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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 ± .2s), ^{122}La (8.7 ± .7s), ^{123}Ce (3.8 ± .2s), ^{141}Dy (1.0 ± .2s), ^{141}Gd, and ^{143}Dy (3.2 ± .6s). 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.

<u>A = 143</u>: 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 $(Q_{EC} - S_p)$ value of 7.56 MeV (Q_{EC} = Q value for electron capture, S_p = proton separation energy). We have repeated this experment 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.

<u>A = 141</u>: 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 $(Q_{EC} - S_p)$ 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 evergy. 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 ± .2 s; the decay of the La x-ray gives 3.3 ± .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_{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_{EC} - S_p) (Z) for A=120 predicts that in this mass chain beta-delayed proton emission becomes possible for $Z \geq 56$. 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}Mo(^{56}Fe,αn)	275	^{143}Dy	2.5–6.5	3.2±.6	Tb
^{92}Mo(^{54}Fe,αn)	274	^{141}Dy	2.4–6.1	1.0±.2	Tb
^{92}Mo(^{54}Fe,4pn)	274	^{141}Gd	2.0–5.8	–	Eu
^{92}Mo(^{36}Ar,αn)	196	^{123}Ce	2.0–5.8	3.8±.2	La
^{92}Mo(^{36}Ar,αpn)	205	^{122}La	2.0–4.6	8.7±.7	Ba
^{58}Ni(^{64}Zn,pn)	253	^{120}La	2.1–5.6	2.8±.2	Ba

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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.

