Shell evolution in the neutron rich
N=20, N=28 and Z=28 regions
from measurements of moments and spins

Gerda Neyens, IKS, K.U. Leuven, Belgium

 Belgian Research Initiative on eXotic nuclei

regions of interest

→ Along magic numbers:
  • Below $^{40}$Ca, along N=20 → island of inversion due to
    reduction of N=20 gap
  • Below $^{48}$Ca, along N=28 → shape coexistence due to
    reduction of N=28 and Z=16
  • Along Z=28, from N=28 up to N=50 → softness of $^{56}$Ni core,
    monopole migration
    onset of collectivity

$^{16}$O
$^{40}$Ca
$^{48}$Ca
$^{56}$Ni
$^{78}$Ni
Experiments at ISOL and fragmentation facilities

The COLLAPS collaboration at CERN-ISOLDE
Leuven – Mainz – Heidelberg – Manchester – …
- collinear laser spectroscopy on bunched beams: \( I, \mu, Q \) measured
  - \( ^{61}\text{Cu} - ^{75}\text{Cu} \) (Z=29, from N=32 to N=46) odd-even and odd-odd
  - \( ^{67}\text{Ga} - ^{81}\text{Ga} \) (Z=31, from N=36 to N=50) odd-even and odd-odd
- \( \beta\)-NMR and laser spectroscopy on laser-polarized beams: \( I, \mu, \mu \) measured
  - \( ^{21}\text{Mg} - ^{33}\text{Mg} \) (Z=12, from N=9 to N=21) even-odd only

The \( \beta\)-NMR collaboration at LISE-GANIL
Leuven – GANIL – Bruyères-le-Chatel – Tokyo – …
- \( \beta\)-NMR spectroscopy on reaction-polarized beams: \( |g| \) and \( |Q| \) measured, I deduced
  - \( ^{31}\text{Al} - ^{34}\text{Al} \) (Z=13, from N=18 to N=21) odd-even and odd-odd
  - \( ^{44}\text{Cl} \) (Z=17, N=27)

Other input from:
- in-source laser spectroscopy at LISOL@CRC Louvain-la-Neuve: \( ^{57}\text{Cu} (\mu) \)
- TDPAD on isomeric states at GANIL: \( ^{43}\text{S} \) (Z=16, N=27) (|g|)

Nuclear moments near magic shells
→ very sensitive to nuclear wave function!

Magnetic moment of odd-even, even-odd and odd-odd isotopes \((\mu=g.I)\) near closed shells:

→ g-factor is determined by the orbital occupied by unpaired valence protons and/or neutrons
  - depends on spin and orbital g-factors for protons and neutrons \((g_s, g_l, g_s', g_l')\)
  - depends on orbital momentum I and spin j of orbit occupied by unpaired nucleons
    → sign of g determines the parity of the wave function !
  - g-factor is not depending on the number of unpaired nucleons in an orbit

→ Comparing experimental and calculated g-factors:
  - confirm the proposed wave function
  - in some cases: assign spin and/or parity
  - test the shell model interaction and used model space
  - find deviations from ‘normal’ shell model configurations

\[ ^{57}\text{Cu} = ^{56}\text{Ni} + p \]
\[ ^{57}\text{Cu} = ^{40}\text{Ca} + 9p + 8n \]
Nuclear moments near magic shells → very sensitive to nuclear wave function!

Quadrupole moments of odd-even, even-odd and odd-odd isotopes

→ Q-moment is determined by the spin $j$ and the $<r^2>$ of the orbit occupied by unpaired valence protons
  - neutrons are not charged → but induce core polarization through p-n interaction
  - more sensitive to collectivity in the wave function

→ Comparing experimental and calculated Q-moments near closed shells:
  - probing the proton-neutron interaction
  - study the softness of a core as a function of N and/or Z
  - study effects of core polarization
  - study shape coexistence in nuclei
  - confirm the proposed wave function
  - test the shell model interaction
  - find deviations from ‘normal’ shell model configurations

57Cu = 56Ni + p 57Cu = 40Ca + 9p + 8n

The “island of inversion”

active neutron orbits around N=20

$p_{3/2}$

$f_{7/2}$ fp-shell

$d_{5/2}$

$s_{1/2}$ sd-shell

emptying $sd_{5/2}$

influence of particle-hole excitations

In the ground state wave functions?

