THEORETICAL ANALYSIS OF PROTON EMISSION FOLLOWING BETA-DECAY OF ^{56}ZN

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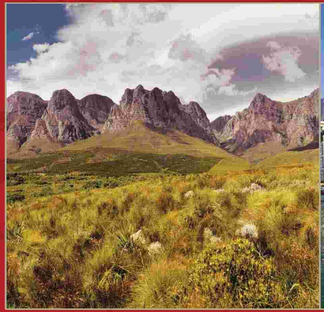
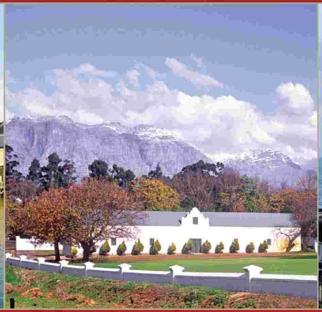




OUTLINE

Introduction: First observation of β-delayed γ-proton decay in the fp shell – Zn-56 (Dossat NPA 792, 2007)

Detailed measurements (Orrigo PRL 112, 2014)
Strong isospin mixing of T=2, 0^+ IAS with nearby 0^+, T=1 state deduced

Question: Why is gamma de-excitation from IAS observed in competition with p decay ? Similar intensities

This work addresses this question using shell-model calculations with 2 INC interactions

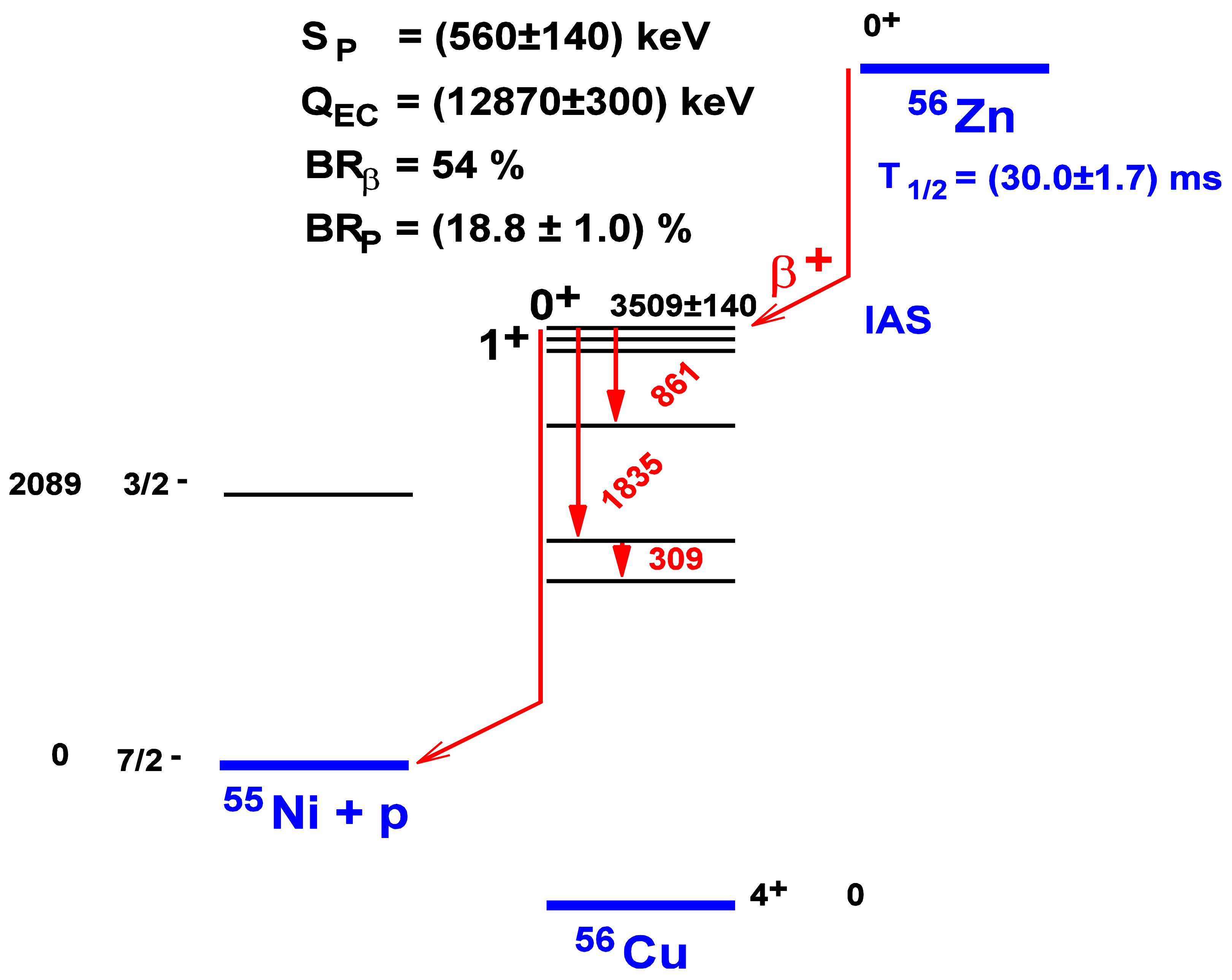
INTRODUCTION

To explain the observed proton decays to Ni-55 (T=1/2) from the IAS in Cu-56, which are isospin forbidden, it is assumed that the IAS mixes with a nearby T=1 state.

