



Decay spectroscopy of ²²⁵Pa : Study of octupole deformation in the neutron deficient actinides

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ÉCOLE DOCTORALE

Particules, hadrons, énergie et noyau: instrumentation, imagerie, cosmos et simulation (PHENIICS)



Physics Motivations

Prediction of strong octupole deformations in the ground state of neutron-deficient actinides:



S. E. Agbemava et al. PRC 96 (2017)



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Prediction of strong octupole deformations in the ground state of neutron-deficient actinides:





Decay spectroscopy observables **Parity doublets** Soft octupole deformation octupole vibration B3 'K+3^{-π} K+4^{-π} K+2^{-π} -K+4^π •K+4^π **K+3**^{-π} -K+1^{-π} **-**Κ+3^π K+3^π K+2^{-π} K^{-π} •K+2^π -K+2^π K+1^{-π} •K+1^π 'K+1^π **κ**-π ·Κ^π -Κ^π Splitting: 10s of keV Splitting: 100s of keV

Decay spectroscopy observables

Parity doublets



Hindrance Factors

Hindrance factor: Empirical measurement of the impact of structure effects on α-decay

HF ~ 1-4: Identical initial and final single-particle states **HF** ~ **4-10**: Initial and final single-particle states are mixed/have a favourable overlap

HF ~ **10-100**: Initial and final single-particle states do not have a favourable overlap, but have same parity and spin projection **HF** ~ **100-1000**: No favourable overlap, parity change, same spin projection

HF > 1000: No favourable overlap, parity change, spin flip

Alpha-decay tends to conserve parity and parity change will produce large (>100) hindrance factors

However: Octupole deformation breaks parity



Alpha-decay towards opposite parity states becomes more favoured (HF~10)

The I262 experiment @IGISOL (Jyväskylä)



The I262 experiment @IGISOL (Jyväskylä)

