Changing nuclear shell structure near exotic magic nuclei

Nuclei are collections of tightly bound neutrons and protons. These nucleons organize themselves into segregated proton or neutron pairs that follow specific rules that, when taken together, can be described as orbitals in the nuclear shell model. This is analogous to the electronic shell model which governs the atom. Specific numbers of protons or neutrons such as 28 and 50 are especially strongly bound into closed shells and are called magic nuclei. The atomic equivalent are the noble gases. However, as more and more nucleons are added, a reordering of these orbitals may occur and altering the properties of these nuclei. This is particularly relevant for nuclei produced in the fission of uranium that produces nuclei with very asymmetric neutron and proton numbers. The world relies on the knowledge of nuclear structure as we strive to understand the stellar evolution of matter in the universe as well as the operation of nuclear reactors which operate using nuclear fission as a clean energy source.

Researchers at the Holifield Radioactive Ion Beam Facility observed the changes in nuclear structure of fission products by studying the beta decay of copper (Cu) nuclei which has 29 protons but can have different numbers of neutrons. The two stable Cu isotopes found in nature have 34 and 36 neutrons. This work studied ^{77}Cu which has 48 neutrons and lies near the closed shell of 50 neutrons. Thus, ^{77}Cu is very far from stability and near "double magic" ^{78}Ni with both 50 neutrons and 28 protons tightly bound. Recent theoretical [1] and experimental [2] work indicate a change in nuclear properties when going from ^{73}Cu to ^{75}Cu.

We have established the decay properties of ^{77}Cu by observing over 60 gamma rays that populate 35 energy levels in the ^{77}Zn daughter [3] as well as ^{76}Zn through the beta-delayed neutron process. Because HRIBF can produce essentially pure ^{77}Cu samples, we were able to follow the decay to the grand daughters. The data have allowed us to conclude that the decay properties of ^{77}Cu are distinctly different from those of ^{73}Cu; the addition of neutrons has resulted in the reorganization of protons such that the outermost proton changes from the $2p_{3/2}$ orbital to the $1f_{5/2}$ orbital of different angular momentum.

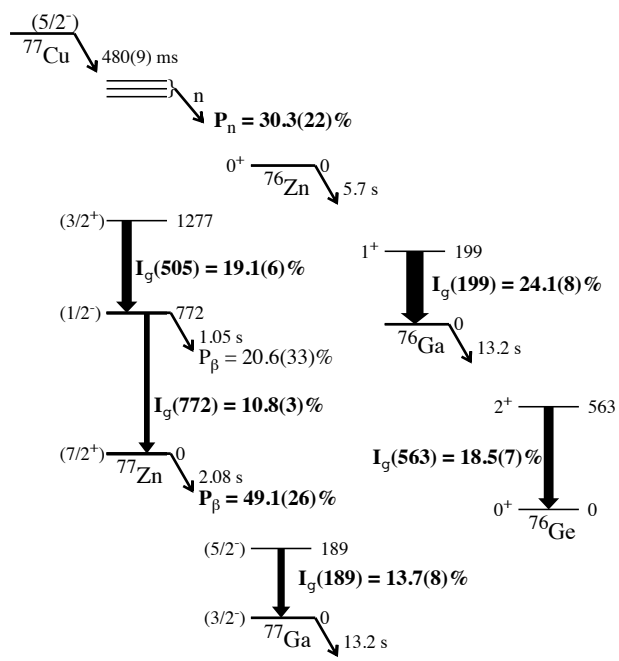

Fig 1. - The beta decay branches of ^{77}Cu and its daughters and grand daughters are shown.

[1] T. Otsuka *et al.*, Phys. Rev. Lett. **95**, 232502 (2005)
[2] K. Flanagan *et al*., Phys. Rev. Lett., **103,** 142501 (2009).
[3] S. V. Ilyushkin *et al.*, Phys. Rev. C **80**, 054304 (2009)