α decay studies of the nuclides ^{218}U and ^{219}U

A. P. Leppänen,[1,*] J. Uusitalo,[1] M. Leino,[1] S. Eeckhaudt,[1] T. Grahn,[1,†] P. T. Greenlees,[1] P. Jones,[1] R. Julin,[1] S. Juutinen,[1] H. Kettunen,[1] P. Kuusiniemi,[1,‡] P. Nieminen,[1,§] J. Pakarinen,[1,‖] P. Rahkila,[1] C. Scholey,[1] and G. Sletten[2]

[1]*Department of Physics, University of Jyväskylä, P. O. Box 35, FI-40014 Jyväskylä, Finland*

[2]*Department of Physics, University of Copenhagen, Copenhagen, Denmark*

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Very neutron deficient uranium isotopes were produced in fusion evaporation reactions using ^{40}Ar ions on ^{182}W targets. The gas-filled recoil separator RITU was employed to collect the fusion products and to separate them from the scattered beam and other reaction products. The activities were implanted into a position sensitive silicon detector after passing through a gas-counter system. The isotopes were identified using spatial and time correlations between the implants and the decays. Two α-decaying states, with $E_\alpha = (8612 \pm 9)$ keV and $T_{1/2} = (0.51^{+0.17}_{-0.10})$ ms for the ground state and $E_\alpha = (10678 \pm 17)$ keV and $T_{1/2} = (0.56^{+0.26}_{-0.14})$ ms for an isomeric state, were identified in ^{218}U. In addition, the half-life and α-decay energy of ^{219}U were measured with improved precision. The measured decay properties deduced for ^{218}U suggest that there is no subshell closure at $Z = 92$.

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I. INTRODUCTION

A substantial shell gap for the $Z = 92$ nucleus ^{218}U between the proton $h_{9/2}$ and $f_{7/2}$ orbitals is predicted by systematic mean-field calculations for heavy elements [1,2]. This is in contradiction with the findings of the single quasiparticle energies deduced from the experimental values measured for the lighter $N = 126$ isotones. However, the positions of the $i_{13/2}$ and $f_{7/2}$ orbitals can be strongly shifted by octupole correlations, which are known to be significant in the heavier thorium and uranium isotopes and which are not taken into account in the mean-field approach.

The latest study of neutron deficient uranium isotopes was performed by O. N. Malyshev *et al*. [3]. Their identification of the new α-decaying isotope ^{217}U was based on three correlated recoil$-\alpha-\alpha$ chains where the second α decay in the chain had decay properties characteristic of ^{213}Th. In the same work, one decay chain originating from ^{218}U was recognized. The uranium isotope ^{218}U was previously studied by Andreyev *et al*. [4]. In that work four chains were identified but only one correlation chain, which started from a recoil event, was found (one decay time). For the isotope ^{219}U six decay chains were reported by Andreyev *et al*. [5]. No assignments for the spins and parities of the decaying states are given in the aforementioned references.

The even-even $N = 126$ isotone ^{216}Th was studied in Jyväskylä by employing isomer spectroscopy at the focal plane of the RITU separator [6]. A number of isomers with simple shell model configurations and a low-lying $I^\pi = 3^-$ state were found, implying strong $L = 3$ correlations. The shell model isomeric ($t_{1/2} = 128(8)$ μs) state $(\pi h_{9/2}\pi f_{7/2})8^+$ was measured to have an α-decay branch of 5%, which is in good agreement with the value of 3% estimated in the previous work [7]. Very recently, ^{216}Th was once again studied employing the $\alpha-\gamma$-coincidence technique [8]. This time the half-life for the isomeric state was measured to be $t_{1/2} = 135(4)$ μs and the α-decay branch was determined to be 2.8(9)%.

