF-TOF data). The results of a preliminary experiment [1] show a possible transfer up to about 20 nucleons. Furthermore, there is a good agreement with cross section calculations [2] in the region of interest (A ~ 200 and Qgg ~ 0) and the yield is even underestimated of up to a factor 2 in the region of superasymmetric fragments. The results of a recent experiment held at Laboratori Nazionali di Legnaro with the PRISMA setup, aimed at identifying the charge and the mass of the produced neutron-rich nuclei, will be shown.

[1] E.M. Kozulin, E. Vardaci et al., Phys. Rev. C86, 044611 (2012).
[2] V. Zagrebaev, W. Greiner, Phys. Rev. Lett. 101 (2008) 122701.

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