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DECAY PROPERTIES OF ^{186}Pb AND THE LEAD ALPHA-DECAY RATE ANOMALY

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Alpha-decay transitions between ground states of doubly-even nuclei are taken to represent unhindered decays. Reduced widths for these s-wave transitions behave in a regular fashion as a function of both neutron and atomic number. They are largest for nuclei two or four particles beyond a closed shell (with sharp minima at the shell) and they then decrease as the next closure is approached. The s-wave widths for ^{186,188,190,192}Pb, however, have been reported[1] to behave anomalously, i.e., they purportedly increase by a factor of 30 between ^{186}Pb (N = 104) and ^{192}Pb (N = 110) instead of decreasing as one nears N = 126. Theoretical calculations[2,3] have not reproduced this unusual behavior.

The [electron-capture (EC) + β^+] strengths were deduced in Ref. 1 from K x-ray intensities. A number of corrections are involved in such determinations. We undertook the investigation of the (EC+β^+) decay schemes of these neutron-deficient lead isotopes, in conjunction with studies of their α-decay properties, to obtain more reliable α-branching ratios. Results for ^{192}Pb, ^{190}Pb, and ^{188}Pb have been published in Refs. 4, 5, and 6, respectively. Herein we present new information on ^{186}Pb and discuss the partial α half-lives for all four isotopes together with α-decay rates for even-even nuclei with Z > 78.

We produced ^{186}Pb in the ^{160}Dy(^{32}S,6n) reaction by bombarding a 2.92-mg/cm^2 thick dysprosium metal foil enriched in ^{160}Dy to 78.9% with 200-MeV ^{32}S ions from the Holifield Heavy Ion Research Facility tandem accelerator. Reaction products were mass-separated with the UNISOR (University Isotope Separator at Oak Ridge) on-line facility, collected onto an automated tape system, and, transported to a counting station. Singles and coincidence γ-ray data were accumulated simultaneously with a large volume Ge(Li) detector and a γ-x detector. A Si(Au) surface barrier detector was used for α-particle counting. All three detectors were placed in calibrated geometries so that absolute counting rates could be determined. Production and collection cycles were 20 s in duration while the counting time was broken up into four 5-s intervals.

The accumulated α spectrum, shown in Fig. 1(a), was found to be dominated by the single group known[7,8] to belong to ^{186}Pb α decay. Gamma-ray spectra clearly showed the presence of ^{186}Tl and ^{186}Hg (Refs. 9 and 10) produced in reactions involving charged-particle plus neutron evaporation, but no transitions that could be assigned to ^{186}Pb either on the basis of half-life or K-x-ray coincidences. There was no indication of a short-lived component, consistent with a 4.7-s half-life, in the decay curve of the annihilation radiation peak. Thallium K x rays were not observed as illustrated in Fig. 1(b). The figure shows the total coincidence spectrum, in the neighborhood of the K-x-ray energy region, accumulated in the γ-x detector. While gold and mercury K x rays are seen in Fig. 1(b), there are no thallium x rays either from ^{186}Pb (EC+β+) or ^{186}Tl 3.0-s isomeric decay. [No transitions have been observed (Refs. 9 and 10 and present study) in coincidence with the ^{186}Tl E3 γ ray; if any exist their energies must be less than the thallium K-shell binding energy.] Finally, we note that the ^{186}Tl isomer apparently has a low spin.[10] One would therefore expect most of ^{186}Pb (EC+β+) decay to proceed either directly or through intermediate states to this isomer. The decay curve for the 374.0-keV γ ray showed a single (3.0±0.2)-s component with no hint of a parent-daughter, growth and decay, correlation further indicating an absence of ^{186}Pb (EC+β+) decay.

Our data therefore suggest a ^{186}Pb α branching of 100%, a value which is much larger than the 2.4% branch estimated[7] from expected cross sections for the production of ^{186}Pb in heavy-ion reactions. On the basis of their measured ^{188}Pb and ^{189}Pb α branches Hörnshoj et al.[1], in their discussion of α widths, increased the ^{186}Pb ratio by a factor of two, i.e., to 4.8%. This augmented branch is still much less than our value.