Experimental challenge: how large is this ‘region of inversion’?

Study transition region → difficult to make theoretical predictions!
g-factors of Al isotopes → ground states dominated by πd_{5/2}^{-1}


\[ \text{Z=13: hole in } \pi d_{5/2} \text{ orbital} \]

→ \( I^* = 5/2^+ \) expected for odd-Al isotopes
→ wave function and spin confirmed by g-factor
through comparison with calculated \( \mu = g.I \) in
sd-shell model (USD – 0p0h)
sdf_{7/2}P_{3/2} shell model space
- SDPF-M (MCSM, mixed)
- sdpf-interaction (2p2h)

(free-nucleon g-factors)

\[ \text{Conclusion for } ^{33}\text{Al (N=20):} \]
→ small (<25-30 %) intruder admixture
in the \(^{33}\text{Al ground state}. \]

Y. Utsuno et al., PRC 64, 011301R, 2001

quadrupole moments of \(^{31,33}\text{Al} \rightarrow \text{more sensitive to neutron excitations} \)

M. De Rydt et al., PLB 678, 344 (2009) → Q(31Al)

to be continued!

Calculations in sdp_{3/2}^2f_{7/2}^- shell:
* SDPF-M interaction (MCSM)
  Otsuka, Utsuno et al., private communication
* sdpf-NR interaction (ANTOINE code)
  Nummela et al., PRC63 (2001)

→ very good agreement for \(^{27,31}\text{Al} \)
with proton effective charge :
\( e_p = 1.1 \text{ e} \)
electron effective charge:
\( e_n = 0.5 \text{ e} \)

→ \(^{33}\text{Al} \) has a mixed g.s. configuration:
  \( \nu(sd)^2(fp)^2 \) contribution in wave function !

To determine amount of mixing:
need more precise Q-moment value !
Experiment at GANIL, july 2010

\[ \text{Error bars smaller than dot size !} \]

\[ \text{2p-2h} \]

\[ \text{exp} \]
Fitted effective charges using all known sd-shell Q-moments

M. De Rydt et al., PLB 678, 344 (2009)

Compare \( Q_{\text{exp}} \) of sd-shell isotopes (errors smaller than dot-size) with calculated values in \( \text{sdp}_3/2f7/2 \)-space using sdpf effective interaction

\[ \chi^2 = 3.4 \]

\[ \chi^2 = 1.5 \]

\( \rightarrow \) sd-shell proton effective charge: \( e_p = 1.12 \) e

neutron effective charge: \( e_n = 1.45 \) e

"g-factor (+ sign) and spin of the \( ^{31,33}\text{Mg} \) ground state"

G. Neyens et al., PRL 94, 022501 (2005)

D. Yordanov et al., PRL 99, 212501 (2007)

Measured spin \( ^{31}\text{Mg} \), \( I^\pi = 1/2^+ \)

\( ^{33}\text{Mg} \), \( I^\pi = 3/2^- \)

\( \rightarrow \) pure 2p-2h intruder ground states!

Normal ground state configurations:

\( ^{31}\text{Mg} \) (N=19)

\( ^{33}\text{Mg} \) (N=21)
Spin/parity of the $^{33}\text{Mg}$ ground state in the shell model

Look at the g-factors of isotones with similar configuration

N=19 isotone: $^{33}\text{Si}$

$$\begin{array}{cccc}
\text{p}_{3/2} & f_{7/2} \\
20 & 28 \\
\text{d}_{5/2} & \text{f}_{5/2} \\
& 1^+ = 3/2^+ \\
\text{s}_{1/2} & \\
\end{array}$$

$1p1h$ intruder ground state in $^{33}\text{Mg}$ \(\rightarrow\) same g-factor as $^{33}\text{Si}$

\[ g(^{33}\text{Si}) = +0.76 \]

$$\begin{array}{cccc}
\text{p}_{3/2} & f_{7/2} \\
20 & 28 \\
\text{d}_{5/2} & \text{f}_{5/2} \\
& 1^+ = 7/2^+ \\
\text{s}_{1/2} & \text{sd} \\
\end{array}$$