²¹⁷ Ра	²¹⁸ Ра	²¹⁹ Ра	²²⁰ Ра	²²¹ Pa	²²² Ра	²²³ Ра	²²⁴ Pa	²²⁵ Ра	²²⁶ Pa	²²⁷ Pa	²²⁸ Pa	²²⁹ Ра	²³⁰ Ра	²³¹ Ра	²³² Ра	²³³ Ра		
_{0.01 MeV}	0.02 меV	0.07 MeV	0.01 меV	0.06 MeV	0.09 MeV	0.08 MeV	_{0.01 MeV}	_{0.08 Ме} у	_{0.01 MeV}	_{0.01 MeV}	_{0 MeV}	_{0 Ме} у	_{0 меV}	_{0 ме}	0.01 меV	_{0 Ме} у		
²¹⁶ Тһ	²¹⁷ Th	²¹⁸ Th	²¹⁹ Th	²²⁰ Тһ	²²¹ Th	²²² Th	²²³ Th	²²⁴ Th	²²⁵ Th	²²⁶ Th	²²⁷ Th	²²⁸ Th	²²⁹ Th	²³⁰ Th	²³¹ Th	²³² Tł		
0.01 МеV	0.01 MeV	0.01 MeV	0.06 меV	_{0.01 Ме} у	0.01 MeV	0.01 MeV	0.01 MeV	0.01 MeV	0.01 меV	^{0 MeV}	^{0 MeV}	0 МеV	^{0 MeV}	_{0 МеV}	^{0 меv}	^{0 MeV}		
²¹⁵ Ac	²¹⁶ Ac	²¹⁷ Ac	²¹⁸ Ac	²¹⁹ Ac	²²⁰ Ac	²²¹ Ac	²²² Ac	²²³ Ac	²²⁴ Ac	²²⁵ Ac	²²⁶ Ac	²²⁷ Ac	²²⁸ Ac	²²⁹ Ac	²³⁰ Ac	²³¹ Ac		
0.01 MeV	0.01 MeV	0.01 MeV	0.06 MeV	0.05 MeV	0.01 MeV	0.06 MeV	0 MeV	0.01 MeV	_{0 MeV}	0 MeV	0 MeV	_{0 MeV}	_{0 MeV}	0.01 MeV	0.02 MeV	0.01 Me		
²¹⁴ Ra	²¹⁵ Rа	²¹⁶ Ra	²¹⁷ Rа	²¹⁸ Ra	²¹⁹ Rа	²²⁰ Ra	²²¹ Rа	²²² Rа	²²³ Rа	²²⁴ Rа	²²⁵ Rа	²²⁶ Rа	²²⁷ Ra	²²⁸ Rа	²²⁹ Ra	²³⁰ Rа		
_{0.01 MeV}	0.01 меV	_{0.01 MeV}	0.01 меV	_{0.01 MeV}	0.01 меV	_{0.01 MeV}	_{0 Ме} у	^{0 меV}	^{0 меV}	_{0 МеV}	_{0 Ме} у	_{0 Ме} у	^{0 MeV}	_{0 МеV}	_{0.02 MeV}	0.01 Ме		
²¹³ Fr	²¹⁴ Fr	²¹⁵ Fr	²¹⁶ Fr	²¹⁷ Fr	²¹⁸ Fr	²¹⁹ Fr	²²⁰ Fr	²²¹ Fr	²²² Fr	²²³ Fr	²²⁴ Fr	²²⁵ Fr	²²⁶ Fr	²²⁷ Fr	²²⁸ Fr	²²⁹ Fr		
0 меV	0.01 MeV	0.01 MeV	0 меV	0.01 MeV	0 меV	0.01 MeV	^{0 меV}	0 меV	0.01 MeV	0 меV	0.01 MeV	0.01 MeV	0.01 MeV	0.01 MeV	0.01 MeV	0.01 Me		
²¹² Rn	²¹³ Rn	²¹⁴ Rn	²¹⁵ Rn	²¹⁶ Rn	²¹⁷ Rn	²¹⁸ Rn	²¹⁹ Rn	²²⁰ Rn	²²¹ Rn	²²² Rn	²²³ Rn	²²⁴ Rn	²²⁵ Rn	²²⁶ Rn	²²⁷ Rn	²²⁸ Rr		
^{0 MeV}	^{0 меV}	0.01 MeV	0.01 меV	_{0.01 MeV}	^{0 MeV}	^{0 MeV}	^{0 меV}	^{0 меV}	_{0.01 MeV}	^{0 меV}	0.01 меV	0.01 меV	0.01 MeV	0.01 MeV	0.01 MeV	0.02 Ме		
²¹¹ At _{0 MeV}	²¹² At _{0 MeV}	²¹³ At _{0 MeV}	²¹⁴ At _{0 MeV}	²¹⁵ At 0.01 MeV	²¹⁶ At _{0 MeV}	²¹⁷ At 0.01 MeV	²¹⁸ At 0.01 MeV	²¹⁹ Аt _{0 МеV}	²²⁰ At 0.01 MeV	²²¹ At 0.01 MeV	²²² At 0.02 MeV	²²³ At 0.01 MeV	²²⁴ At 0.02 MeV					
²¹⁰ Po	²¹¹ Po	²¹² Po	²¹³ Po	²¹⁴ Po	²¹⁵ Po	²¹⁶ Po	²¹⁷ Po	²¹⁸ Ро	Mass Excess error [MeV]									
_{0 MeV}	_{0 MeV}	_{0 MeV}	_{0 MeV}	_{0 MeV}	_{0 MeV}	_{0 MeV}	0.01 MeV	0 меV										
²⁰⁹ Ві 0 меv	²¹⁰ Bi _{0 MeV}	²¹¹ Bi 0.01 MeV	²¹² Bi _{0 MeV}	²¹³ Bi 0.01 MeV	²¹⁴ Bi 0.01 MeV	²¹⁵ Bi 0.01 MeV	²¹⁶ Bi 0.01 MeV	²¹⁷ Bi 0.02 MeV		0.	02	0.05		.07	0.09	,		
²⁰⁸ Pb _{0 MeV}	²⁰⁹ Рb 0 меV	²¹⁰ Рb 0 МеV	²¹¹ Pb _{0 MeV}	²¹² Рb 0 МеV	²¹³ Pb 0.01 MeV	²¹⁴ Pb _{0 MeV}	²¹⁵ Рb 0.05 меV		Long-lived Unknown									



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The I262 experiment @IGISOL (Jyväskylä)