For the odd-even $N = 126$ isotones experimental nuclear data are available up to ^{217}Pa. In the work of Ref. [9] two α-decaying states in ^{217}Pa were reported. The α-decaying ground state was associated with a $9/2^-$ configuration. For the α-decaying isomeric state two possible configurations, $(\pi h^2_{9/2}\pi i_{13/2})29/2^+$ and $(\pi h^2_{9/2}\pi f_{7/2})23/2^-$, were given. The same nucleus was later studied by Ikuta *et al*. [10]. In that work three α-decaying states were reported having configurations $\pi h_{9/2}$ (g.s.), $(\pi h^2_{9/2}\pi i_{13/2})29/2^+$, and $(\pi h^2_{9/2}\pi f_{7/2})23/2^-$. Recently ^{217}Pa was again studied employing the $\alpha-\gamma$-coincidence method [11]. The earlier results were confirmed with the exception that the α decay from the isomeric state with $I^\pi = 23/2^-$ reported in Ref. [10] was discovered to be a fine structure decay from the isomeric state with $I^\pi = 29/2^-$. In Ref. [11] a configuration of $(\pi h^2_{9/2}\pi i_{13/2})29/2^+$ is suggested for the α-decaying isomeric state. Very recently, the odd $N = 126$ isotone ^{215}Ac was studied employing the $\alpha-\gamma$-coincidence technique [12]. No evidence for isomeric α decays was found in this isotone.

Recently, large-scale shell model calculations for the $N = 126$ isotones were performed in the full proton model space $(0h_{9/2}, 1f_{7/2}, 0i_{13/2}, 2p_{3/2}, 1f_{5/2}, 2p_{1/2})$ [13]. These calculations showed excellent agreement with experimental values, the main results being that octupole correlations must be taken into account and that there is no shell gap at $Z = 92$. These calculations predict that the $(\pi h^2_{9/2}\pi f_{7/2})23/2^-$ state lies below the $(\pi h^3_{9/2})21/2^-$ and $(\pi h^3_{9/2})19/2^-$ states in ^{217}Pa forming an yrast trap. It is further predicted that the states

*Present address: Radiation Nuclear Safety Authority STUK, Rovaniemi, Finland.

†Present address: Oliver Lodge Laboratory, University of Liverpool, Liverpool L69 7ZE, United Kingdom.

‡Present address: Centre for Underground Physics in Pyhäsalmi CUPP, Pyhäjärvi, Finland

§Present address: Australian National University, Canberra ACT0200, Australia.

‖Present address: Oliver Lodge Laboratory, University of Liverpool, Liverpool L69 7ZE, United Kingdom.

$(\pi h_{9/2}\pi f_{7/2})8^+$ and $(\pi h_{9/2}^2)6^+$ are almost degenerate in ^{216}Th. In ^{218}U the configuration $(\pi h_{9/2}\pi f_{7/2})8^+$ is predicted to fall below the $(\pi h_{9/2}^2)6^+$ configuration.

It is of interest to experimentally verify what is the case in the next $N = 126$ isotone ^{218}U. The production cross section for ^{218}U is expected to be at a level of 1 nb. Thus, α decay then provides the only viable means to obtain spectroscopic information. In the present work the uranium isotope ^{218}U was studied using α decay as a spectroscopic tool. In addition, the uranium isotope ^{219}U was investigated in more detail.

II. EXPERIMENTAL DETAILS

Heavy ion induced fusion evaporation reactions of the type ^{182}W(^{40}Ar,xn)$^{222-x}$U were used to synthesize neutron deficient uranium isotopes in two separate experiments. The ^{40}Ar beam was delivered by the $K = 130$ MeV cyclotron of the Accelerator Laboratory at the Department of Physics of the University of Jyväskylä (JYFL). Fine adjustment of the bombarding energies was performed using a set of carbon foils in front of the target. Energy losses in the degrader foils, in the targets, and in the helium gas filling of the separator used (see below) were calculated using the TRIM code [14].

Typical ^{40}Ar beam intensities were 60–200 pnA and the total beam on target time was 98 h. Bombarding energies varied between $E_{\mathrm{lab}} = 191$ and 197 MeV. Rolled ^{182}W targets of 0.6 and 0.8 mg/cm^2 thickness enriched in ^{182}W (96%) were used.

