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INVESTIGATION OF SHORT-LIVED PT AND PB α EMITTERS NEAR THE PROTON DRIP LINE

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In a series of experiments at the Argonne ATLAS Accelerator Facility, several α emitters near the proton drip line were produced with fusion evaporation reactions, separated from the beam and dispersed in M/Q with a recoil mass spectrometer, and implanted and studied in a double-sided silicon strip detector. In ^{78}Kr bombardments of ^{92}Mo and ^{96}Ru, the new isotopes ^{166}Pt and ^{167}Pt were identified *via* their α-decay properties and more accurate half-lives were measured for ^{168}Pt and ^{170}Pt. The light isotopes of lead, ^{180}Pb, ^{182}Pb, and ^{184}Pb were produced in Mo bombardments of Zr target nuclei. The α-decay energies and half-lives of the new isotopes are as follows: 1) ^{166}Pt, E_α = 7110(15) keV, $T_{1/2}$ = 0.3(1) ms; and 2) ^{167}Pt, E_α = 6988(10) keV, $T_{1/2}$ = 0.7(2) ms. Also, the half-life of ^{168}Pt, which was previously unknown, was determined to be 2.0(4) ms and that of ^{170}Pt was observed to be 14.7(5) ms. The tentative α-decay energies and half-lives of the even Pb isotopes are: 1) ^{184}Pb, E_α = 6625(10) keV, $T_{1/2}$ = 500(25) ms; 2) ^{182}Pb, E_α = 6895(10) keV, $T_{1/2}$ = 62(5) ms; and 3) ^{180}Pb, E_α = 7250(15) keV, $T_{1/2}$ = $5.8^{+2.8}_{-1.4}$ ms. The α-decay rates for these Pt and Pb nuclides are compared with earlier measurements and systematic trends of the reduced widths with neutron number are discussed.

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INTRODUCTION

The study of nuclei near the proton drip line presents a number of experimental challenges. First of all, the production of these very radioactive nuclei can be accomplished only with particle accelerators under very selective conditions, usually with a very small cross section. Secondly, the greater production cross sections for nuclei nearer stability results in a very high background level, thus requiring special techniques to observe the relatively small fraction of the desired product. A spectrometer to separate the various activities according to their mass/charge ratios is a useful tool to purify the sources. The development of high efficiency charged particle detectors makes detection of relatively few decays by proton or alpha emission practical. In this paper we describe, briefly, an experimental setup at Argonne National Laboratory to make these studies and report on some of the α-decay results of nuclei near the proton drip line produced with that facility.

The emission of α particles is a decay mode that can be observed sensitively with charged particle detectors. The energy of the observed α gives a direct measurement of the mass difference of the α emitter and its daughter nucleus and provides a sensitive test of mass formulas. The α-decay rate depends on two factors, one which expresses the probability of the α penetrating the combined Coulomb and centrifugal barrier, and another which depends on the probability of formation of the α within the nucleus, and thus, the nuclear structure of the parent and daughter. Within a formalism developed by Rasmussen (1), the decay constant λ is expressed as δ^2P/h, where P is the probability of penetrating the barrier and δ^2 is called the reduced width. A study of the systematic variation in δ^2 with proton and neutron numbers reveals changes in nuclear structure. In particular, closed neutron and proton shells have a huge effect on the reduced widths. It is of interest to study these reduced widths in the region near Z and N = 82.

EXPERIMENTAL METHOD

The Pt α emitters studied here were produced by bombarding a ^{92}Mo (>97% enrichment) metal foil (0.565 mg/cm2) thick) with a 5 particle nA beam of ^{78}Kr beams from the ATLAS accelerator facility at Argonne National Laboratory. Incident energies of 357 and 384 MeV were used to emphasize A = 167 and A = 166 isotopes, respectively. The light Pb nuclides were produced by bombardment of metal foils of several Zr isotopes with a 422-MeV ^{92}Mo beam. The recoiling products were separated from the incident beam and separated by their mass/charge ratio (A/Q) by use of the Fragment Mass Analyzer (FMA) (2) and, after passing through a parallel grid avalanche detector (PGAC) located at the FMA focal plane, were implanted in a Double-sided Silicon Strip Detector (DSSD). Signals from the PGAC were used to identify implantation events in the DSSD and to determine A/Q for the implant. For the Pt experiments, the DSSD was of the same size (1.6 x 1.6 cm), granularity (48 x 48 strips), and thickness (≈65 μm) as the ones recently developed (3) for use in proton and α-decay studies. The DSSD used for the Pb experiments was of the same thickness but had an area of 4 x 4 cm and a granularity of 40 x 40. The decay-energy signals from the different strips were gain matched by use of a mixed ^{244}Cm and ^{240}Pu α source. Final energy calibrations for implanted α emitters were provided by using known α lines of Hf, Yb, W, Ta, Lu, Os, Hg, and Pb.

