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Proton decay of the closed neutron shell nucleus ^{155}Ta*

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Abstract

The new proton radioactivity ^{155}Ta has been observed. It was produced via the *p4n* fusion evaporation channel using a ^{58}Ni beam on a ^{102}Pd target. The measured decay properties were: $E_p = (1765 \pm 10)$ keV and $t_{1/2} = (12^{+4}_{-3})$ μs. Using the WKB approximation a spin and parity of $J^\pi = 11/2^-$ and a spectroscopic factor of $S_p^{exp} = 0.58^{+0.22}_{-0.17}$ were determined.

Nuclear structure studies of nuclei beyond the proton drip line have been intensively pursued lately. Many new ground-state proton emitters have been found. In addition, in-beam γ-ray studies using the Recoil Decay Tagging (RDT) method have been performed or are planned for a number of these nuclei. The proton decay energy yields the mass difference between the initial and the final states, and combining it with the partial proton decay half-life, one can obtain the total angular momentum change in the decay process. So far direct proton decays have been investigated for nuclei 50<Z<84 beyond the proton drip line. Below Z = 69 the proton drip line nuclei are predicted to be well deformed, while the heavier ones are predicted to be at most slightly deformed [1]. The WKB barrier penetration approximation combined with a low-seniority shell-model calculation of the spectroscopic factors have succesfully reproduced the proton decay rates when applied to spherical or at most slightly deformed nuclei [2], [3]. In these calculations the model space consists of 18 particles in the degenerate $s_{1/2}$, $d_{3/2}$, and $h_{11/2}$ proton orbitals above the magic core 64, with neutrons considered to be spectators. In the case of well-deformed nuclei a more complex method using the Nilsson model has recently been developed and applied [4], [5]. For more details, see also the contribution of Sonzogni at this conference. In the present paper, the discovery of the proton-unbound closed shell nucleus $^{155}_{73}$Ta$_{82}$ will be presented and discussed.

The proton rich nucleus $^{155}_{73}$Ta$_{82}$ was produced via the *p4n* fusion evaporation channel using a ^{58}Ni beam on a ^{102}Pd target. The beam was delivered by the Argonne ATLAS accelerator, and bombarding energies of 315 MeV and 320 MeV were

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used. The target thickness was 1.0 mg/cm^2, leading to excitation energies of 77 MeV and 80 MeV, respectively, in the middle of the target. The total doses transported to the target were 1.3$\times$10^{15} particles and 1.7$\times$10^{15} particles, respectively. The Fragment Mass Analyzer (FMA) was used to separate the reaction products from the beam, and to disperse them by mass/charge state. The FMA was set to focus mass A=155 and charqe state Q=28, with Q = 27 and 29 collected at the same time. After passing through the focal plane the products were implanted into a Double-sided Silicon Strip Detector (DSSD), with thickness 65 μm, area 16$\times$16 mm^2, and having 48 orthogonal strips on the front and rear. The time of arrival, position and energy of the implants were recorded. This information was then used to correlate with the position of the subsequent decays. At the front of the DSSD were placed four silicon detectors, forming a seven cm-deep box. These detectors served as veto detectors, providing a decrease in the background caused by escaping alphas in the region where the possible discrete proton decay energy lines were expected to be. Behind the DSSD was placed a large (5$\times$5 cm^2) 500 μm thick silicon detector, used to reduce the background caused by electrons and β-delayed protons. The decay energy calibration was performed using the known proton decay lines of ^{147}Tm, E_p = 1051 keV [6] and ^{147m}Tm, E_p = 1119 keV [7], produced in a separate reaction ^{58}Ni+^{92}Mo.