Evaporation residues resulting from fusion reactions were separated from the beam using the JYFL gas-filled recoil separator RITU [15]. In the first experiment, after passing through two multiwire proportional gas counters (MWPC), the residues were implanted into a position sensitive silicon detector (PAD detector). The silicon detector (300 μm thick) was divided into 16 position sensitive strips and the total area of the detector was 35×80 mm^2. Because the vertical position resolution of each strip was better than 500 μm, the silicon detector could be treated as a pixel detector of more than 1000 pixels. The recoil time-of-flight measured using the gas counters combined with the recoil energy deposited in the silicon detector was used to separate the candidate fusion evaporation products from the scattered beam particles. In addition, the gas counters were used to separate the α particles from low-energy recoils. Behind the main silicon detector, quadrant silicon detectors were used to veto energetic light particles (protons and α's) punching through the first silicon detector. These particles may originate from elastic head-on collisions of full-energy beam particles with foils, residual gas, and the helium filling gas.

In the second experiment, the GREAT spectrometer [16] was used at the focal plane of RITU. The GREAT setup consisted of one multiwire proportional gas counter and two double-sided silicon strip detectors (DSSD). The silicon strip detectors had 40 vertical and 60 horizontal 1-mm-wide strips giving a total of 4800 pixels and the two detectors were placed side by side such that the total width of the detector system was 120 mm. In this experiment the recoil time-of-flight measured using the gas counter and the silicon detectors combined with the recoil energy deposited in the silicon detectors was used to separate the candidate fusion evaporation products from scattered beam particles. In both experiments the implants were linked with their subsequent α decays and with α decays of their daughter nuclei using spatial and time correlations.

The pressure of the helium filling gas in RITU was typically 60 Pa. The RITU gas volume was separated from the high vacuum of the beam line using a differential pumping system consisting of a Roots pump and collimators. The counter gas in the MWPC was isobutane of 300 Pa pressure and the counter windows, made of 120 μg/cm^2 Mylar, were also used to keep the silicon detector chamber in high vacuum. The silicon detectors were cooled to 253 K using circulating alcohol.

The α spectra were gain matched and calibrated using well-known α activities produced in a separate bombardment where the ^{182}W target was replaced with a ^{175}Lu target. For the energy calibration the α-particle energies were taken from Refs. [17,18] and are 7462(8) keV ^{210}Ac, 7480(8) keV ^{211}Ac, 7019(5) keV ^{210}Ra, 6910(5) keV ^{211}Ra, 6899(2) keV ^{212}Ra, 6790(3) keV ^{206}Fr, 6768(3) keV ^{207}Fr, 6641(3) keV ^{208}Fr, 6647(4) keV ^{209}Fr, 6262(3) keV ^{205}Rn, and 6259(2) keV ^{206}Rn. The validity of the gain matching and the calibration at the higher α-particle energy region was checked using the known α activities produced in the production run. Good agreement with the activities ^{216}Th, ^{216}Ac, ^{217}Th, and ^{218}Pa [11] was noticed. The full-width-at-half-maximum value with all the 16 strips summed up was measured to be 30 keV at an α-particle energy of 7000 keV in the first experiment. In the second experiment the full-width-at-half-maximum value with all the horizontal 120 strips summed up was measured to be 23 keV at an α-particle energy of 7000 keV.

III. RESULTS

Figure 1(a) presents the energy spectrum of all particles observed in the silicon detector and vetoed with the gas counter in the second experiment using the ^{40}Ar $+^{182}$W reaction. The spectrum is dominated by activities formed in fusion channels involving α-particle evaporation. The thorium isotopes ^{216}Th and ^{215}Th and their corresponding daughter and granddaughter activities can be identified. The broad distribution at the right-hand side from the α peaks is caused by the high energy He ions that punch through the silicon detector. The gas counter is not triggered by these energetic particles and in the second experiment no punch-through detectors were used. In Fig. 1(b), only α decays correlated within 100 ms to implanted residues inside the proper recoil energy gates are shown. Activities produced involving pure neutron evaporation or one proton in addition to neutron evaporation are now visible.