Implant and decay events in each pixel location of the DSSD were time stamped with signals from a continuously running clock. Both position and time correlations between individual implants and their subsequent decay events were observed. Half-lives of the implanted parent nuclei could be determined from the differences between implantation and first decay times within the same pixel. Also, in similar fashion the half-lives of the subsequent decay products can also be determined if they decay by proton or α decay. The method of maximum likelihood was used to obtain half-lives and uncertainties.

EXPERIMENTAL RESULTS

The α spectra obtained by bombarding ^{92}Mo with 357-MeV ^{78}Kr under various gating conditions are shown in Fig. 1. Parts (a) and (b) show spectra gated with A = 168 and A = 167 recoils, respectively. Parts (c) and (d) show the same spectra with additional requirements, namely, correlation with subsequent α decay in the same pixel of ^{164}Os and ^{163}Os, respectively. These spectra demonstrate unambiguously the assignments of the 6832 and 6988 keV peaks to ^{168}Pt and ^{167}Pt, respectively. A similar set of spectra taken at the bombarding energy of 384 MeV reveals an α line in the A = 166 spectrum which is correlated with the α decay of the ^{162}Os daughter at an energy of 7110 keV. This permits the assignment of this peak to the new isotope ^{166}Pt. Similarly, by bombarding ^{96}Ru with 420-MeV ^{78}Kr, we have produced ^{170}Pt and observed its decay via a 6550-keV α particle.

The α spectra obtained by bombarding ^{90}Zr with 422-MeV ^{92}Mo under several different gating conditions are shown in Fig. 2. Part (a) shows the α particles which were observed within 10 ms after an implant was incident on the same pixiel. The broad peak near 7.2 MeV belongs to the decay of ^{179}Tl and to ^{180}Pb which was just