From experiment there is a 0+ T=1 state at 3423 keV i.e. 85 keV below the IAS.

A striking feature of the decay is that the proton and gamma decay widths are very similar, despite a large amount of isospin mixing.

I_p = 18.8(10)% and I_γ = 19.2(10)%



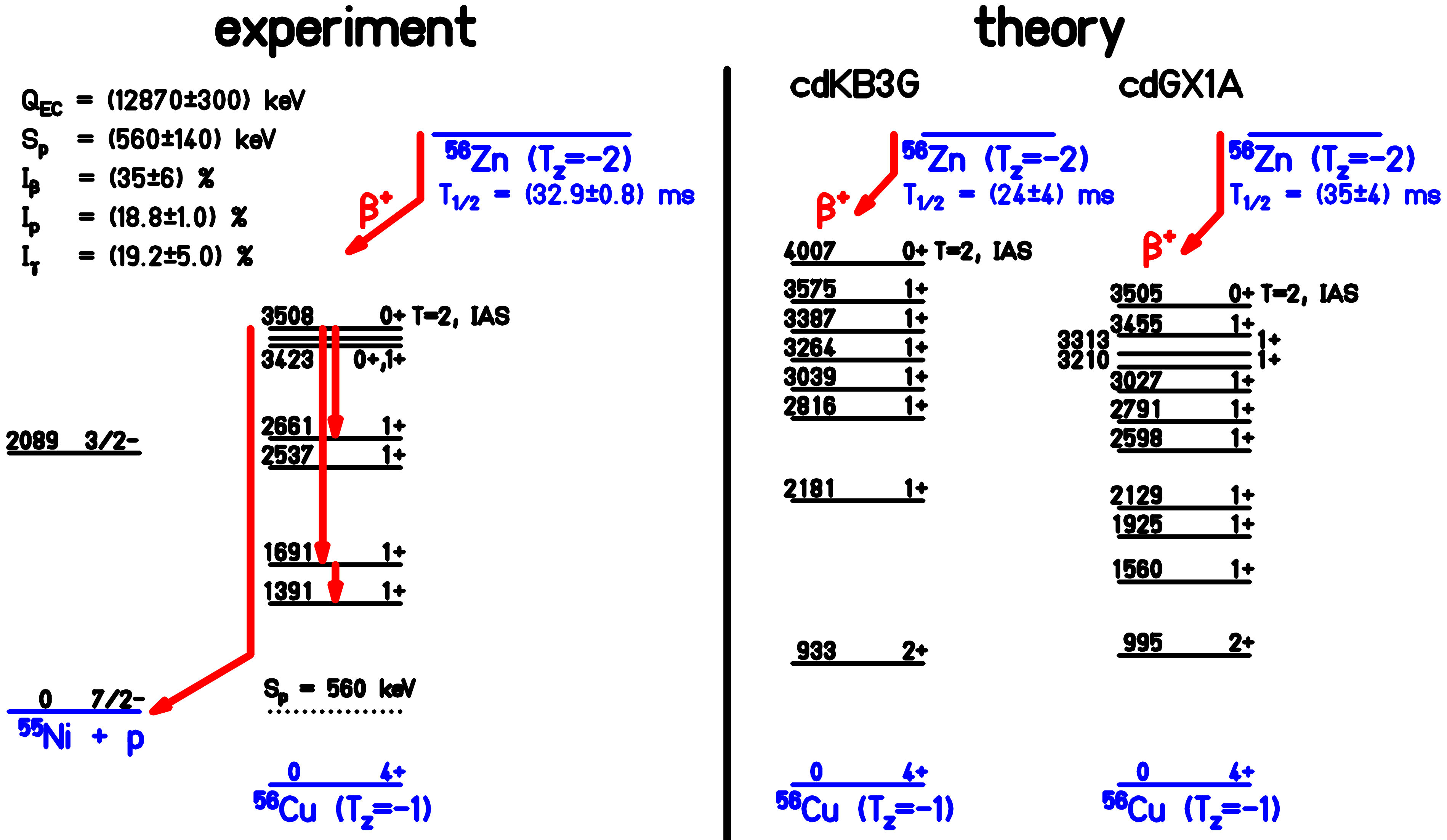
S P = (560±140) keV
QEC = (12870±300) keV
BRβ = 54 %
BRP = (18.8 ± 1.0) %
0+
56 Zn
T 1/2 = (30.0±1.7) ms
β +
IAS
0+
3509±140
1+
861
1835
309
2089
3/2 -
0
7/2 -
55 Ni + p
4+
0
56 Cu

To understand the decay features and to cross-check theoretical descriptions, we performed large-scale shell-model calculations in the full fp shell.

Interactions used:

1) cdGX1A (NuShellX).
Based on GXPF1A with addition of Coulomb, strong charge-asymmetry and charge-independence-breaking interactions and isovector SPE.

