Studies of Nuclei Beyond the Proton Drip Line by Tracking Technique

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Extremely proton-rich nuclei with odd or even atomic numbers were predicted [1] to decay through one- or two-proton radioactivity, respectively. Two-proton (2p) radioactivity, a spontaneous decay of an atomic nucleus by emission of two protons, is the most recently discovered nuclear disintegration mode. It has first been reported for ^{45}Fe with a half-life of about 4 ms [2], which is about 1000 times longer than the quasi-classical estimate of "di-proton" (or ^{2}He) cluster emission. Further observations of 2p radioactivity, e.g. reported for ^{94m}Ag [3] where first proton-proton correlations were observed, have confirmed unexpectedly large half-lives of 2p precursors. The recently-developed first quantum-mechanical theory of 2p radioactivity which uses a three-body "core"+p+p model [4] explains this observation due to considerable influence of the three-body Coulomb and centrifugal barriers, and it predicts the regular existence of long-lived 2p precursors.

Experiments investigating such exotic nuclear decays are usually based on implantation of the radioactive atoms and subsequent detection of their decay. For the first time in studies of radioactivity, we performed an in-flight-decay experiment in which trajectories of all fragments were precisely tracked. The distribution of 2p-decay vertices along a beam direction and the angular correlations of the decay products were deduced from the measured trajectories. In this way, we observed the 2p-radioactivity of the previously unknown ^{19}Mg ground-state [5]. The trajectories of its decay products, ^{17}Ne+p+p, were measured by tracking with micro-strip detectors. The measured half-life of ^{19}Mg deduced from the decay vertex distribution is 4.0(15) ps, which is the pioneering result in studies of short-time radioactivity. The Q-value of the 2p-decay of the ^{19} Mg ground state is 0.75(5) MeV. The method of measuring 2p-decays in flight provides new specific observables, thus yielding valuable spectroscopic information. For example, proton-proton correlations were observed for the 2p decays of the ground states of ^{19}Mg and ^{16}Ne for the first time [6]. These data were used to reconstruct the angular correlations of fragments projected on planes transverse to the precursor momenta. The measured proton-proton correlations reflect a genuine three-body decay mechanism, in contrast to the quasi-classical "di-proton" model which fails to describe our observations. These correlations are sensitive to the structure of the parent nucleus. The comparison between experiment and theory yields an evidence that in ^{16}Ne, the valence protons are equally distributed in the *s*- and *d*- shells. For ^{19}Mg, however, a dominating *d*-shell configuration is the preferred description which is also consistent with the lifetime information [6]. Using this technique, systematic studies of about dozen other 2p emitters predicted theoretically are foreseen.

Information about one-proton unbound nuclei, e.g., ^{15,16}F, ^{18,19}Na, was obtained as well [7]. This opened a new way for systematic studies of proton-rich exotic nuclei beyond the proton drip line. For example, the properties of the proton-unbound isotopes ^{69}Br and ^{73}Rb which are above the well-known "waiting point" nuclei ^{68}Se and ^{72}Kr are important for understanding the element abundance in nature, providing the input data for modeling of the astrophysical *rp*- process.

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