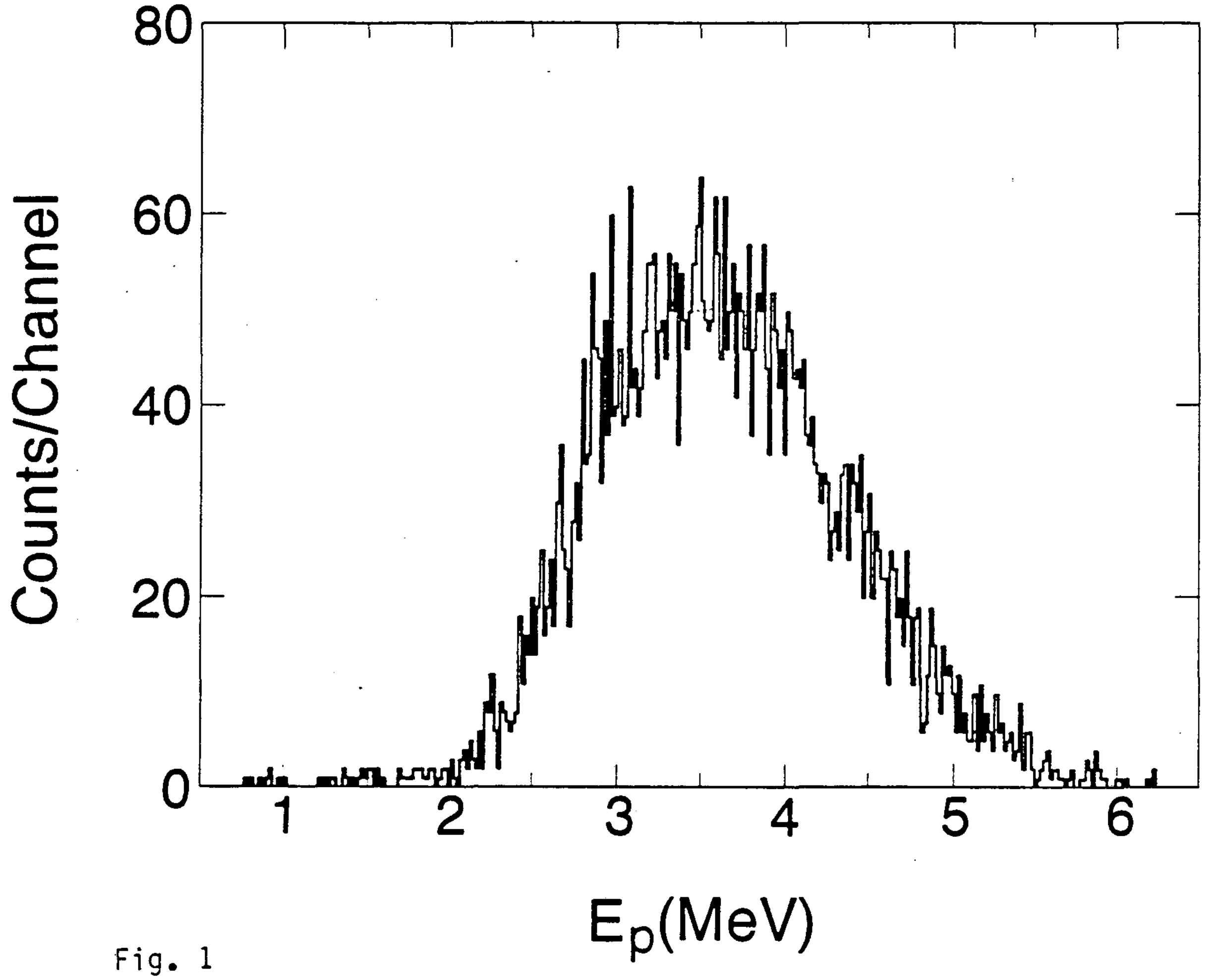

Fig. 1

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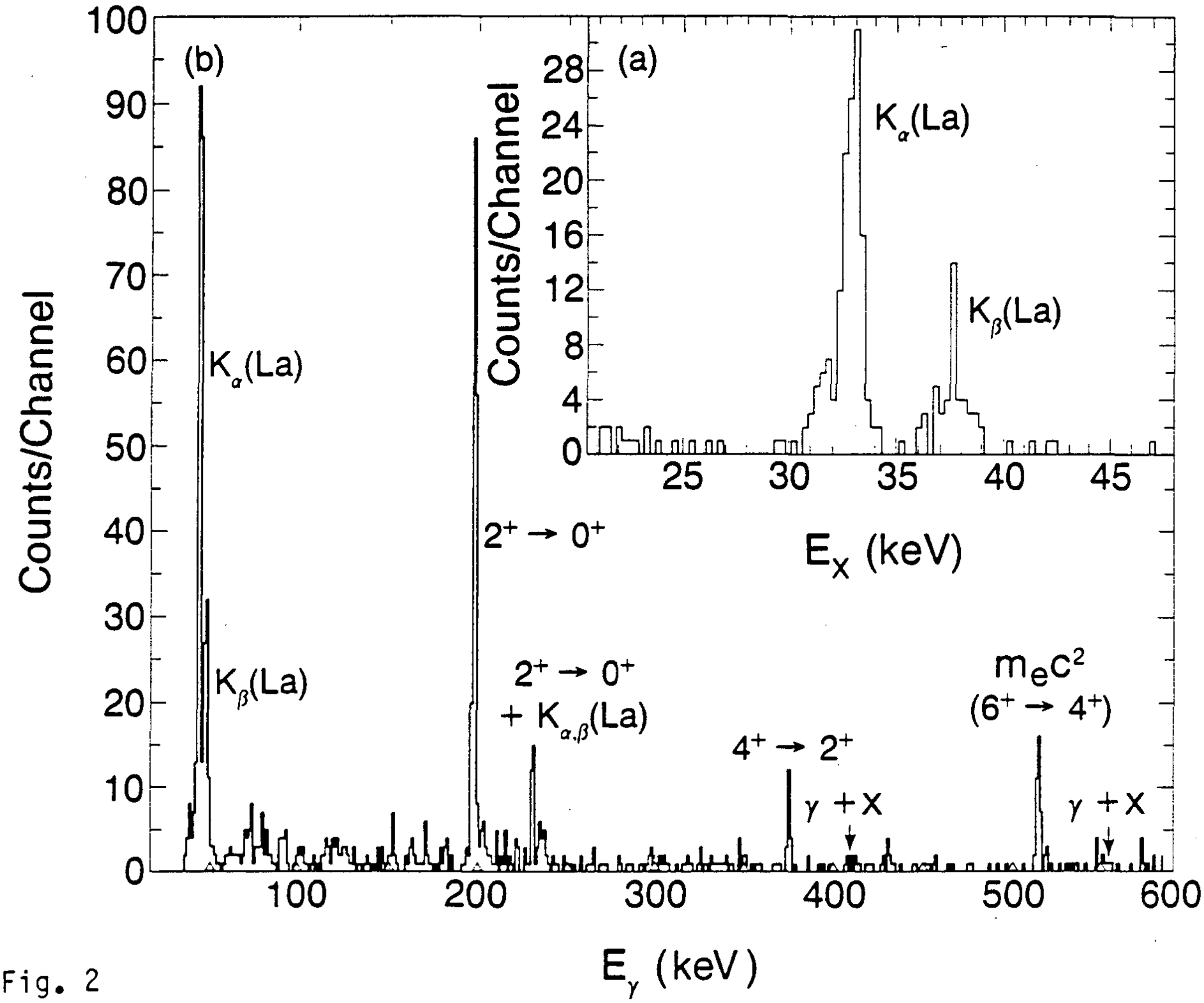

Fig. 2

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