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Beta-Delayed Proton Emission Observed in New Lanthanide Isotopes

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Abstract:

The following new, beta-delayed proton emitters have been observed at the on-line isotope separator OASIS: ^{120}La ($2.8 \pm .2\text{s}$), ^{122}La ($8.7 \pm .7\text{s}$), ^{123}Ce ($3.8 \pm .2\text{s}$), ^{141}Dy ($1.0 \pm .2\text{s}$), ^{141}Gd , and ^{143}Dy ($3.2 \pm .6\text{s}$). Z-identification was achieved through observation of characteristic x-rays in coincidence with protons.

We previously reported the discovery of several new, beta-delayed proton emitters in the lanthanide region [1]. The masses of these new isotopes were uniquely determined by the on-line isotope separator OASIS at the SuperHILAC [2] and the Z-values were inferred from half-lives, mass-energy systematics and cross sections. A major addition to OASIS now allows us to obtain unique Z-identifications of new isotopes by observing characteristic x-rays in coincidence with beta-delayed protons. The isotope under study is passed through a slit in the focal plane of the isotope separator and is transported via ionoptical devices to a low background spectroscopy laboratory. Here the isotope is deposited on a fast-cycling tape and moved within 65 ms to an array of detectors which register protons, α - and β -particles, x-rays, and γ -rays. For neutron deficient isotopes two classes of events are recorded: (1) protons (or alphas) in coincidence with positrons, γ 's, and x-rays, and (2) positrons and x-rays in coincidence with γ 's. This preliminary report covers only events of the first category.

The new results summarized in Table I are listed below by mass number.

A = 143: This mass was investigated because ^{143}Ho has been predicted to be a ground state proton emitter [3]. We previously reported the observation of a beta-delayed proton activity with 4.1 s half-life which was assigned to ^{143}Dy . This assignment was based on the good agreement with the predicted half-life of 3.1 s from the gross theory of beta decay and a predicted ($Q_{\text{EC}} - S_{\text{p}}$) value of 7.56 MeV ($Q_{\text{EC}} = Q$ value for electron capture, S_{p} = proton separation energy). We have repeated this experiment with the new tape system and observed a low background x-ray spectrum of K_{α} - and K_{β} -x-rays from Tb in coincidence with protons. These protons are "electron capture delayed" since it is the capture of a K-electron which subsequently gives rise to the observed x-ray that is emitted when the K-vacancy is filled from the L- or M-shell of the Tb atom. This method yields an unambiguous Z-identification of the proton precursor. We have also observed γ -rays in coincidence with protons and positrons. These measurements will be reported at a later date.

A = 141: The reactions leading to isobars in this mass chain are listed in Table I. Measurable cross sections are expected for the three unknown isotopes ^{141}Dy , ^{141}Tb , and ^{141}Gd . ^{141}Dy has the highest calculated ($Q_{\text{EC}} - S_{\text{p}}$) value (9.15 MeV), while the other two are 4.98 and 4.96 MeV; the predicted half-lives are 1, 4, and 11 s, respectively. Two experiments with tape cycles of 5 and 50 s were carried out. In both cases Tb and Eu but no Gd x-rays in coincidence with protons were observed. The shorter cycle time showed a larger Tb/Eu x-ray ratio than the 50 s

cycle; it also produced a higher average proton energy. Protons in coincidence with Tb x-rays showed higher energies than protons in coincidence with Eu x-rays, and the half-life of the Tb-related proton-decay seemed to be shorter than the protons coincident with Eu x-rays. The ensemble of these observations lead us to the conclusion that two new beta delayed proton emitters ^{141}Dy and ^{141}Gd were being observed. No evidence for proton emission from ^{141}Tb was found. From data of the 5 s tape cycle an average half-life for all observed protons of 1.0 s was calculated. The arguments presented above indicate that this should be due mostly to ^{141}Dy with a small, as yet unknown contribution from ^{141}Gd . The half-life of protons in coincidence with the Tb x-rays is approximately 0.7 s with a large error due to poor statistics but in agreement with the 1s half-life of ^{141}Dy .