In discussing α-decay rates we consider them within the theoretical formalism developed by Rasmussen[11] wherein decay probabilities are represented by a reduced width, δ^2. Decay energies, half-lives, and α branches are needed to compute the reduced widths. In Table I we compare these quantities for ^{186,188,190,192}Pb as obtained in our current investigations with data from Refs. 1, 7, 8, 12, and 13. Even though the ^{184}Pb α branch has not been measured we have included in Table I its half-life and decay-energy data[8] and calculated a reduced width by assuming a branching of 100%.

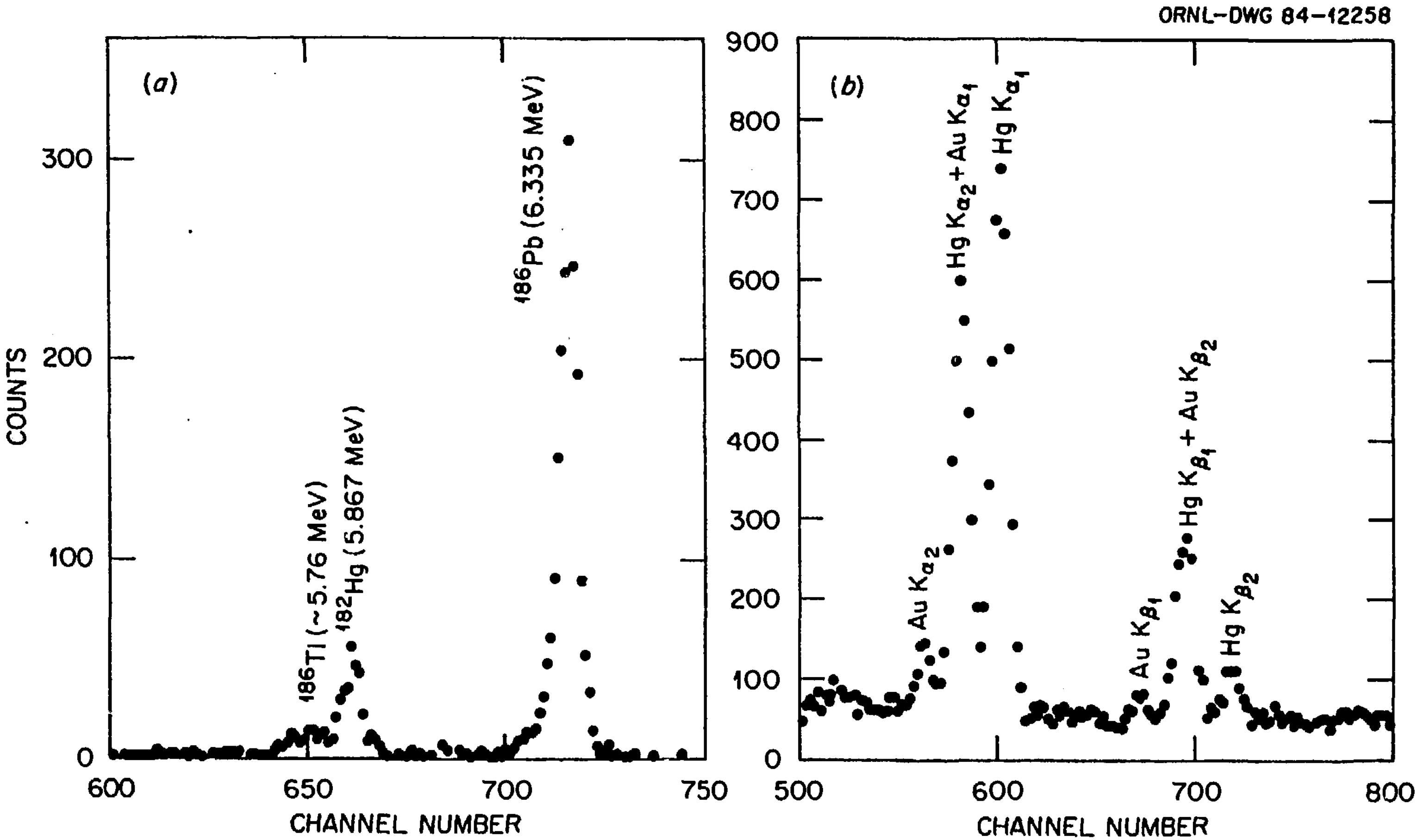

Fig. 1. Parts (a) and (b) show the singles α-particle spectrum and the total coincidence x-ray spectrum, respectively, measured at A = 186.