In Fig. 2, a two-dimensional energy plot is created by demanding that the correlated α decays are followed within 20 s by a second α decay. These data from both experiments were combined. From the plot, different isotopes can be recognized. The thorium isotopes ^{217}Th, ^{216}Th, ^{215}Th, and ^{214}Th produced in the αn (2p3n), α2n, α3n, and α4n fusion-evaporation channels, respectively, can be identified. In the p3n and p4n fusion-evaporation channels the protactinium isotopes ^{218}Pa and ^{217}Pa were produced. Finally the 3n and 4n fusion

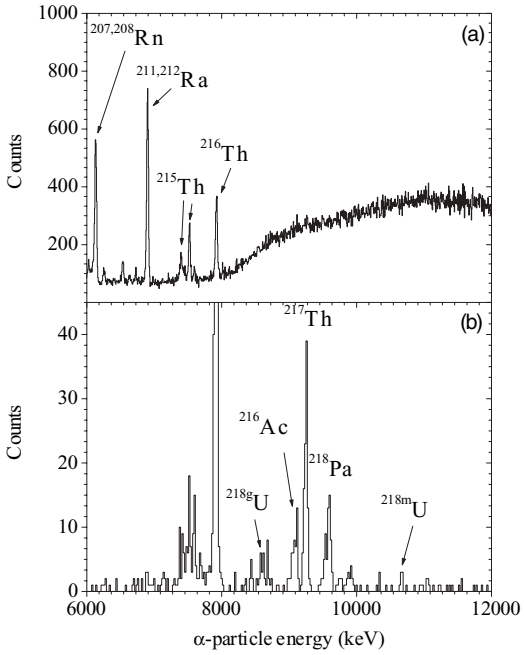

FIG. 1. Energy spectra of particles measured in the silicon detector and vetoed with the gas counter using the ^{40}Ar $+^{182}$W reaction: (a) all particles; (b) decays following recoil implants within 100 ms.

evaporation channels yielded the uranium isotopes ^{219}U and ^{218}U. For the uranium isotopes triple α-decay chains, including the daughter activities ^{215}Th and ^{214}Th and granddaughter activities ^{211}Ra and ^{210}Ra, were identified and are illustrated in Fig. 2.

The chains originating from the ^{219}U and ^{218}U isotopes are discussed in more detail in the following. Four decay chains were identified where the mother activity with $E_\alpha = 9774$ keV and $T_{1/2} = 0.08$ ms was followed in three cases by a second decay with $E_\alpha = 7520$ keV and $T_{1/2} = 1.1$ s and in one case

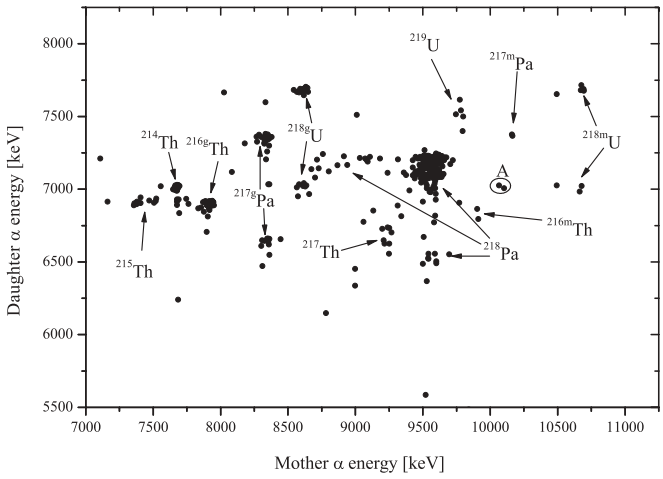

FIG. 2. Mother and daughter α-particle energies for all chains of the type ER $-\alpha_m - \alpha_d$ observed in the ^{40}Ar $+^{182}$W irradiation. Maximum search times were 100 ms for the ER $-\alpha_m$ pair and 20 s for the $\alpha_m - \alpha_d$ pair.

by a second decay with $E_\alpha = 7399$ keV and $T_{1/2} = 0.4$ s. One of the chains was followed by a third decay with $E_\alpha = 6906$ keV and $T_{1/2} = 9$ s. The second decay in the chains can be recognized as belonging to ^{215}Th for which decay properties of $E_\alpha = 7522(8)$ keV, 7393(8) keV, and 7331(10) keV with $T_{1/2} = 1.2(2)$ s [19] have been reported to originate from the $1/2^+$ ground state. The third decay in one of the chains can be associated with ^{211}Ra for which decay properties of $E_\alpha = 6910(5)$ keV and $T_{1/2} = 15(2)$ s [20] are reported for the $5/2^+$ ground state. Therefore the activity with $E_\alpha = 9774$ keV and $T_{1/2} = 0.08$ ms can be identified as belonging to ^{219}U.

