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Short Note

First observation of ^{55,56}Zn

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Abstract. In an experiment at the SISSI/LISE3 facility of GANIL, the most proton-rich zinc isotopes ^{55,56}Zn have been observed for the first time. The experiment was performed using a high-intensity ^{58}Ni beam at 74.5 MeV/nucleon impinging on a nickel target. The identification of ^{55,56}Zn opens the way to ^{54}Zn, a good candidate for two-proton radioactivity according to theoretical predictions.

PACS. 27.40.+z 39 $\leq A \leq$ 58 – 21.10.Dr Binding energies and masses – 23.50.+z Decay by proton emission – 25.70.Mn Projectile and target fragmentation

Nuclear structure experiments near the proton drip line represent an important tool to investigate the properties of the atomic nucleus. The mapping of the proton drip line provides a first stringent test for mass models. One of the most exciting new phenomena at the proton drip line is probably the occurence of the two-proton ground-state (2p) decay which has been predicted about 40 years ago [1]. Although considerable experimental and theoretical efforts have been made in order to observe this new radioactivity, no evidence was found up to now. Instead, a three-body break-up regime has been observed in the ground-state decays of ^{6}Be [2] and ^{12}O [3]. In β-delayed processes where the emission occurs from excited states, a sequential-emission picture via an intermediate state is able to describe the experimental data (see, *e.g.* [4,5]).

For the 2p-decay candidates, the two-proton separation energy is negative. In the case of nuclei, for which one-proton emission is energetically forbidden, the emission of the two protons has to be simultanous. Therefore, there are two possibilities: i) an uncorrelated emission, where the two protons occupy the whole phase space or ii) a correlated emission, where an angular correlation of the two protons may be observed. According to mass predictions [6–9], the best candidates for this radioactivity are ^{45}Fe, ^{48}Ni, and ^{54}Zn with predicted half-lives in the $1\,\mu$s–1 ms range.

^{45}Fe and ^{48}Ni have been observed in recent experiments at GSI [10] and at GANIL [11]. The production rate of ^{45}Fe at the LISE3 separator [12] of GANIL reaches now a level where spectroscopic studies become feasible to investigate the main decay modes/branches of the exotic proton-rich nuclei. However, ^{48}Ni is produced only with 1-2 counts per day, making spectroscopic studies difficult, if not impossible. Therefore, it seems to be very interesting to search for new candidates for this decay mode. In the lighter mass region, the proton drip line has been reached for all even-Z nuclei up to nickel. The search for new 2p candidates has thus to concentrate on the medium-mass region above nickel.

The next heavier even-Z element being zinc, we searched for ^{55,56}Zn during the run leading to the discovery of doubly magic ^{48}Ni. These isotopes were in the acceptance of the LISE3 separator for an intermediate setting on ^{52}Ni used to optimize the SISSI and LISE3 settings for the search of ^{48}Ni. The estimated transmissions were 8% and 0.5% for ^{55}Zn and ^{56}Zn, respectively. However, as the transmission of LISE3 was not optimized for these nuclei, ^{56}Zn ions were transmitted at the edge of the acceptance of LISE3, and these calculations may have therefore an error of about a factor of two.

The fragments of interest were produced by projectile fragmentation of a primary ^{58}Ni^{26+} beam with an intensity of about $1\,\mu$A and an energy of 74.5 MeV/nucleon.

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This beam was fragmented on a 230.6 mg/cm^2 thick natural nickel target followed by a 2.7 mg/cm^2 carbon stripper foil. After passing the first LISE dipole section, the selected fragments impinged on a 10.36 mg/cm^2 beryllium degrader before entering the second dipole stage and the velocity filter.

In this part of the experiment, we used a three-element implantation device consisting of three silicon detectors with thicknesses of 300 μm, 700 μm, and 6 mm. The nuclides of interest were stopped in the second detector. Two time-of-flight (TOF) signals were measured between i) a micro-channelplate (MCP) detector at the exit of the second LISE dipole stage and the implantation setup (TOF1) as well as ii) between the cyclotron radiofrequency and the implantation setup (TOF2). All parameters were calibrated by means of the primary beam. Fragments transmitted to the end of the LISE3 separator were identified event by event using five parameters: i) the energy loss in the first silicon detector, ii) the residual energy in the second detector, iii) TOF1, iv) TOF2, and v) the veto signal from the third silicon detector.

