ALPHA-DECAY RATES OF EVEN-EVEN LEAD ISOTOPES

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Abstract

The α-decay rates of ^{186,188,190,192}Pb have been reported to have an anomalous dependence on neutron number. Theoretical calculations do not reproduce this unusual behavior. To obtain more precise α-decay branching ratios, we reinvestigated the decay properties of ^{188,190,192}Pb. Our data result in α-decay reduced widths whose dependence on N is similar to that observed for other elements.

A rather regular behavior as a function of neutron number is observed for the reduced widths of α-decay transitions which connect ground states of doubly-even isotopes. These s-wave transitions have reduced widths that are largest for parent nuclei with a few nucleons beyond a closed shell and which then decrease as the next shell is approached. In contrast, the s-wave widths of ^{186,188,190,192}Pb have been reported¹) to behave anomalously. Their widths were found¹) to increase by a factor of 30 between ^{186}Pb (N=104) and ^{192}Pb (N=110) instead of decreasing in value as the neutron number approached 126. This unusual behavior has not been reproduced by theoretical calculations²,³).

In Ref. 1 the α-decay branching ratios were obtained by comparing α-particle and K x-ray counting rates. The determination of an electron-capture plus positron (E.C. + β^+) decay strength from K x-ray intensities entails a number of corrections. To obtain more reliable α-branching ratios, we undertook the investigation of the (E.C. + β^+) decay properties of these neutron-deficient lead nuclei.

The isotopes ^{192}Pb, ^{190}Pb and ^{188}Pb were produced in ^{180}W(^{16}O,xn) reactions by bombarding tungsten, enriched in ^{180}W to 92.6%, with ^{16}O ions accelerated in the Oak Ridge isochronous cyclotron. Reaction products were then mass-separated by using the UNISOR (University Isotope Separator at Oak Ridge) on-line facility, collected onto an automated tape system and transported to counting stations for radioactive assay. Singles and coincidence γ-ray data were accumulated simultaneously with two large-volume Ge(Li) detectors. Also, the production yields for ^{192}Pb and ^{190}Pb were large enough to allow us to obtain conversion-electron data by using a Si(Li) detector. With these data, (E.C. + β^+) decay schemes were constructed. For the determination of branching ratios, singles γ-ray and α-particle spectra were measured with the Ge(Li) and Si(Au) detectors placed in calibrated geometries. The α-decay strengths were calculated from the observed intensities of the α groups of ^{188,190,192}Pb. The (E.C. + β^+) strengths were obtained from the intensities of prominent γ-ray transitions utilizing the proposed decay schemes (see Fig. 1). The α-decay branches were then determined from the two decay strengths.

These results have been recently published, and the interested reader is referred to the publications for detailed discussions of the decay characteristics of ^{192}Pb (Ref. 4), ^{190}Pb (Ref. 5), and ^{188}Pb (Ref. 6). Herein, we examine the partial α half-lives for all three nuclei within the framework of α decay-rate systematics for elements with $Z > 78$. In our discussion we consider the α-decay

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*) Operated by Union Carbide Corporation under Contract No. W-7405-eng-26 with the U.S. Department of Energy

**) Nuclear Physics research at the University of Tennessee is supported by the U.S. Department of Energy under Contract No. DE-AS05-76ER04936.

†) UNISOR is a consortium of 13 institutions and is supported by them and by the U.S. Department of Energy under Contract No. DE-AC05-76OR00033 with Oak Ridge Associated Universities.