TABLE I. Alpha-decay properties of ^{192}Pb, ^{190}Pb, ^{188}Pb, ^{186}Pb, and ^{184}Pb.

		Current Investigations[a]	Earlier Data	(References)
^{192}Pb	E_α (keV)	5112 (5)	5110[b]	14
	$T_{1/2}$ (min)	3.5 (1)	2.3 (5)	7
	α branch	5.7×10^{-5} (10)	6.9×10^{-5} (24)	1
	δ^2 (MeV)	$0.049^{+0.014}_{-0.012}$	0.094	
^{190}Pb	E_α (keV)	5577 (5)	5580 (10)	7
	$T_{1/2}$ (min)	1.2 (1)	1.2 (2)	7
	α branch	9.0×10^{-3} (20)	2.1×10^{-3} (7)	1
	δ^2 (MeV)	$0.094^{+0.036}_{-0.028}$	$0.021^{+0.017}_{-0.010}$	
^{188}Pb	E_α (keV)	5980 (5)	5980 (10)[c]	7
	$T_{1/2}$ (s)	22 (2)	24.5 (15)[d]	15
	α branch	0.22 (7)	3.3×10^{-2} (11)	1
	δ^2 (MeV)	$0.114^{+0.055}_{-0.041}$	$0.015^{+0.009}_{-0.007}$	
^{186}Pb	E_α (keV)	6.335 (10)	6320 (20)[e]	7
	$T_{1/2}$ (s)	4.7 (1)	8 (2)[f]	7
	α branch	1.0	4.8×10^{-2}	1
	δ^2 (MeV)	0.09	0.0028	
^{184}Pb	E_α (keV)		6632 (10)	8
	$T_{1/2}$ (s)		0.55 (6)	8
	α branch		1.0 (estimate)	
	δ^2 (MeV)		0.06	

[a]Data for ^{192}Pb, ^{190}Pb, ^{188}Pb and ^{186}Pb are from Refs. 4, 5, 6, and this study.

[b]Other value: 5060 (30) keV (Ref. 7).

[c]Other values: 5975 (15) keV (Ref. 15) and 5990 (15) keV (Ref. 8).

[d]Other value: 26 (2) s (Ref. 7).

[e]Other value: 6332 (10) keV (Ref. 8).

[f]Other value: 4.79 (5) s (Ref. 8).

Figure 2 shows s-wave reduced widths for nuclei with Z from 78 to 100 plotted as a function of N. One sees the regularity of the reduced widths as a function of neutron number with the extremely sharp break at N = 126. This discontinuity has been shown to be a shell structure effect. A less pronounced minimum is seen at the subshell closure at N = 152. The lead anomaly[1] is indicated by the dashed line which connects the ^{186,188,190,192}Pb widths calculated from the earlier data summarized in Table I. The widths for ^{186,188,190,192}Pb, computed from our data are shown by the open points. It is clear that they have a dependence on N which is similar to that observed for other elements. However, these new data indicate neutron-deficient lead isotopes to be less hindered toward α decay than mercury isotopes contrary to the expectation of a shell effect at Z = 82.

Our results seem to be related to the predicted[14] disappearance of the Z = 82 gap in the vicinity of N = 114 based on Hartree-Fock-Bogoliubov calculations of proton single-particle energies and to the existence of varying shapes in mercury and platinum isotopes in this mass region. In ^{182,184,186,188}Hg it has been shown[15] that well-deformed prolate bands cross the slightly oblate ($\varepsilon \sim 0.1$) ground-state bands. Platinum nuclei with A < 190, on the other hand, are believed[16] to be prolate in their ground states. If one supposes that ^{186,188,190,192}Pb also have slightly oblate ground states then α transitions from oblate mercuries to prolate platinums would be expected to be hindered vis-â-vis lead α decays which do not involve shape changes between the parent and daughter nuclei. (Note that low-lying 0^+ excited states in ^{192,194,196,198}Pb have been described[17] by oblate two-particle, two-hole configurations; their ground states, however, have been assumed to be spherical.) Further detailed calculations of α-decay rates incorporating shape changes are needed. If such theoretical results do indeed agree with our experimental observations, then the study of α-decay rates may prove to be a useful tool to deduce information concerning nuclear shapes. Finally, we note that the ^{184}Pb reduced width (see Table I) is appreciably smaller than that of ^{186}Pb. This is in accord with Sorensen's calculations[14] which indicate the reappearance of the Z = 82 gap for N < 102.