As in the analysis of the runs optimized on ^{48}Ni, the position and the width of each nuclide have been determined for each of the five parameters. In order to accept a count as a valid event, each value of the parameters (except those used for the representation, see fig. 1) had to lie within a two-FWHM window of the determined central position. The results of this analysis is presented in fig. 1. We observe 17 counts of ^{56}Zn and 14 counts of ^{55}Zn. Although all isotopes, even those known to be unbound like ^{53,54}Cu, have been analysed in the same way and thus admitted to show up in the spectrum, almost no background events are visible in the spectrum of fig. 1. The isotope identification is unambiguous, as i) the limits of stability in the mass region are very well known and ii) all parameters were calibrated at the beginning of the experiment with the primary beam transmitted to the final LISE3 focus. These counting rates, together with the estimated transmissions, lead to production cross-sections of about $2^{+0.6}_{-0.5}\times10^{-8}$mb for ^{55}Zn and of $5^{+20}_{-2}\times10^{-7}$mb for ^{56}Zn.

The nucleus ^{56}Zn is predicted bound by all commonly used mass models [9,13–17] with a two-proton separation energy ranging from 0.1 MeV to 1.2 MeV. This nuclide is expected to decay by β and βp decay to either ^{56}Cu or ^{55}Ni.

^{55}Zn is also expected to β^+-decay to states in ^{55}Cu which may then decay by one- or two-proton emission to ^{54}Ni or ^{53}Co, respectively. However, some models [9,14,16,17] predict a negative two-proton separation energy ranging between −0.4 MeV and −1.2 MeV. It is interesting to note that a two-proton emission Q value of 1.2 MeV yields a barrier penetration half-life of about 10 ms in the di-proton model which assumes that the two protons are in a relative s state with zero binding energy.

From the experimental observation of ^{55,56}Zn and the counting rates measured in the present experiment, extrapolations for an experiment optimized for the identification of ^{54}Zn and for the observation of its main decay channels are possible. Assuming similar conditions as in the present experiment, however, with the LISE3 separator optimized on ^{54}Zn, we expect about 10–20 events for ^{54}Zn per day for a primary-beam intensity of about 3 μA. This production rate should be sufficient to determine the main decay modes/branches of this nuclide. It is hoped that ^{54}Zn decays by 2p emission, as all commonly used mass predictions [9,13–17] expect it to be two-proton unbound. Except the 2p separation energy of Aboussir *et al.* [15], which yields a value of only −0.1 MeV, all other models give values between −1.5 MeV and −2.2 MeV.

In summary, we observed for the first time the proton-rich zinc isotopes ^{55,56}Zn in a projectile fragmentation experiment at the LISE3 facility of GANIL. The observed production rates indicate that the two-proton emission candidate ^{54}Zn may be produced with a rate of 10–20 events per day in an experiment optimized for its production.

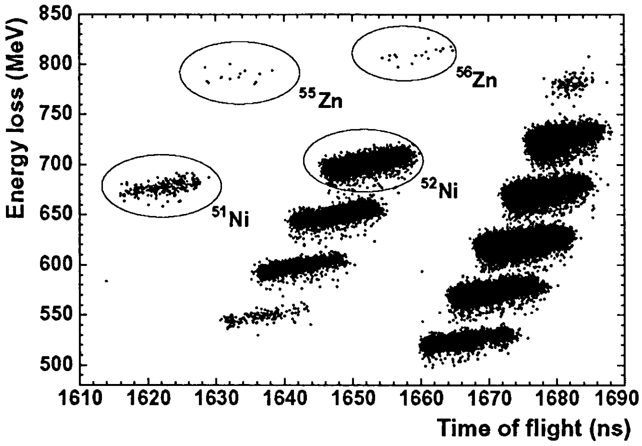

Fig. 1. Two-dimensional identification plot of energy loss in the first silicon detector *vs.* the TOF between the target and the silicon detector generated by means of the cyclotron radiofrequency. To produce this spectrum, software conditions were applied to all parameters except those represented here.

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