A = 123: In an experiment in which ^{92}Mo was bombarded with ^{36}Ar an intense proton activity was observed. The proton energy spectrum (fig. 1) is characteristic for beta-delayed proton decay. The spectrum of x-rays obtained in coincidence with protons is shown in fig. 2a. The energies of the two x-ray lines are in excellent agreement with the literature values for La K_{α} - and K_{β} - radiation, which uniquely identifies the new isotope as ^{123}Ce . The half-life obtained from the proton decay data is $3.9 \pm .2$ s; the decay of the La x-ray gives $3.3 \pm .6$ s. Additional information about the decay of ^{123}Ce was obtained from a γ -spectrum measured in coincidence with the protons (fig. 2b). It clearly shows that the proton decay populates the known rotational 2^+ , 4^+ , and perhaps 6^+ levels in ^{122}Ba . Since some of the proton decay is subsequent to electron capture in ^{123}Ce , several weak lines in the γ -spectrum are observed at energies which correspond to the sum of transition energies in ^{122}Ba and K_{α} - and K_{β} -x-ray energies in La. A preliminary evaluation of the proton branches to different rotational levels in ^{122}Ba and a comparison with calculations yields a spin of $5/2$ for the new ^{123}Ce precursor.

A = 122: Two experiments were performed at this mass value: one with a dual proton telescope [1] where a total of about 1800 protons were recorded and one with the tape system where x- and γ -rays were measured in coincidence with protons. The x-ray spectrum in the second experiment showed only Ba K_{α} - and K_{β} - lines which lead us to the conclusion that the new beta-delayed proton precursor is ^{122}La . The calculated low ($Q_{\text{EC}} - S_p$) value of 5.50 MeV is reflected in the observed low upper proton energy of 4.6 MeV.

A = 120: The systematics of ($Q_{\text{EC}} - S_p$) (Z) for A=120 predicts that in this mass chain beta-delayed proton emission becomes possible for $Z > 56$. In an experiment with a ^{64}Zn beam and a ^{58}Ni target we observed beta-delayed protons in coincidence with Ba x-rays and conclude that the new precursor is ^{120}La . Additional evidence for the ^{120}La assignment comes from the γ -spectrum measured in coincidence with protons where a weak γ -line at 237 keV is seen which corresponds to the $11/2^+ \rightarrow 9/2^+$ (g.s.) transition in ^{119}Cs .

The half-life of 2.8 s is in poor agreement with the calculated value of 1.2 s, and it can not be excluded that we are observing an isomer similar to the case of ^{118}Cs .

The above experiment also served to test the separating power of OASIS which is defined as the intensity that an adjacent mass contributes to the mass under study: In the ^{120}La experiment a very strong, delayed proton precursor is produced concurrently at mass 119 (^{119}Ba). It generates characteristic γ -lines in the (mass 119) β - γ coincidence spectrum but none of these lines are visible in the corresponding spectrum at mass 120 at a level of less than 1 part in 10^4 .

Table I: Target projectile combinations and reaction channels for the production of new beta-delayed proton precursors. E_{lab} = bombarding energy, E_p = observed proton energy range, and $T_{1/2}$ = half-life of the precursor.

Table I

Reaction	E_{lab} (MeV)	Precursor	E_p (MeV)	$T_{1/2}$ (s)	$K_{\alpha,\beta}$ x-rays
$^{92}\text{Mo}(^{56}\text{Fe},\alpha n)$	275	^{143}Dy	2.5-6.5	$3.2 \pm .6$	Tb
$^{92}\text{Mo}(^{54}\text{Fe},\alpha n)$	274	^{141}Dy	2.4-6.1	$1.0 \pm .2$	Tb
$^{92}\text{Mo}(^{54}\text{Fe},4pn)$	274	^{141}Gd	2.0-5.8	-	Eu
$^{92}\text{Mo}(^{36}\text{Ar},\alpha n)$	196	^{123}Ce	2.0-5.8	$3.8 \pm .2$	La
$^{92}\text{Mo}(^{36}\text{Ar},\alpha pn)$	205	^{122}La	2.0-4.6	$8.7 \pm .7$	Ba
$^{58}\text{Ni}(^{64}\text{Zn},pn)$	253	^{120}La	2.1-5.6	$2.8 \pm .2$	Ba

References

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3. W. F. Feix and E. R. Hilf, Darmstadt, IKDA 82/12.

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Figure Captions

Fig. 1. Beta-delayed proton spectrum observed in the reaction ^{92}Mo (^{36}Ar , αn) ^{123}Ce .

Fig. 2. (a) x-ray and (b) γ -spectra observed in coincidence with beta-delayed protons (Fig. 1) from ^{123}Ce . $m_e c^2$ = annihilation radiation.

Fig. 1

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Fig. 2

XBL 8312-6725

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