

Exotic decay modes of medium-mass proton drip-line nuclei

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Abstract

The high energy available in the β^+ /EC decay of nuclei lying far to the left of the stability path leads to the population of highly excited states in the daughter nuclei. This, combined with decreasing charged-particle separation energies in the daughter nuclei, opens windows for a variety of decay modes with β -delayed (multi-) particle emission. The study of these decay channels provides a unique tool for gaining insight and understanding the nuclear structure of (multi-) particle unbound states, given their competitiveness against de-excitation via gamma radiation. Moreover, decay data of these nuclei provide input for the astrophysical rp-process modeling and thus understanding the abundance of elements in the Universe.

The measurements forming the basis of this thesis were conducted during two experimental campaigns aiming at investigating exotic phenomena in the structure of medium-mass nuclei in the vicinity of the proton drip line. Neutron-deficient silicon isotopes were produced and investigated at the Cyclotron Institute at Texas A&M University, while neutron-deficient germanium and zinc isotopes were produced and studied at the National Superconducting Cyclotron Laboratory at Michigan State University. In each of these experiments, the ions of interest were produced in the fragmentation reaction of a heavier projectile and electromagnetically separated from the other reaction products and from the primary beam. They were then implanted into and their decays were studied by means of the optical time projection chamber (OTPC) detector. Within this work the complete analysis of the data collected was performed, from Monte Carlo simulations to reconstruction of the momenta of decay products and interpretation of the results in the context of literature, when available, and theoretical modeling.

Among the results of the first experiment are the confirmation of the previously known β -delayed one and two-proton emission (βp and $\beta 2p$) from ^{22}Si and ^{23}Si . Moreover, two new decay modes were observed in ^{23}Si : β -delayed $3p$ - and $p\alpha$ emission. The branching ratios for the two latter are discussed in the context of the properties of other known emitters of these exotic decay channels with T_z from $-3/2$ to $-7/2$. In the second experiment, the new isotope ^{59}Ge was observed for the first time. Its production rate, as well as the production rates of less exotic germanium isotopes ($^{60-62}\text{Ge}$), yielded cross-section values that are discussed in the context of previously measured values. The limited prediction capabilities of models when looking at the production of nuclei so far from stability make in fact the measurement of production cross-sections of vital importance for planning future experiments. The β decay of ^{60}Ge was measured for the first time and found to proceed via βp emission with a branching ratio of $\approx 100\%$. The β -delayed proton emission channel of ^{58}Zn was also observed for the first time and the energy spectrum of the detected protons allowed to investigate the B(GT) distribution above the proton-separation energy in the daughter nucleus ^{58}Cu . Despite the small branching ratio, the Gamow-Teller strength for the main observed proton group was comparable in intensity to the values known for proton-bound states, emphasizing the importance of taking into account the channels involving the emission of the particles while investigating the B(GT) distribution. The obtained distribution is discussed in the framework of QRPA calculations. The impact of the obtained branching ratio on the rp-process and in particular on the abundance of $A = 57$ nuclei was investigated, yet found to be of the order of a few percent.