For the uranium isotope ^{218}U, two groups were identified. The first group represents the 0^+ ground state to 0^+ ground state α-particle decay. The mother activity with $E_\alpha = 8612$ keV and $T_{1/2} = 0.51$ ms was identified to be followed by a second decay with $E_\alpha = 7681$ keV and $T_{1/2} = 92$ ms and by a third decay with $E_\alpha = 7009$ keV and $T_{1/2} = 2.5$ s. The second decay in the chains can be recognized as belonging to ^{214}Th for which decay properties of $E_\alpha = 7677(10)$ keV and $T_{1/2} = 80(10)$ ms [21] have been assigned to the 0^+ ground state. The third decay in the chains can be associated with ^{210}Ra for which decay properties of $E_\alpha = 7018(5)$ keV and $T_{1/2} = 3.8(2)$ s [20] are reported for the ground state.

In the second group the mother activity with $E_\alpha = 10678$ keV and $T_{1/2} = 0.56$ ms was found to be followed by a second decay with $E_\alpha = 7683$ keV and $T_{1/2} = 83$ ms and by a third decay with $E_\alpha = 7011$ keV and $T_{1/2} = 3.5$ s. As above, the second decay in the chains can be assigned to ^{214}Ra and the third decay in one of the chains can be associated with ^{210}Rn. Therefore, the activities with $E_\alpha = 8612$ keV, $T_{1/2} = 0.51$ ms and $E_\alpha = 10678$ keV, $T_{1/2} = 0.56$ ms can both be identified to originate from ^{218}U. They de-excite different states as is discussed later.

When the efficiency of the RITU separator is assumed to be 40%, uranium isotopes were produced with the following cross sections: for ^{218}U, 1.1 nb, and for ^{219}U, 220 pb. These cross-section values, having uncertainties of a factor of 2 to 3, do not necessarily represent the maximum values because excitation functions were not measured.

IV. DISCUSSION

In the present work α-decay hindrance factors HF and reduced widths δ^2, determined according to the formalism of Rasmussen [22], are used to obtain information on the structure of the decaying states. The α-decay properties of the uranium isotopes and their corresponding daughter and granddaughter isotopes observed in the present work are summarized in Table I. The reduced width values shown in Table I are calculated taking into account the α-decay branch values given in Ref. [23]. If the α-decay branch is not known, a 100% α-decay branch value is assumed, which is a reasonably good approximation for most cases when considering the predicted β-decay half-life values given in Ref. [2].

The decay properties measured for the even-odd nucleus ^{219}U and for the corresponding descendants ^{215}Th and ^{211}Ra are quite compatible with the decay properties reported in the literature. Only the α-decay energy of ^{219}U is about

TABLE I. The α-decay properties of the uranium isotopes and their corresponding daughter and granddaughter isotopes observed in the present work. The literature values are taken from Refs. [4,5,19–21]. The α-decay reduced widths δ^2 ($\Delta l = 0$ is assumed) and half-lives normalized to ^{212}Po (the α-particle knocking frequency is taken to be equal to that of ^{212}Po), calculated according to Ref. [22], are also given. In column 8, the spin and parity of the decaying state are given. Notice that some of the spin and parity assignments are tentative.

Nuclide	E_α (keV) Meas.	E_α (keV) Lit.	$T_{1/2}$ (ms) Meas.	$T_{1/2}$ (ms) Lit.	$T_{1/2}$ (ms) Calc.	δ^2 (keV)	I^π
^{219}U	9774(18)	9680(40)	$0.08^{+0.10}_{-0.03}$	$0.042^{+0.034}_{-0.013}$	5.6×10^{-4}	$0.51^{+0.64}_{-0.20}$	$(9/2^+)$
^{215}Th	7520(10)	7522(8) 40%	$(0.63^{+1.26}_{-0.21})$ s	1.2(2) s	0.19 s	4.5(9)	$(1/2^-)$
	7399(20)	7393(8) 52%			0.52 s	16(3)	
		7331(10) 8%			0.85 s	4.1(8)	
^{211}Ra	6906(6)	6910(5)	9(5) s	15(2) s	4.8 s	23(4)	$(5/2^-)$
^{218}U^g	8612(9)	8625(25)	$0.51^{+0.17}_{-0.10}$	$1.5^{+7.3}_{-0.7}$	0.47	66^{+23}_{-14}	0^+
^{214}Th^g	7681(8)	7677(10)	92^{+32}_{-19}	80(10)	60	54(8)	0^+
^{210}Ra^g	7009(8)	7019(5)	$(2.5^{+1.4}_{-0.7})$ s	3.8(2) s	1.9 s	37(3)	0^+
^{218}U^m	10678(17)	—	$0.56^{+0.26}_{-0.14}$	—	7.5×10^{-6}	$(9.6^{+4.6}_{-2.6})\times10^{-4}$	(8^+)
^{214}Th^g	7683(8)	7677(10)	83^{+58}_{-25}	80(10)	60	54(8)	0^+
^{210}Ra^g	7011(8)	7019(5)	$(3.5^{+4.8}_{-1.3})$ s	3.8(2) s	1.9 s	37(3)	0^+

