Deducing how Nuclear deformation affects proton and gamma transition rates.

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David M. Cullen



Research on transition rates in proton emitters as deformation changes across a shell:



[1] P. Möller et al., Phys. Rev. Lett. 97 (2006) 162502.



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The Method:



Lifetime \Leftrightarrow Deformation

here > B(E2) => Q0 => β2

Needed an efficient differential plunger to use with proton tagging...



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Contents lists available at SciVerse ScienceDirect Nuclear Instruments and Methods in Physics Research A

107
100
NUCLEAR
INSTRUMENTS
A METHODS
PHONOS
DEST ADOM
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Address of a second second second

journal homepage: www.elsevier.com/locate/nima

A new differentially pumped plunger device to measure excited-state lifetimes in proton emitting nuclei

M.J. Taylor^{a,*}, D.M. Cullen^a, A.J. Smith^a, A. McFarlane^a, V. Twist^a, G.A. Alharshan^a, M.G. Procter^a,

Differential Plunger for Unbound Nuclear States. D.M. Cullen, SSNET 2016. S

D.M. Cullen, SSNET 2016.



DPUNS Proton Emitters studied so far...

Physics Letters B

CrossMark



M.G. Procter^{a,*}, D.M. Cullen^a, M.J. Taylor^a, G.A. Alharshan^a, L.S. Ferreira^b, E. Maglione^c, K. Auranen^d, T. Crahn^d, P.T. Creenlees^d, H. Jakobsson^d, R. Julin^d, A. Herráň^d, I. Konki^d

Many other isomer-tagged experiments in this region, cross sections $\sim 40 \mu b$ (2 weeks)



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Lifetime Methodology

- Measuring experimental nuclear lifetimes to constrain theoretical calculations at and beyond the proton drip line.
- Quasi-particle model based on a deformed mean-field Woods-Saxon potential with spin-orbit interaction. Ferreira, Maglione Internat. Journal Modern Physics E15 (2006) 1789. Deduce wave functions for odd proton + core in adiabatic (strongly coupled to rotational core).



 Using this set of wave functions to calculate EM (gamma) and particle decay (proton) transition rates.

Theoretical Approach

Quasi-particle model generates excitation energy of states (compared with experimental level scheme)... and then extract wave functions.



Calculating Electromagnetic and Proton decays with a single set of wavefunctions D.M. Cullen, SSNET 2016.

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New non-adiabatic calculations 2013:

Previous calculations were adiabatic with proton strongly coupled to the core.

New non-adiabatic calculations (Ferreira, Maglione) Procter et al. Phys Lett B 725 (2013) 79.

Calculate wave functions where core is softer which affects how the oddproton couples to the core.





Lifetime of deformed proton emitter, 113Cs



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113Cs deformed proton emitter?



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113Cs Experimental setup (12 days)



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113Cs Decay events in DSSD

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113Cs Gamma-ray spectra as function of distance

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D.M. Cullen, SSNET 2016.



113Cs Theoretical Calculations.

D.M. Cullen, SSNET 2016.

113Cs Theoretical excitation energies of states

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Extract wave functions from model and use in EM and P decay calculations



Electromagnetic Transition Rates: using one set of wave functions.



$$T_{!} ! \frac{2!}{f} |\langle ! f_{f} | M (IL) | ! \rangle|^{2} ! (E) dE$$





Proton decay Transition Rates: using one set of wave functions.





113Cs Proton decay half-life versus deformation (non-adiabatic code).

D.M. Cullen, SSNET 2016.

1000T_{1/2}=16.9(1) μs $|T_p! \frac{2!}{f} | \langle ! _f^{*daughter} | M_{i} p \rangle | ! _i^{parent} \rangle |^2 ! (E) dE$ Half-life of Proton Emission (µs) 100 $3/2^{+}$ Experimental proton t1/2 10 $5/2^{+}$ (/2+ 0.10.2 0.10.3 0.4 β_2

Proton decay half-life in agreement with deformation, $\beta 2 = 0.23$



113Cs deformed proton emitter?

State	Measurement type	β_2
$(11/2^+)$	Excitation energy	~ 0.18
$(11/2^+)$	B(E2) calculation	0.22 - 0.26
$(15/2^+)$	Excitation energy	~ 0.15
$(15/2^+)$	B(E2) calculation	> 0.19
$(3/2^+)$	Proton Emission calculation	~ 0.22

Both particle and gamma decay rates fit best with experimental deformation of $\beta 2 = 0.2$, which compares well with Möller-Nix $\beta 2 = 0.207$. 113Cs really seems to be a deformed protons emitter.



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Conclusions

- Measurement of experimental lifetimes of nuclear states at and beyond the proton drip line has helped define deformation in non-adiabatic theoretical nuclear code.
- 2 Computation of nuclear wave functions at these experimental deformations has allowed a better approach to understanding both proton and gamma decay rates in a simultaneous way.
- 3. Future radioactive + stable beam facilities + MARA with new TPEN will allow us to go further...



D.M. Cullen, SSNET 2016.

Triple-Foil Plunger for Exotic Nuclear States (TPEN)



Commission at JYFL in not too distant future...



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