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Alpha-decay studies using the JYFL gas-filled recoil separator RITU

J. Uusitalo[1,a], S. Eeckhaudt[1], T. Enqvist[1], K. Eskola[2], T. Grahn[1], P.T. Greenlees[1], P. Jones[1], R. Julin[1], S. Juutinen[1], H. Kettunen[1], P. Kuusiniemi[1], M. Leino[1], A.-P. Leppänen[1], P. Nieminen[1], M. Nyman[1], J. Pakarinen[1], P. Rahkila[1], and C. Scholey[1]

[1] Department of Physic, University of Jyväskylä, P.O. Box 35, FI-40014, Jyväskylä, Finland
[2] Department of Physics, University of Helsinki, FI-00014, Helsinki, Finland

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Abstract. Neutron-deficient α-decaying nuclei have been produced using fusion-evaporation reactions. A gas-filled recoil separator was used to separate the fusion products from the scattered beam. The activities were implanted in a position sensitive silicon detector. The isotopes were identified using spatial and time correlations between implants and decays. During ten years of operation time about twenty new α-decaying isotopes have been identified in the translead region. In addition numerous α-decay studies have been performed on already known isotopes yielding much improved precision for the measured decay properties. An overview of the α-decay studies performed for the translead nuclei employing the gas-filled recoil separator will be given.

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The gas-filled recoil separator RITU [1] at Jyväskylä Accelerator Laboratory (JYFL) has been used intensively for α-decay studies of heavy neutron-deficient nuclei for about ten years. Most of these studies have been performed in the translead region at the extreme limit of nuclear existence. The low production yields due to the strong fission competition have demanded high performance from the separator system and from the focal plane detector system used in these studies.

In the present work α-decay hindrance factors HF and reduced widths δ^2, determined according to Rasmussen [2], have been used to obtain structure information of the decaying states. 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 decay between states of equal spin, parity, and configuration [3]. For even-even nuclei the systematic study of reduced widths δ^2 is used to obtain important structure information on the decaying states. In the lead region the multiproton-multihole intruder states and the occurrence of shape coexistence have been investigated using α-decay as a spectroscopic tool [4,5]. In addition the vicinity of the proton drip line has offered the possibility to study proton-unbound systems and even to search for direct proton emission [6,7,8]. While in the lead region the proton drip line crosses the magic proton number 82 at the neutron mid-shell, in the uranium region the drip line crosses the magic neutron number 126. One of the recently investigated isotopes has been the semi magic nucleus ^{218}U for which two α-decaying isomeric states were observed [9]. In addition to the structural information the present α-decay studies have given a lot of valuable information for the mass evaluations [10].

When the reduced widths for the ground state to ground state transitions are reviewed it can be noticed that they remain constant for even-mass Po isotopes lighter than ^{196}Po and even decrease significantly for ^{188}Po. This behaviour is illustrated in fig. 1a. The reason for this is that the α-decays from the Po 0^+ ground states to the proton ($2p$-$2h$) 0^+ intruder states in Pb nuclei are getting increasingly favorable. The interpretation has been that the ground states of neutron-deficient Po isotopes are mixtures of different configurations, spherical $\pi(2p\text{-}0h)$, oblate $\pi(4p\text{-}2h)$ (and prolate $\pi(6p\text{-}4h)$). Recently α-decay properties of very neutron-deficient Rn nuclei were studied in Jyväskylä [11]. Intriguingly it was noticed that the α-decays of ^{198}Rn and ^{196}Rn were clearly faster than the smooth behaviour of heavier even-mass Rn isotopes predicts (fig. 1a.). The conclusion from this study was that especially in the case of ^{196}Rn the α-decay is taking place between deformed (and strongly mixed) 0^+ ground states.