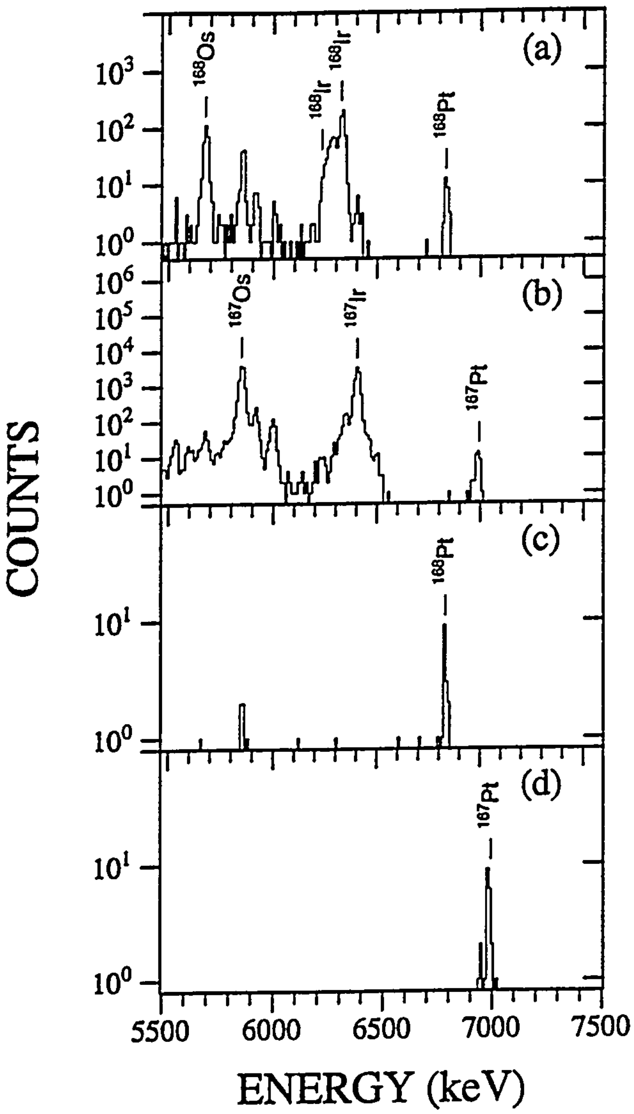

Fig. 1. High-energy portion (5.5-7.5 MeV) of the α spectrum resulting from bombardment of ^{92}Mo with 357-MeV ^{78}Kr displayed with various gates: (a) A = 168 gate, (b) A = 167 gate, (c) A = 168 correlated with the α decay of ^{164}Os, and (d) A = 167 correlated with ^{163}Os α decay.

recently identified [4]. Parts (b) and (c) show the resulting spectra when additional gates on A = 179 and A = 180, respectively, are included. Part (d) shows the result when an additional requirement that an α particle was emitted later by ^{176}Hg (6750-keV) in the same pixel is placed on the spectrum in part (c). The results of these gated spectra permit an unequivocal assignment of the 7250-keV line to the decay of ^{180}Pb.

The half-lives of all the α peaks observed were determined through fitting the distribution of time differences between the implant and the decay with an

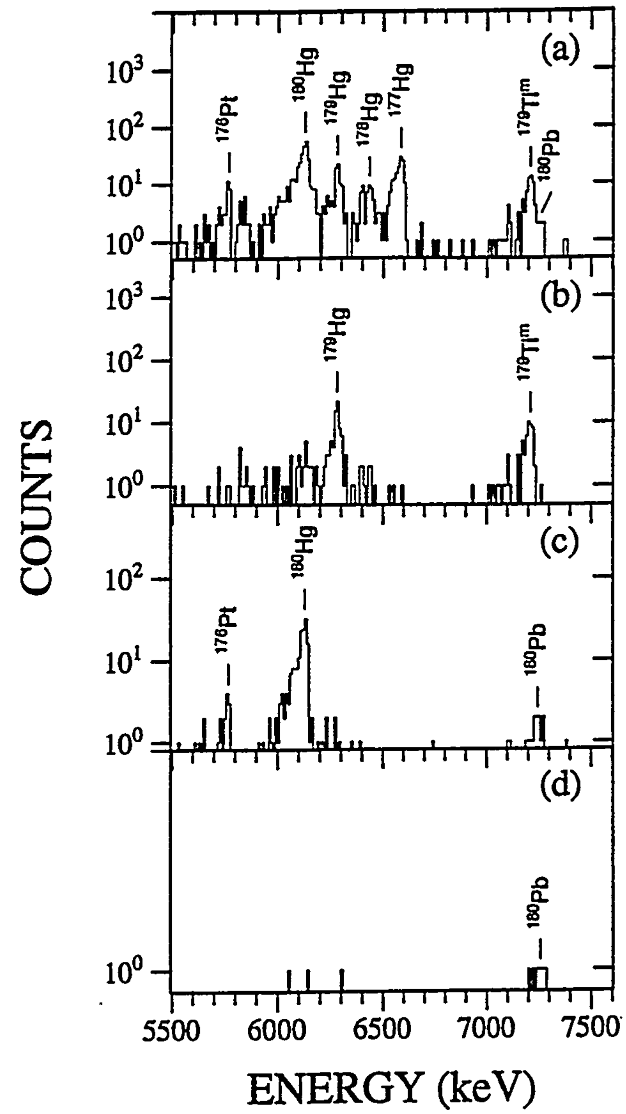

Fig. 2. High-energy portion of the α spectrum resulting from bombardment of ^{90}Zr with 422-MeV ^{92}Mo displayed with various gates: (a) decay occurred within 10 ms of implant in same pixel, (b) same with A = 179, (c) same with A = 180, (d) A = 180 correlated with ^{176}Hg α decay.

exponentially decaying function, utilizing the method of maximum likelihood for the weakly-produced activities. A summary of the observed α energies and half-lives observed in the present experiments are given in Table I along with some results from previous experiments (4-7). Where earlier results were available, the current energies and half-lives generally agree with the previous results, though error bars are significantly less in the present results.