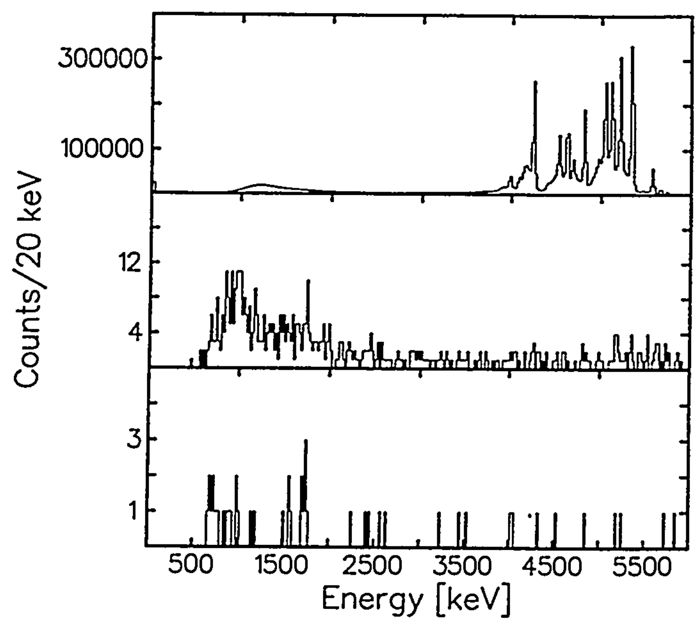

Fig. 1. *a.) The total decay spectrum vetoed with the box detectors and with the back detector is shown. b.) The decay spectrum correlated with implants of mass A = 155 and with maximum time between implant and decay of 50 μs is shown. c.) Same as b) but in addition a second decay was demanded as described in the text. In spectra b) and c) the vetos are still in effect.*

When correlated with mass A=155 and using a maximum time between implant and decay of 50 μs, a peak can be seen as shown in the decay spectrum in fig 1b. The energy of this peak was determined to be E_p=1765±10 keV. This peak is assumed to originate from the proton decay of ^{155}Ta. The measured half-life for this decay was $12\pm^4_3$ μs. The continuum background is caused by real correlations between ^{155}Lu-implants and escaped alpha particles. The full energy part of the ^{155}Lu decay alphas was used to obtain a correction for the pile-up effect caused by the fast decay energy signal falling on the tail of the implant signal. This effect is significant for decays faster than 20 μs.

The theoretical partial β-decay half-life is of the order of $t_{1/2}^{beta} \sim 1$ s [8] which is too long to be significant. The daughter ^{154}Hf β-decays with a half-life of $t_{1/2}$ = 2 s [9] to ^{154}Lu which in turn β-decays with a half-life of $t_{1/2}$ = 1.12 s [9]. The grand-grand daughter ^{154}Yb has a 93 % alpha branch, and it decays with a half-life of $t_{1/2}$ = 0.41 s [9] (see fig. 1c). A total of seven correlations between ^{154}Yb alphas and candidate ^{155}Ta protons were found. A maximum time between implant and these alphas of 15 seconds was used, while at the same time rejecting those cases where there was an A = 154 implant in a 4 second time window preceding the alpha decay in the same detector position. The expected number of such random correlations was calculated to be 2, based on the method given in ref. [10]. This leads to an error probability of less than 0.5 % to accidentally produce at least seven of the above-mentioned correlations. The relatively high calculated number of random correlations is due to the high counting rates in the detector setup and the required long correlation time of the second decay. The cross section for producing ^{155}Ta was deduced to be 60 nb at a bombarding energy of 320 MeV.

Table 1. *Measured and theoretical decay properties of ^{155}Ta are shown. The predicted ground state to ground state decay Q_p-value is obtained using the mass table from ref. [11].*

Measured Q_p [keV]	Liran-Zeldes Q_p [keV]	Measured $T_{1/2}$ [μs]	WKB-$T_{1/2}$ [μs]	Proton orbital
1776 ± 10	1371	$12\pm^4_3$	4.3×10^{-4} 3.5×10^{-3} 7.0	$s_{1/2}$ $d_{3/2}$ $h_{11/2}$

Using the measured proton decay energy and WKB approximation the calculated half-life is $t_{1/2}$ = 7.0 μs, leading to a spin and parity of $J^\pi = 11/2^-$ for the decaying state. From the ratio of theoretical and measured half-life a spectroscopic factor of $S_p^{exp} = 0.58^{+0.22}_{-0.17}$ is obtained. This is in good agreement with the theoretical spectroscopic factor of S_p^{th} = 0.56 predicted by the low-seniority shell model [3]. The measured excitation energies of isomeric states in heavier Tantalum isotopes are 102 keV (9^+ i.s. - 2^- g.s.) [13], 22 keV ($11/2^-$ i.s. - $1/2^+$ g.s.) [12], 141 keV (9^+ i.s. - 2^- g.s.) [3], and 64 keV ($11/2^-$ i.s. - $1/2^+$ g.s.) [3] for ^{156}Ta, ^{157}Ta, ^{158}Ta, and ^{159}Ta, respectively, suggesting that the same isomeric state lies at most some tens of keV above the ground state in ^{155}Ta. Using this estimate the WKB-approximation gives a partial half-life much less than 1 μs for $\ell = 0$ proton decay (see table 1.), which is too short to be observed.

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