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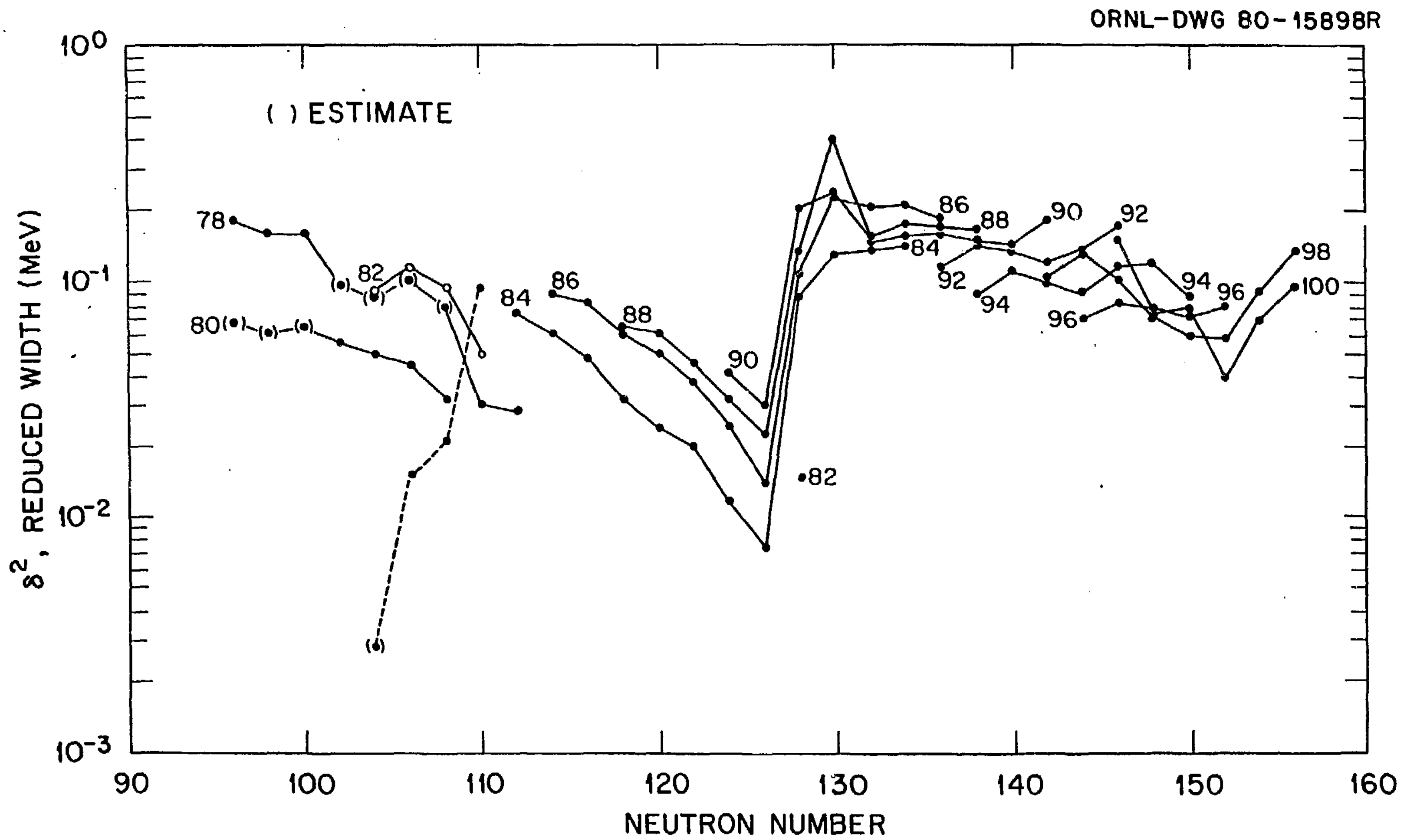

Fig. 2. Reduced widths for s-wave α transitions plotted as a function of N for isotopes with Z from 78 to 100. The dashed line connects widths for $^{186,188,190,192}Pb$ calculated from earlier data. Open points for Z = 82, connected by the full line, are widths for $^{186,188,190,192}Pb$ calculated from our experimental results.

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