100 keV higher than the value given in Ref. [5]. The reason could be that the energy resolution of the silicon detector used in Ref. [5] was quite poor (about 70–90 keV FWHM). In Ref. [5] no interpretation concerning the structure of the decaying state in ^{219}U was given. If the reduced width value of 0.51 keV (^{219}U) is compared to the corresponding values of 0.61 keV (^{217}Th), 0.50 keV (^{215}Ra), 0.28 keV (^{213}Rn), and 0.20 keV (^{211}Po), striking similarities can be noticed. These reduced width values, when compared to the values obtained for the closest even-even neighbors for the ground state to ground state decays (some tens of keV), show that these decays are hindered. Because in the lighter $N = 127$ isotones the hindered α decays occur from the ground states $(\nu g^1_{9/2})9/2^-$ to the ground states $(\nu p^1_{1/2})1/2^-$, the same can be assumed to occur also in ^{219}U. The hindrance factor is defined as the ratio of the reduced width of the ground state to ground state transition in the closest even-even neighbor to the reduced width of the transition in question. In odd-mass nuclei a hindrance factor of less than 4 implies an unhindered α decay between states of equal spin, parity, and configuration [24]. This is also illustrated in Table I where the α decay with an energy of $E_\alpha = 7393(3)$ keV represents the favored decay from the ground state $(\nu p^1_{1/2})1/2^-$ in ^{215}Th to the corresponding excited state in ^{211}Ra.

For ^{218}U two α-decaying states were observed. The α decay with an energy of $E_\alpha = 8612(9)$ keV is unhindered and represents the decay between 0^+ ground states. The α decay with an energy of $E_\alpha = 10678(17)$ keV is clearly strongly hindered as can be seen if the measured half-life is compared to the calculated half-life shown in Table I. In Table II the decay properties of ^{218}U are compared to the decay properties of the corresponding $N = 126$ isotones ^{217}Pa and ^{216}Th. It is striking how similar the hindrance factors are for the isomeric α decays of these three $N = 126$ isotones. Here it should be noted that in the Rasmussen model non-zero angular-momentum change between mother and daughter can be included but possible additional nuclear structure effects cannot be taken into account.

In the present work, for two isomeric α decays, five ground-state α decays were obtained (ratio 2/5) for ^{218}U. This ratio compares well with the corresponding ratio of about 1/3 that was determined for ^{217}Pa [9].

As mentioned above the even-even $N = 126$ isotone ^{216}Th was recently studied in Jyväskylä by employing isomer spectroscopy at the focal plane of the RITU separator [6]. In that experiment it was unambiguously demonstrated that a shell model isomeric ($t_{1/2} = 128$ μs) state $(\pi h_{9/2}\pi f_{7/2})8^+$ comes close in energy to the $(\pi h^2_{9/2})6^+$ state and an α decay with a branch of 5% was measured. This α decay occurs directly to the 0^+ ground state in the daughter nucleus ^{212}Ra. From Table II it can be noticed that even with an angular-momentum change of 8 in the α decay from the isomeric state in ^{216}Th a significant amount of hindrance remains, which is caused by nuclear structure effects. The α decay occurs between two different configurations, $(\pi h_{9/2}\pi f_{7/2})8^+$ and $(\pi h^2_{9/2})0^+$, which in a simplified picture means that after the α-decay process the nucleons have to regroup. Because the behavior of the hindrance factors is strikingly similar as a function of angular-momentum change it is proposed that the structures of the α-decaying isomeric states in ^{217}Pa and in ^{218}U studied in this work have the same origin. As mentioned earlier this interpretation is also in very good agreement with the recent shell model study [13]. Analogously with ^{217}Pa, it was predicted that in the case of ^{218}U the $(\pi h_{9/2}\pi f_{7/2})8^+$ state falls below the $(\pi h^2_{9/2})6^+$ state forming an yrast trap. If the excitation energy of the $(\pi h_{9/2}\pi f_{7/2})8^+$ state in ^{218}U is determined from the α-decay energies measured in this work, a value of 2105(20) keV can be obtained. This in good agreement with the value of 2085 keV given in Refs. [13,25]. The α-decay scheme is illustrated in Fig. 3.