N=21 isotone: $^{35}\text{Si}$

normal ground state in $^{33}\text{Mg}$ \(\rightarrow\) same g-factor (particle in $f_{7/2}$) as $^{35}\text{Si}$

\[ g(^{35}\text{Si}) = -0.47 \]

$$g_\text{exp}(^{33}\text{Mg}) = -0.4971(4)$$

$$g_{\text{sdpf}}(3/2^+) = +0.78 \ (1p1h)$$

$$g_{\text{sdpf}}(3/2^-) = -0.47 \ (2p2h)$$

Spin/parity of the $^{33}\text{Mg}$ ground state in Nilsson model

D. Yordanov et al., comment to PRL, accepted

<table>
<thead>
<tr>
<th>$^\pi$</th>
<th>s.p. orbital</th>
<th>$\beta$</th>
<th>$\mu$ ($\mu_{II}$)</th>
<th>$g$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$3/2^-$</td>
<td>1/2 $[330]$</td>
<td>0.30</td>
<td>$-0.76$</td>
<td>$-0.51$</td>
</tr>
<tr>
<td>$3/2^+$</td>
<td>3/2 $[202]$</td>
<td>0.40</td>
<td>+0.80</td>
<td>+0.56</td>
</tr>
<tr>
<td>$3/2^-$</td>
<td>3/2 $[321]$</td>
<td>0.50</td>
<td>$-0.32$</td>
<td>$-0.21$</td>
</tr>
<tr>
<td>$1/2^+$</td>
<td>1/2 $[200]$</td>
<td>0.55</td>
<td>$-0.94$</td>
<td>$-1.98$</td>
</tr>
<tr>
<td>$1/2^+$</td>
<td>1/2 $[200]$</td>
<td>0.45</td>
<td>$-0.86$</td>
<td>$-1.72$</td>
</tr>
</tbody>
</table>

**Hamamoto, PRC76, 054319 (2007)**

$$g_\text{exp}(^{33}\text{Mg}) = -0.4971(4)$$

Interpretation in Nilsson Model:

31Mg ground state: build on $1/2^+[200]$ \( g = -1.72 \ \text{(exp=-1.7671)} \)

33Mg ground state: and on $3/2^-[321]$ \( g = -0.21 \ \text{(exp=-0.4971)} \)

and on $3/2^-[330]$ \( g = -0.51 \ \text{(exp=-0.4971)} \)
Summary: “island of inversion” around $^{32}$Mg

Present status of the “Island of inversion” as deduced from static and dynamic moments measurements

All intruder g.s. configurations are of the 2p-2h type !!
(two neutrons excited across N=20)

Evolution of the experimental 5/2- and 1/2- energies in Cu isotopes

Steep decrease of the 5/2- and 1/2- levels when $\nu g_{9/2}$ is filled
Experiment: g.s. spin assigned up to $^{73}$Cu (3/2-) from $\beta$-decay

S. Franchoo et al., PRC 64, 054308 (2001)  Stefañescu et al., PRL 100, 112502 (2008)
J.M. Daugas, Ph.D. Thesis, GANIL
Ground state spin of $^{71,73,75}$Cu

K.T. Flanagan et al., PRL 103, 142501 (2009)

- g.s. spins measured with laser spectroscopy
- spins assigned to isomeric levels in $^{75}$Cu (based on measured lifetimes)

- Theory reproduces lowering of $5/2^-$ correctly
- theory overestimates the $1/2^-$ energy from $^{69}$Cu to $^{75}$Cu !!!

Model space: $^{56}$Ni core + $f_{5/2} p_{3/2} p_{1/2} g_{9/2}$


Ground state spin of $^{72,74}$Cu

- Ratio of A-factors should be constant, if the hyperfine structure is fitted with correct spin value (input in fit: I, Au, Ad, Bu, IS)

- Ground state spins I=2, with more than 4 sigma confidence level
Ground state parity and structure of $^{72}$Cu

$^{72}$Cu $\rightarrow$ expected low-energy levels: use Paar’s rule

$Z=29$  
$N=43$

J.C. Thomas et al., PRC74, 054309, 2006

Ground state has spin I=2  
$\Rightarrow$ But what is the parity??

