

6th European Summer School on Experimental Nuclear Astrophysics

Triple configuration coexistence in ⁴⁴S

> Daniel Santiago-González

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Previous works

Getting ⁴⁴ via 2p-KO

 γ spectrum and $\gamma\gamma$ matrix

Parallel momentum distributions

Level scheme

P-H projection

Summary





Triple configuration coexistence in ⁴⁴S

Daniel Santiago-González

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Triple configuration coexistence in ⁴⁴ S

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A familiar series

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Summary

2, 8, 20, 28, 50, 82, 126

- Stable magic nuclei have higher binding energy per nucleon.
- Magic numbers are related to shell closure (in stable nuclei)
- Shell closure \rightarrow spherical symmetry (of ground state).



Nuclear shell model

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The shells are effects of an average potential analogous to the ones observed in atoms. *The nuclear many-body problem*, Ring and Schuck, 1980.

A single particle Hamiltonian can be used ... at least for some very special nuclei.

The simplest case

Potential = (isotropic H.O.) + $(L^2 \text{ term}) + (L \cdot S \text{ coupling})$

Shell model prediction of *magic* numbers



2011

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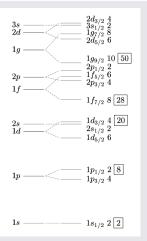


Figure: Taken from http://en.wikipedia.org/wiki/File:Shells.png



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Things change away from stability.



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Things change away from stability.

"Semi-magic" ⁴⁴S (N=28, Z=16): an example of shell breaking.



Where is ⁴⁴S?

Triple configuration coexistence in ⁴⁴S

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z					42.Cr	43 Cr	44Cr	45 Cr	46Cr	47 Cr	48 Cr	49 Cr	50Cr	51Cr	52Cr	53Cr	54Cr	55 Cr	56Cr	57Cr	58Cr	59Cr	60Cr	61Cr	62.Cr	63 Cr	64Cr	65 Cr	61
				4 0V	41∀	427	437	447	45V	46V	47V	4877	497	507	517	527	537	54V	55V	56V	577	587	597	60V	617	627	63V	647	T
zz			38Ti	39Ti	40Ti	41Ti	42Ti	43Ti	44Ti	45Ti	46Ti	47Ti	48Ti	49Ti	50Ti	51Ti	52Ti	53Ti	54Ti	55Ti	56Ti	57Ti	58Ti	59Ti	60Ti	61Ti	62Ti	63Ti	
		365¢	37\$e	385e	395c	405c	415 c	42.Se	43 S c	445c	45Se	465 c	475e	48.Se	495c	50\$c	515 e	523 e	538e	548c	55\$c	565 c	578e	585e	595e	60\$c			
20	34C a	35 C a	36C x	37Ca	38Ca	39 C a	40 C x	41Cx	@Cx	43Cx	44C a	45 C x	46C x	47Ca	48Ca	49 C a	50C x	51Ca	52Ca	53Ca	54Ca	55 C x	56C x	57Ca					
	33K	34K	35K	36K	37K	38K	39K	40 K	41K	42K	49K	44K	45K	46K	47K	48K	49K	50K	51K	52K	53K	54K	55K						
18	32.Ar	33 Ar	34Ar	35Ar	36Ar	37 A r	38Ar	39Ar	40Ar	41Ar	42.Ar	43 Ar	44Ar	45Ar	46 Ar	47 Ar	48 Ar	49Ar	50Ar	51Ar	52 Ar	53Ar							
	3101	32 01	33 (1	3401	35 01	36 01	37C1	38C1	39 CI	40 01	4101	4201	4301	4401	4501	46 01	4701	4801	4901	50 01	5101								
16	305	315	325	335	345	353	365	375	385	395	405	415	425	435	445	4 55	465		485	495									
	29P	30P	31P	32P	33P	34P	35P	36P	37P	38P	39P	40P	41P	42P	43P	44P	4SP	46P					[Seco	10-0			
14	285i	29\$i	30 Si	31Si	32 <i>5</i> i	33 <i>5</i> 1	34Si	35 Si	36 S i	375i	38 <i>5</i> i	39 <i>5</i> i	40 Si	41\$i	42 Si	43 Si	44Si							10-		10-0	2		
	27.A1	28A1	29A1	30.A1	31A1	32.A1	33 A1	34A1	35.A1	36 A1	37 A1	38A1	39A1	40.A1	41.A1	42 A1	43 A1							10+ 10+		10-0 10-0			
12	26Mg	27Mg	28Mg	29Mg	30Mg	31Mg	32Mg	33Mg	34Mg	35Mg	36Mg	37Mg	38Mg	39Mg	40Mg									10+		10-0 10-0			
	25Na	26Na	27Na	28Na	29Na	30Na	31Na	32Na	33Na	34N a	35Na	36N a	37Na											10+		10-0 10-1			
10	24Ne	25Ne	26Ne	27Ne	28Ne	29Ne	30Ne	31Ne	32Ne	33Ne	34Ne													10-	-00 unkr	< 10			
	23F	24F	25F	26F	27F	28F	29F	30F	31F														l		UNN	own			
8	220	230	240	250	260	270	280									I													
	14		16		18		20		22		24		26		28		30		32		34		36		38		40		