Very recently, ^{216}Th was studied employing the $\alpha - \gamma$-coincidence technique [8]. In this study the half-life for the

TABLE II. The α-decay properties of the $N = 126$ isotones ^{216}Th, ^{217}Pa, and ^{218}U. The experimental values for ^{216}Th and ^{217}Pa are taken from Refs. [8,11]. For ^{218}U, the experimental values are from this work. The α-decay reduced widths δ^2 and half-lives normalized to ^{212}Po, calculated according to Ref. [22], are also given. The hindrance factor HF1 is defined as HF1 = $T^{\alpha}_{1/2}$(Meas.)/$T^{\alpha}_{1/2}$(Calc.) and the hindrance factor HF2 is defined as HF2 = δ^2(closest even-even g.s. to g.s.)/δ^2(under examination).

Nuclide	E_α (keV) Meas.	$T^{\alpha}_{1/2}$ (ms) Meas.	Δl	$T^{\alpha}_{1/2}$ (ms) Calc.	δ^2 (keV)	HF1	HF2
^{216}Th^g	7923(5)	26(2)	0	9.22	26(3)	2.8(3)	1
^{217}Pa^g	8337(5)	3.8(2)	0	1.24	24(2)	3.1(2)	1.1(2)
^{218}U^g	8612(9)	$0.51^{+0.17}_{-0.10}$	0	0.47	66^{+23}_{-14}	$1.1^{+0.4}_{-0.3}$	1
^{216}Th^m	9930(10)	6.5(3)	0	6.4×10^{-5}	7.1×10^{-4}	102000	37000
			4	3.1×10^{-4}	3.5×10^{-3}	21000	7400
			8	1.8×10^{-2}	0.20	360	130
			10	0.32	3.6	19	7.2
			12	9.8	109	0.66	0.24
^{217}Pa^m	10157(5)	2.1(7)	0	4.2×10^{-5}	1.5×10^{-3}	50000	18000
			4	2.1×10^{-4}	7.6×10^{-3}	10000	3500
			8	1.1×10^{-2}	0.39	190	70
			10	0.2	6.9	11	3.9
			12	5.9	204	0.36	0.13
^{218}U^m	10678(17)	$0.56^{+0.26}_{-0.14}$	0	7.5×10^{-6}	9.6×10^{-4}	75000	69000
			4	3.5×10^{-5}	4.6×10^{-3}	16000	14000
			8	1.8×10^{-3}	0.24	310	280
			10	3.0×10^{-2}	3.9	19	17
			12	0.85	110	0.66	0.6

isomeric state was measured to be $t_{1/2} = 135(4)$ μs with an α-decay branch of 2.8(9)%. In addition, it was measured that this α-decaying state feeds three different states in the daughter nucleus ^{212}Ra. The α decay with an energy of 9930(10) keV was observed to feed the ground state with a 74(4)% branch. The 2^+ state was measured to be fed by an α decay with an energy of 9312(12) keV with a branch of 13(3)%. Both these decays are strongly hindered. Finally, it was observed that an α decay with an energy of 7999(10) keV with a branch of 13(2)% feeds the corresponding 8^+ state in the daughter nucleus ^{212}Ra. This interpretation was partly based on the fact that this α decay is unhindered.