²¹⁷ Pa	²¹⁸ Ра	²¹⁹ Ра	²²⁰ Ра	²²¹ Pa	²²² Ра	²²³ Pa	²²⁴ Pa	²²⁵ Ра	²²⁶ Ра	²²⁷ Pa	²²⁸ Ра	²²⁹ Ра	²³⁰ Ра	²³¹ Ра	²³² Pa	²³³ Ра		
_{0.01 MeV}	0.02 меV	0.07 меV	0.01 меV	0.06 MeV	0.09 MeV	0.08 MeV	_{0.01 MeV}	0.08 меV	0.01 МеV	_{0.01 MeV}	_{0 МеV}	_{0 МеV}	_{0 меV}	_{0 МеV}	_{0.01 MeV}	_{0 Ме} у		
²¹⁶ Th	²¹⁷ Th	²¹⁸ Th	²¹⁹ Th	²²⁰ Тһ	²²¹ Th	²²² Th	²²³ Th	²²⁴ Тһ	²²⁵ Th	²²⁶ Тһ	²²⁷ Th	²²⁸ Th	²²⁹ Th	²³⁰ Th	²³¹ Th	²³² Th		
_{0.01 MeV}	0.01 MeV	0.01 меV	_{0.06 MeV}	_{0.01 Ме} у	0.01 MeV	0.01 МеV	0.01 меV	0.01 меV	0.01 МеV	^{0 меу}	^{0 MeV}	^{0 MeV}	^{0 меV}	_{0 MeV}	^{0 MeV}	^{0 меv}		
²¹⁵ Ac	²¹⁶ Ac	²¹⁷ Ac	²¹⁸ Ac	²¹⁹ Ac	²²⁰ Ac	²²¹ Ac	²²² Ac	²²³ Ac	²²⁴ Ac	²²⁵ Ac	²²⁶ Ac	²²⁷ Ac	²²⁸ Ac	²²⁹ Ac	²³⁰ Ac	²³¹ Ac		
0.01 MeV	0.01 MeV	0.01 MeV	0.06 MeV	0.05 MeV	0.01 MeV	0.06 MeV	_{0 MeV}	0.01 MeV	_{0 MeV}	0.01 MeV	0.02 MeV	0.01 MeV						
²¹⁴ Ra	²¹⁵ Rа	²¹⁶ Rа	²¹⁷ Ra	²¹⁸ Rа	²¹⁹ Rа	²²⁰ Ra	²²¹ Rа	²²² Rа	²²³ Ra	²²⁴ Rа	²²⁵ Rа	²²⁶ Rа	²²⁷ Rа	²²⁸ Rа	²²⁹ Rа	²³⁰ Rа		
_{0.01 MeV}	0.01 меV	_{0.01 MeV}	0.01 MeV	^{0.01 меV}	0.01 меV	_{0.01 MeV}	_{0 Ме} у	_{0 ме} у	^{0 меV}	^{0 меV}	_{0 Ме} у	^{0 меV}	_{0 Ме} у	^{0 меV}	_{0.02 MeV}	_{0.01 Ме} у		
²¹³ Fr	²¹⁴ Fr	²¹⁵ Fr	²¹⁶ Fr	²¹⁷ Fr	²¹⁸ Fr	²¹⁹ Fr	²²⁰ Fr	²²¹ Fr	²²² Fr	²²³ Fr	²²⁴ Fr	²²⁵ Fr	²²⁶ Fr	²²⁷ Fr	²²⁸ Fr	²²⁹ Fr		
0 MeV	0.01 MeV	0.01 MeV	0 меV	0.01 MeV	0 меV	0.01 MeV	^{0 MeV}	0 меV	0.01 MeV	0 меV	0.01 MeV	0.01 MeV	0.01 MeV	0.01 MeV	0.01 MeV	0.01 MeV		
²¹² Rn	²¹³ Rn	²¹⁴ Rn	²¹⁵ Rn	²¹⁶ Rn	²¹⁷ Rn	²¹⁸ Rn	²¹⁹ Rn	²²⁰ Rn	²²¹ Rn	²²² Rn	²²³ Rn	²²⁴ Rn	²²⁵ Rn	²²⁶ Rn	²²⁷ Rn	²²⁸ Rn		
^{0 меV}	^{0 MeV}	0.01 меV	0.01 MeV	0.01 МеV	^{0 MeV}	^{0 MeV}	0 меV	0 меV	_{0.01 MeV}	^{0 меV}	_{0.01 MeV}	_{0.01 MeV}	0.01 MeV	0.01 МеV	0.01 меV	0.02 MeV		
²¹¹ At _{0 MeV}	²¹² At _{0 MeV}	²¹³ At _{0 MeV}	²¹⁴ At _{0 MeV}	²¹⁵ At 0.01 MeV	²¹⁶ At _{0 MeV}	²¹⁷ At 0.01 MeV	²¹⁸ At 0.01 MeV	²¹⁹ At _{0 MeV}	²²⁰ At 0.01 MeV	²²¹ At 0.01 MeV	²²² At 0.02 MeV	²²³ At 0.01 MeV	²²⁴ At 0.02 MeV					
²¹⁰ Po	²¹¹ Po	²¹² Po	²¹³ Po	²¹⁴ Po	²¹⁵ Po	²¹⁶ Po	²¹⁷ Po	²¹⁸ Po	Mass Excess error [MeV]									
_{0 MeV}	_{0 MeV}	0 MeV	_{0 MeV}	_{0 MeV}	_{0 MeV}	_{0 MeV}	0.01 MeV	_{0 MeV}										
²⁰⁹ Ві _{0 ме}	²¹⁰ Bi _{0 MeV}	²¹¹ Bi 0.01 MeV	²¹² Bi 0 MeV	²¹³ Bi 0.01 MeV	²¹⁴ Bi 0.01 MeV	²¹⁵ Bi 0.01 MeV	²¹⁶ Bi 0.01 MeV	²¹⁷ Bi 0.02 MeV		0.	02	0.05		.07	0.09	,		
²⁰⁸ Рb 0 меV	²⁰⁹ Pb _{0 MeV}	²¹⁰ Pb 0 MeV	²¹¹ Pb 0 MeV	²¹² Pb _{0 MeV}	²¹³ Pb 0.01 MeV	²¹⁴ Pb _{0 MeV}	²¹⁵ Рb 0.05 меv		Long-lived Unknown									