Figure: Taken from http://www.nndc.bnl.gov.



Previous experimental works on $^{\rm 44}{\rm S}$

Triple configuration coexistence in ⁴⁴S

1997, Glasmacher et al. Collectivity in ⁴⁴S.

- Coulomb excitation to populate the 1st exc. state 2⁺₁.
- $E_{exc}(2_1^+) = 1297(18)$ keV.

•
$$B(E2, 0^+_{g.s.} \to 2^+_1) = 314(88) \ e^2 \text{fm}^4.$$

Previous works

 γ spectrum and $\gamma\gamma$ matrix

Parallel momentum distributions

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P-H projection



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- Coulomb excitation to populate the 1st exc. state 2⁺₁.
- $E_{exc}(2_1^+) = 1297(18)$ keV.

■
$$B(E2, 0^+_{g.s.} \rightarrow 2^+_1) = 314(88) \ e^2 \text{fm}^4.$$

Introduced intruder configuration





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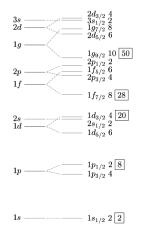


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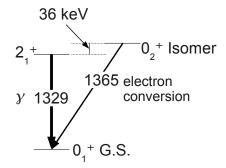
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Summary

2005, Grevy et al. Observation of the 0^+_2 state in $^{44}\mbox{S}.$



Isomeric 0^+ state and 1st exc. state 2^+_1 were observed.



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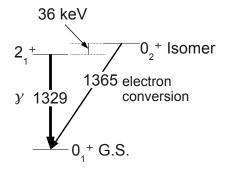
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Summary

2005, Grevy et al. Observation of the 0^+_2 state in $^{44}\text{S}.$



Isomeric 0⁺ state and 1st exc. state 2⁺₁ were observed.
0⁺₂ half-life of 2.3(3)µs and exc. energy of 1365(1) keV.
Comparison: half-life of 2⁺₁ is ~ 2.4 ps (10⁻⁶µs).



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2010, Force et al. Prolate-spherical shape coexistence at N=28 in 44 S.

"... it is found that $^{44}{\rm S}$ exhibit a shape coexistence between a prolate ground state ($\beta\sim0.25)$ and a rather spherical 0+ state."



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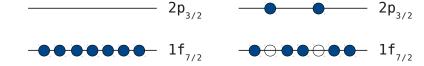
P-H projection

Summary

2010, Force et al. Prolate-spherical shape coexistence at N=28 in 44 S.

"... it is found that $^{44}{\rm S}$ exhibit a shape coexistence between a prolate ground state ($\beta\sim0.25)$ and a rather spherical 0^+ state."

This study highlights the interaction between the "normal" configuration and the intruder configuration.