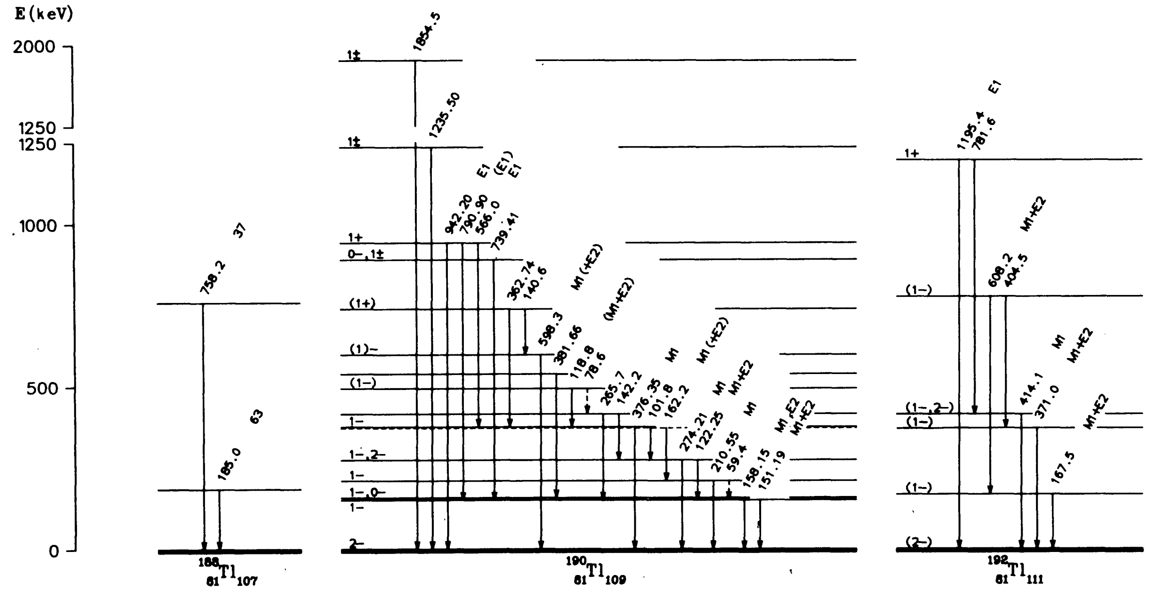

Fig. 1 Decay schemes for ^{192}Pb and ^{190}Pb shown together with the proposed partial scheme for ^{188}Pb.

rates within a theoretical context so that relative probabilities can be obtained. In the formalism[7]) used, a reduced width, δ^2, is defined by the equation, $\lambda = \delta^2 P/h$, where λ is the decay constant, h is Planck's constant, and P is the penetrability factor calculated for the α-particle to tunnel through a barrier.

Decay energies and partial α half-lives are needed to compute α-decay reduced widths. In Table 1 we compare these quantities for ^{188}Pb, ^{190}Pb and ^{192}Pb, as obtained in our current investigations with data reported in Refs. 1 and 8-11. Discrepancies can be noted in the case of ^{188}Pb and ^{190}Pb α-branches. The new branches increase the corresponding widths by factors of 7.6 and 4.5. Contrastingly, our width for ^{192}Pb, 0.049 MeV, is much less than the value of 0.094 MeV calculated from the earlier data. Here the discrepancy is due primarily to the fact that the nuclide's half-life[4]) is 3.5 min, rather than 2.3 min as reported by Le Beyec *et al.*[8]) and used in Ref. 1.

Figure 2 shows s-wave reduced widths for nuclei with Z from 78 to 100 plotted as a function of N. Information used to calculate the reduced