Table I. Decay energies, half-lives, and reduced widths of proton-rich platinum and lead α emitters.

	E_α(keV)	$T_{1/2}$(ms)	δ^2(keV)	Ref.
^{166}Pt	7110(15)	0.3(1)	88^{+58}_{-29}	Present
^{167}Pt	6988(10)	0.7(2)	88^{+41}_{-24}	Present
^{168}Pt	6832(10)	2.0(4)	96^{+14}_{-26}	Present
	6824(20)			(7)
^{170}Pt	6550(6)	14.7(5)	114^{+10}_{-9}	Present
	6545(8)	6^{+5}_{-3}	290^{+180}_{-140}	(7)
^{180}Pb	7250(15)	$5.8^{+2.8}_{-1.4}$	40^{+47}_{-11}	Present
	7230(40)	4^{+4}_{-2}	68^{+115}_{-43}	(4)
^{182}Pb	6895(10)	62(5)	54^{+10}_{-8}	Present
	6919(15)	50^{+40}_{-35}	55^{+152}_{-28}	(5)
^{184}Pb	6625(10)	500(25)	58^{+10}_{-9}	Present
	6632(10)	550(60)	49^{+11}_{-8}	(6)

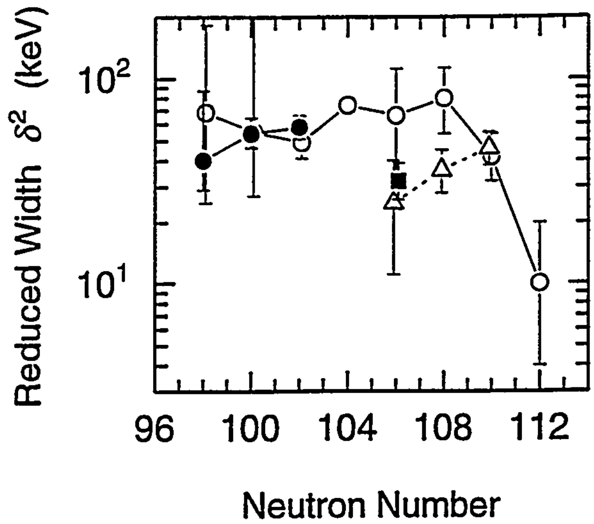

Fig. 3. Present reduced widths (solid circles) in comparison with those calculated from E_α, $T_{1/2}$, and B_α of earlier measurements tabulated in Ref. (4-7, 9-11).

DISCUSSION AND CONCLUSIONS

The α-decay rates of Pt and Pb isotopes listed in Table I were examined within the formalism of Rasmussen (1) wherein the α reduced width δ^2 is defined as $\lambda h/P$, where λ is the α decay constant and P is the α-particle penetrability factor. Calculated widths are given in Table I where error bars were determined by utilizing the experimental uncertainties on E_α and $T_{1/2}$. It was assumed that the α-decay branch is 100% for each of the nuclides treated. The reduced widths for ^{166}Pt, ^{168}Pt, and ^{170}Pt lead to a smooth trend with neutron number N for the widths of the light even-even Pt nuclei. There is a slight downward trend as one approaches the N = 82 neutron shell as shown graphiclly in a recent publication [8]. The δ^2 for the new isotope ^{167}Pt is close to the values of its even-A neighbors, which indicates that it is an unhindered transition. This implies that the spin and nucleon configuration for ^{167}Pt and ^{163}Os are the same. The reduced widths for Pb isotopes are of particular interest since they have a closed proton shell. The reduced widths from the present results are compared with those resulting for heavier Pb isotopes in Fig. 3. The open circles, resulting from one set of measurements, tend to follow the trend of the present measurements. The open triangles from another set of measurements and the solid square from another recent FMA measurement (11) are somewhat lower suggesting a dip in δ^2 at N = 106. If this dip is real it may result because the ground state of ^{184}Hg is at the point of maximum shape mixing in the mercuries, thus reducing its nuclear similarity with spherical ^{188}Pb.

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