Getting ⁴⁴S via 2p-KO

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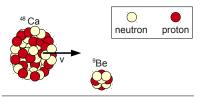
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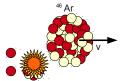
Summary

Experiment done at NSCL, Michigan, USA in 2009

■ ${}^{48}Ca({}^{9}Be,X){}^{46}Ar \rightarrow {}^{46}Ar({}^{9}Be,X){}^{44}S^*$

Peripheral collision smaller steps \rightarrow less background







Particle identification (using S800)



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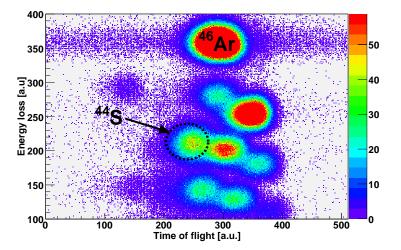
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singles- γ spectrum (using SeGA)



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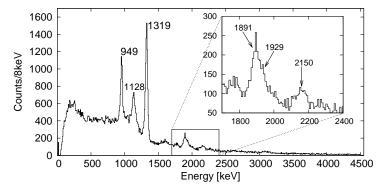
Getting ⁴⁴9 via 2p-KO

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$\gamma\gamma$ matrix

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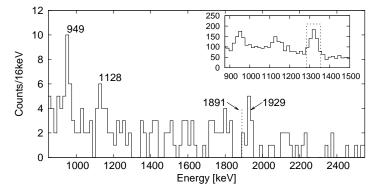
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Advantage of 2-proton knockout reaction:

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Parallel momentum distributions

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Reference

Two-nucleon knockout spectroscopy at the limits of nuclear stability. (PRL 2009)

E.C. Simpson, J.A. Tostevin, D. Bazin, B.A. Brown and A. Gade

"... the residue parallel momentum distributions in these reactions offer a clear spectroscopic signal of the angular momentum of the pair of nucleons removed, and thus of the **residue final state spins** ..."



Parallel momentum distribution made simple

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The higher the J of the recoil particle, the wider its parallel momentum distribution.

Example: 2p removal from ${}^{28}Mg$ to ${}^{26}Ne$ (calculations)

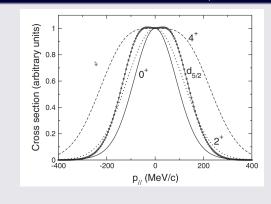
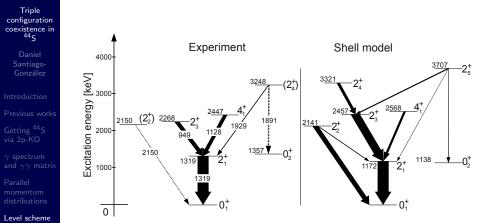


Image taken from: E.C. Simpson et al., 2009.



Level scheme



SDPF-U effective interaction from F. Nowacki and A. Poves Phys. Rev. C 79, 014310 (2009)



P-H projections

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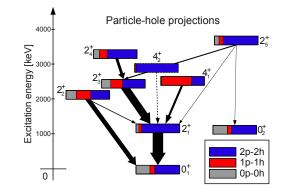
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• 4_2^+ predicted with $\sigma < 1\mu$ b. For 4_1^+ , $\sigma \approx 32\mu$ b.

Comparison with lineshape simulations suggest half-life ~50 ps.



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- Magic numbers can be reproduced by simple SM (stable nuclei).
- In some cases (⁴⁴S), far from stability shells "breaks" (deformation).
- For ⁴⁴S, we reported 5 previously unobserved γ-rays transitions (3 spin assignments)
- New level scheme was proposed using the reported 0^+_2 .
- SM (SDPF-U) predictions are consistent with exp. $E_{exc} < 2.7$ MeV.
- Fundamentally diff. conf. 4⁺₁ (1p-1h). Suggestion of half-life ~50 ps (to be measure).
- The tree coexisting neutron-configurations are then: 2p-2h for the *deformed* 0⁺₁, 1p-1h for the 4⁺₁ and 0p-0h for the isomeric state 0⁺₂.



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Thank you.