2) cdKB3G (ANTOINE) based on KB3G with addition of Coulomb and isovector SPE.


experiment
theory
cdKB3G
cdGX1A
QEC = (12870±300) keV
Sp = (560±140) keV
Iβ = (35±6) %
Ip = (18.8±1.0) %
Iγ = (19.2±5.0) %
56Zn (Tz=-2)
T1/2 = (32.9±0.8) ms
β+
3508 0+ T=2, IAS
3423 0+,1+
2661 1+
2537 1+
1691 1+
1391 1+
2089 3/2-
0 7/2-
55Ni + p
Sp = 560 keV
0 4+
56Cu (Tz=-1)
56Zn (Tz=-2)
T1/2 = (24±4) ms
β+
4007 0+ T=2, IAS
3575 1+
3387 1+
3264 1+
3039 1+
2816 1+
2181 1+
933 2+
0 4+
56Cu (Tz=-1)
56Zn (Tz=-2)
T1/2 = (35±4) ms
β+
3505 0+ T=2, IAS
3455 1+
3313 1+
3210 1+
3027 1+
2791 1+
2598 1+
2129 1+
1925 1+
1560 1+
995 2+
0 4+
56Cu (Tz=-1)

Isospin mixing of the IAS

Suppose the mixing can be modelled as the admixture of a close-lying 0+, T=1 state (two-level mixing). Thus

$$|IAS\rangle = \sqrt{1-\alpha^2}\ |T=2\rangle + \alpha\ |T=1\rangle$$

It is concluded from the splitting of the Fermi strength B(F) from the 0+ ground state of Zn-56 that α^2 = 33(10)%.

Thus despite this large mixing and Ep = 2948(10) keV proton decay is not the dominant mode but comparable to γ decay

Using $R = \frac{B(F)3432}{B(F)3508} = 0.69(20)$ (exp) and

$\Delta E = 85(10)\ keV$, mixing matrix element is

$V = \Delta E.R/(1+R^2) \sim 40$ keV.

The spectroscopic factor for proton emission from the IAS can be expressed as $S^{IAS} = \alpha^2 S^{T=1}$

In 1st order perturbation theory the magnitude of mixing is proportional to $(V/\Delta E)^2$

The mixing matrix elements V_{INC} for the two interactions are reasonably well reproduced (20 keV – cdGX1A and 48 keV – cdKB3G) but the energy spacings are much too large, resulting in a small amount of mixing of the order of 1%.

In Table I we show spectroscopic factors for the 0^+, T=1 state in Cu-56 and the 0^+ IAS, but deduce the latter by using the experimental amount of mixing.

The values are somewhat larger than the experimental spectroscopic factors, but still quite small.

TABLE I: Comparison of experimental and theoretical quantities of ^{56}Zn. The β-decay half-life of ^{56}Zn, the excitation energy of the 0^+ IAS and of the admixed 0^+ state in ^{56}Cu are shown together with their electromagnetic and proton decay characteristics.

	Exp	cdGX1A	cdKB3G
^{56}Zn			
$T_{1/2}$ [ms]	32.9(4)	35(4)	24(4)
^{56}Cu, 0^+,IAS			
E^{IAS} [MeV]	3.508(140)	3.505	3.827
S^{IAS}	$0.12(4) \times 10^{-3}$	1.5×10^{-3}	3.1×10^{-3}
Γ_p^{IAS} [eV]	0.13(4)	1.6(1)	3.2(2)
Γ_γ^{IAS} [eV]		0.16	0.11
^{56}Cu, 0^+, T=1			
$E^{T=1}$ [MeV]	3.423(140)	2.910	3.456
$S^{T=1}$	$0.4(1) \times 10^{-3}$	4.4×10^{-3}	9.4×10^{-3}
$\Gamma_p^{T=1}$ [eV]	0.32(8)	3.6(2)	7.7(3)
$\Gamma_\gamma^{T=1}$ [eV]		0.04	0.02
α^2 (%)	33(10)	11	34

TABLE II: Excitation energies, interaction mixing matrix element and spectroscopic factors of the lowest 0^+ states in ^{56}Cu with respect to proton emission to the $7/2^-$ ground state of ^{55}Ni. The values corresponding to the IAS are shown in bold.

State	cdGX1A			cdKB3G		
	E^* [MeV]	$V_{\rm INC}$ [keV]	S_p	E^* [MeV]	V_{INC} [keV]	S_p
0_1^+	1.253	25	0.0590	1.469	16	0.0336
0_2^+	2.675	20	0.0083	3.456	48	0.0094
0_3^+	2.910	20	0.0044	**3.827**	-	**0.0002**
0_4^+	**3.505**	-	**0.0021**	4.007	16	0.0076
0_5^+	3.511	3	0.0035	4.611	1	0.0044

The main conclusion of our analysis is that the hindrance of the proton decay from the IAS is due to a very small overlap between the admixed 0^+, T=1 state of ^{56}Cu and the ground state of ^{55}Ni plus an $f_{7/2}$ proton.

Proton emission from the admixed 0^+, T=1 state is allowed by the isospin quantum number selection rule, however, it is hindered by nuclear structure effects.


THANK YOU !