(1988) Nuclear Inst. and Methods in Physics Research, B, 31 (3), pp. 483-486



$$Q_{\alpha}(\text{g.s.-to-g.s.}) = Q_{\alpha} + E_{\gamma}$$
$$Q_{\alpha} = \frac{m_d + m_{\alpha}}{m_d} \times E_{\alpha}$$
$$E_{\alpha} = E_{\alpha}(\text{g.s.-to-g.s.}) - \frac{m_d}{m_d + m_{\alpha}} E_{\gamma}$$





























Sheline RK, Liang CF, Paris P. Int J Mod Phys A. 1990;05(14):2821-31.







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<u>5/2+</u> 180.0

(180.0)

0





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Static octupole deformation





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Rey-herme *et al.,* PRC 108, 014304 (2023)





Summary

- Production of neutron deficient actinides at IGISOL using the ²³²Th(p,xn)^{233-x}Pa reaction.
- Alpha, γ and electron decay spectroscopy of $^{225}\mbox{Pa}$
- Signature of a static octupole deformation in ²²¹Ac
- Indication of a transition towards octupole vibration for more neutron deficient actinium isotopes



Summary

- Production of neutron deficient actinides at IGISOL using the ²³²Th(p,xn)^{233-x}Pa reaction.
- Alpha, γ and electron decay spectroscopy of $^{225}\mbox{Pa}$
- Signature of a static octupole deformation in 221 Ac
- Indication of a transition towards octupole vibration for more neutron deficient actinium isotopes

However:

- Insufficient detection efficiencies (especially for conversion electrons)
- Signs of a potential missing state



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Two main goals:

1) Counting detector for laser ionisation spectroscopy of HN/SHN (~ 100 Hz)

SEASON ANR AGENCE NATIONALE DE LA RECHERCHE

Two main goals:

1) Counting detector for laser ionisation spectroscopy of HN/SHN (~ 100 Hz)

2) Alpha, y and conversion electrons decay spectroscopy





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SEASON@IGISOL:

- SEASON's commissioning 2024/2025 using the ²³²Th(p,xn)^{233-x}Pa reaction



SEASON@IGISOL:

- SEASON's commissioning 2024/2025 using the ²³²Th(p,xn)^{233-x}Pa reaction
- Potential experiments:
 - \rightarrow ²³³U(p,xn)^{234-x}Np: Production of ²²⁷Np and study of its decay chain \rightarrow Study of ²¹⁹Ac
 - \rightarrow ²³²Th(α ,xn)^{236-x}U: Neutron deficient uranium (e.g. ²²⁹U)
 - \rightarrow ²³³U(α ,xn)^{237-x}Pu: Neutron deficient Pu and Np isotopes



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SEASON@S3-LEB:

- Combination of decay spectroscopy and laser spectroscopy
 - \rightarrow Access to ground state informations of parent nucleus



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SEASON@S3-LEB:

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 - \rightarrow Access to actinides close to N = 132



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 - \rightarrow ²³³U(α ,xn)^{237-x}Pu: Neutron deficient Pu and Np isotopes

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Thank you for your attention !