[a] Conference presenter;
e-mail: juha.uusitalo@phys.jyu.fi

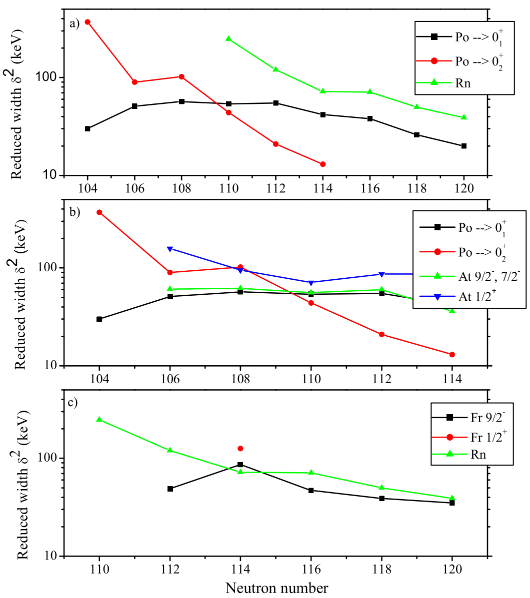

Fig. 1. Reduced α-decay width values of neutron-deficient Fr, Rn, At and Po isotopes. (a) Radons and poloniums are compared, (b) poloniums and astatines are compared and (c) radons and franciums are compared.

The α-decaying proton intruder state $((\pi s^{-1}_{1/2})1/2^+)$ has been shown to exist in many odd-mass Bi isotopes [12] and in At isotopes (investigated recently in Jyväskylä) [6,7]. A falling trend of excitation energy of the $(\pi s^{-1}_{1/2})1/2^+$ state as a function of decreasing neutron number has been observed. Actually the $(\pi s^{-1}_{1/2})1/2^+$ proton intruder state becomes the ground state in ^{195}At [6] and in ^{185}Bi [13,14]. The $(\pi s^{-1}_{1/2})1/2^+$ proton intruder state remains as a ground state in ^{193}At and in ^{191}At [7]. In fig. 1b the reduced widths determined for the odd-mass At isotopes are shown together with the reduced widths determined for the even-mass Po isotopes. The reduced-width values obtained for the α-decays from the high-spin isomers $((\pi h_{9/2})9/2^-)$ in At follow nicely the reduced-width values obtained for the ground state to ground state decays in Po. However, the reduced-width values obtained for the α-decays from the low-spin isomeric intruder states $((\pi s^{-1}_{1/2})1/2^+)$ in At are slightly higher. When more neutron-deficient nuclei are considered these reduced-width values start to follow the reduced-width values obtained for the α-decays from the Po 0^+ ground states to the proton $(2p\text{-}2h)$ 0^+ intruder states in Pb. The work has been extended and recently the neutron-deficient Fr isotopes were examined using RITU [8]. For the first time, a $(\pi s^{-1}_{1/2})1/2^+$ proton intruder state was also identified in a Fr isotope, namely in ^{201}Fr. This is illustrated in fig. 1c from where it can be noticed that again the α-decay from the low-spin isomeric intruder state is relatively faster than the α-decay from the high-spin ground state.

The work [8] and the work [6] suggest the existence of a low-lying $1/2^+$ proton intruder isomeric (ground) state in ^{199}Fr. Since the $(\pi h_{9/2})9/2^-$ state is associated with the spherical shape and the $(\pi s^{-1}_{1/2})1/2^+$ proton intruder state is associated with an oblate character an onset of substantial deformation is expected to occur at neutron number $N = 112$ in odd-mass Fr isotopes.

In conclusion, the reduced widths deduced from the measured decay properties for the neutron-deficient odd-mass Fr isotopes and even-mass Rn isotopes suggest an onset of substantial deformation at neutron number $N = 112$ and at $N = 110$, respectively. This can be compared to the prediction of Möller *et al.* [15] where the predicted onset of deformation for Fr nuclei occurs at neutron number $N = 116$ and for Rn nuclei occurs at neutron number $N = 114$.

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