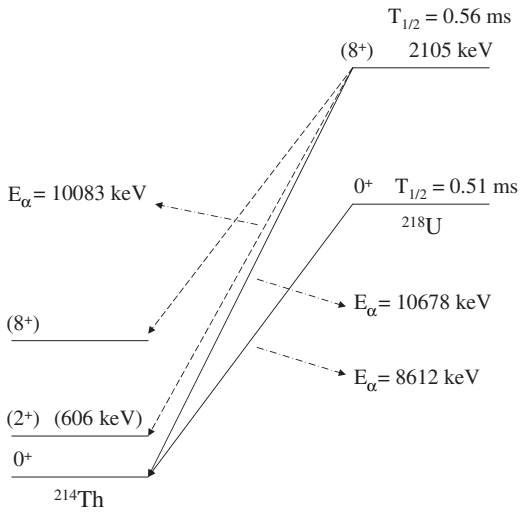

FIG. 3. Suggested α-decay scheme belonging to the even-mass uranium isotope ^{218}U.

Although the data are clean, as can be seen from Fig. 2, some estimates about the origin of the single events should be made. First of all, the expected number of accidental double-chain correlations in the entire shown two-dimensional energy window in Fig. 2 is calculated to be two. Some of the single events shown in Fig. 2 can be explained by being so-called "ghost" events. A ghost event represents a situation where an α particle is not escaping the detector in a backward direction but instead it escapes the pixel in the detector plane direction. While the backward escaped α particles leave about 1–3 MeV energy in the detector, the ghost α particle may have almost all of it's energy deposited. The probability that an α particle causes a ghost event in the DSSD pixel is approximately 1 to 4% depending on the α-particle energy. This probability is a factor of 10 smaller for the PAD detector used in the first experiment. The α-particle range in silicon is about 30 μm for 6 MeV α particles and increases up to about 80 μm for 11 MeV α particles. As an example the triple α chain, where the first α particle has deposited about 10500 keV, can be associated to be a real ghost event originating from the isomeric state of ^{218}U.

On the other hand the two event group, labeled as A, must be real without being ghost events. The probability that these two events (group A) are random is calculated to be less than 10^{-6}. This probability is small because of the short decay times measured for the first decays in the chains. For this group it was measured that the activity with $E_\alpha = 10083$ keV and $T_{1/2} = 0.27$ ms was followed by a decay with $E_\alpha = 7016$ keV and $T_{1/2} = 6.0$ s. The decay properties

measured for the second decay in the chains can be associated with ^{210}Ra ($E_\alpha = 7019(5)$ keV and $T_{1/2} = 3.8(2)$ s) [20]. A reasonable assumption is that in these two chains the second decays were lost (α particles escaping the detector), thus the first decays could represent the α-decay branch from the 8^+ isomeric state in the mother nucleus ^{218}U to the 2^+ state in the daughter nucleus ^{214}Th. The α decay of ^{214}Th is fast (80 ms) relative to the α decay of ^{210}Ra (3.8 s) and therefore does not affect this interpretation. The probability that the two daughter decays are lost as escapes (in backward direction) is about 25%. In the present analysis the escaping α particles are not included because of the high background conditions caused by punch-through protons.

If this is assumed an excitation energy of 606 keV can be deduced for the 2^+ state in the daughter nucleus ^{214}Th. This is in good agreement with the known 2^+ excitation energies 687, 644, and 629 keV measured for the $N = 124$ isotones ^{208}Po, ^{210}Rn, and ^{212}Ra, respectively [26]. No clear evidence was found for the α decay from the 8^+ isomeric state to an 8^+ state in the daughter nucleus ^{214}Th. Single events are not deemed to be of sufficient statistical significance to give positive proof of such decays. On the another hand, it cannot be ruled out that some of the events counted as ground state decays from ^{218}U are in fact decays from the 8^+ isomeric state to the corresponding state in the daughter.

In conclusion, a new α-decaying isomer was identified in ^{218}U. The α decay from the ground state of ^{218}U was studied with improved accuracy. The α-decay properties measured for the uranium isotope ^{219}U were confirmed with improved precision. The α-decaying isomer in ^{218}U is suggested to have the configuration $(\pi h_{9/2}\pi f_{7/2})8^+$. This result was compared to recent shell model calculations and an excellent agreement was found. These calculations suggest that there is no subshell closure at $Z = 92$. Preliminary results from the present work have been published in the conference proceedings [27].

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