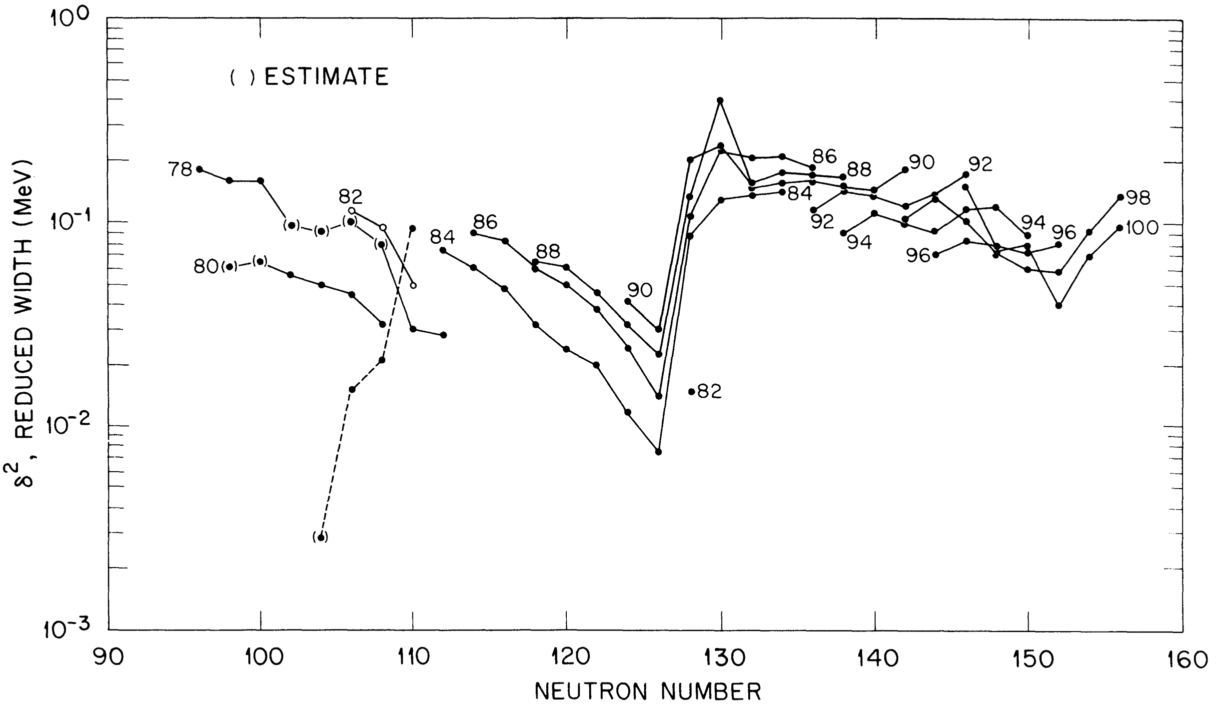

Fig. 2 Reduced widths for s-wave α transitions plotted as a function of N for isotopes with Z from 78 to 100. The dashed line connects widths for $^{186,188,190,192}Pb$ calculated from earlier data (note that the ^{186}Pb value is an estimate). The open points for Z=82, connected by the full line, are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

widths for isotopes with $A > 196$ is taken from Refs. 12, 13. Data for lead, mercury, and platinum nuclei are taken from Table 1; Refs. 9, 10, 14; and Ref. 15, respectively. One sees in Fig. 2 the regularity of the reduced widths as a function neutron number with the extremely sharp break at N=126. This discontinuity has been shown (see e.g. Ref. 16) to be essentially a shell structure effect. A less pronounced minimum is observed for the subshell closure at N=152. The reported lead anomaly is indicated by the dashed line in Fig. 2 which connects the ^{186,188,190,192}Pb widths calculated from the earlier data summarized in Table 1.

The widths for ^{188,190,192}Pb, computed from our data, are shown by the open points. They have a dependence on N which is similar to that observed for other elements. To verify this, the present study has to be extended to ^{186}Pb. Such an investigation is needed particularly because the ^{186}Pb width listed in Table 1 is not based on a measured α-branch but rather on an estimate[1]. Necessity for a measurement is emphasized by the fact that the more recent half-life reported[10] for ^{186}Pb leads to a substantial increase in the δ^2 value (see footnote f in Table 1).

Table 1.

Alpha-decay properties of ^{192}Pb, ^{190}Pb, ^{188}Pb, and ^{186}Pb

		Current Investigations[a]	Earlier Data	Ref.
^{192}Pb	E_α (keV)	5112 (5)	5110 [b]	11
	$T_{1/2}$ (min)	3.5 (1)	2.3 (5)	8
	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)	8
	$T_{1/2}$ (min)	1.2 (1)	1.2 (2)	8
	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]	8
	$T_{1/2}$ (s)	22 (2)	24.5 (15) [d]	9
	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)		6320 (20) [e]	8
	$T_{1/2}$ (s)		8 (2) [f]	8
	α-branch		4.8×10^{-2} [g]	1
	δ^2 (MeV)		0.0028	

[a] Data for ^{192}Pb, ^{190}Pb, ^{188}Pb are taken from Ref. 4, Ref. 5 and Ref. 6, respectively.

[b] Other value: 5060 (30) keV (Ref. 8).

[c] Other values: 5975 (15) keV (Ref. 9) and 5990 (15) keV (Ref. 10).

[d] Other value: 26(2) s (Ref. 8).

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

[f] Other value: 4.79 (5) s (Ref. 10). This half-life yields a δ^2 of 0.0047.

[g] Estimate.

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DISCUSSION

P.G. Hansen: The "lead anomaly" in the alpha widths depends on what you consider normal. Wouldn't you say that the surprise is that the widths are so high? This is the feature that is being confirmed by your work, while we might have expected a very small W_α as for the estimate based on the Orsay result for ^{186}Pb ....

C.R. Bingham: I would like to comment on that. It does seem a little surprising that the reduced widths are so high for the closed shell Pb nuclei. The widths are even higher than those for Pt (Z=78) and Hg (Z=80) nuclei. However, we note that they are lower than those for Z=84, 86, etc. Thus, one might suggest that perhaps there is a nuclear physics reason for suppressing the reduced widths of the Pt and Hg decays.

J.L. Wood: The anomalous Γ_α values in the Pb-Hg-Pt isotopes may be related to very unusual ground state structure in the Pt isotopes. I will speak of this point in my talk.

R.A. Sorensen: The "anomalous" results for Pb at Z=82, N=114 are probably due to the fact that Z=82 is not a magic number at N=114, as will be discussed in my presentation.