Can we assign parity based on measured magnetic moment?  
$\mu = -1.3451(6) \mu_N$

Use additivity rules for proton-neutron configurations:

Main negative parity configuration: $\mu(\pi f_{5/2} \nu g_{9/2}^3; 2^-)$  
$\mu_{\text{free}}(2^-) = -2.13 \mu_N$  
$\mu_{\text{emp}}(2^-) = -1.94 \mu_N$

Main positive parity configuration: $\mu(\pi p_{3/2} \nu p_{1/2}^{-1} g_{9/2}^4; 2^+)$  
$\mu_{\text{free}}(2^+) = +4.44 \mu_N$  
$\mu_{\text{emp}}(2^+) = +1.44 \mu_N$

Conclusion: the measured SIGN of the moment, $\mu = -1.3451(6) \mu_N$, is crucial to decide on the parity!  
$\Rightarrow$ in absolute value it is in agreement with 2+  
however, a negative sign is only compatible with a proton in $f_{5/2}$ orbital

Realistic interaction

Experiment

Realistic interaction
Magnetic moments of odd-Cu isotopes from $N=28$ to $N=40$

Compare performance large scale shell model calculations:
- GXPF1
- GXPF1A

$^{40}$Ca core + full pf-shell ($f_{7/2}p_{3/2}f_{5/2}p_{1/2}$)

Same

Conclusions:
1. Effective $g_s = 0.9g_s^{free}$, close to free-nucleon value (because model space includes all pf levels)
2. Softness of $^{56}$Ni core well reproduced (g with $^{56}$Ni core: 1.997)
3. GXPF1 reproduces all values perfectly, except for $^{69}$Cu
   - shows the need to include $g_{9/2}$ in the model space
4. GXPF1A slightly underestimates the values for $^{63,65,67}$Cu ($N=34,36,38$)

Quadrupole moments of odd-Cu isotopes up to $N=40$

CONCLUSIONS:
1. Effective charges are from a chi$^2$ fit to both odd-odd and odd-even Cu quadrupole moments
2. Quadrupole moments are very similar with GXPF1 and GXPF1A
3. The g-factor is more sensitive to small admixtures in the wave function
4. $^{68}$Ni core is more stiff than $^{56}$Ni core in this interaction and model space (because no excitations across $N=40$ included)

To verify experimentally if neutron excitations to $g_{9/2}$ reduce the core stiffness of $^{68}$Ni, we need to compare Qexp for $^{57}$Cu to $^{69}$Cu
**g-factors of (1,2)+ states in odd-odd Cu isotopes**

Compare to empirical values from weak coupling calculations for pure single particle configurations → very sensitive to purity of the configuration and small effects of configuration mixing!

Note: the experimental sign of $^{64}$Cu was wrong in literature!!

**g-factors and Q-moments of odd-odd Cu isotopes: GXPF1 and GXPF1A**

Conclusions: (1) the experimental g-factors agree well with single particle estimates for rather pure $\pi-\nu$ configurations with normal filling of the $v_{p_{3/2}}f_{5/2}p_{1/2}$ orbits
(2) GXPF1 does overall rather well for $\mu$ and Q
(3) GXPF1A strongly deviates at $N=35$ and $N=37$ ($^{64,66}$Cu) for $g$ and Q !!! → most likely too much $v_{p_{1/2}}$ into the g.s. wave function ??

OVERALL CONCLUSION: GXPF1A has a problem between $N=34$ and $N=38$
Magnetic moments of odd-Cu isotopes from N=28 to N=46

Calculations:
Model space \((^{56}\text{Ni core}) + f_{5/2} P_{3/2} P_{1/2} g_{9/2}\)

Effective Interactions:
* JUN45, Honma et al., PRC80, 064323, 2009
* jj4b, Brown, private communication

Conclusions:
(1) \(^{69}\text{Cu}\) magnetic moment very close to the reduced single particle value
(2) used \(g_s = 0.7 g_s^{\text{free}}\) (56Ni core, no f7/2)
(3) Towards N=28: both \(\pi\) and \(\nu\) f7/2 core excitations needed to reproduce core softness!
(4) Beyond N=40:
* \(^{75}\text{Cu}\), 5/2 g-factor well reproduced (because nearly pure \(\pi f_{5/2}\) wave function)
* \(^{71,73}\text{Cu}\), 3/2 values largely overestimated \(\Rightarrow\) need more mixing with \((\pi f_{5/2} \odot 2^+)^{3/2}\)

Quadrupole moments of odd-Cu isotopes from N=32 to N=46

Conclusions:
(1) Effective charges are adapted to get best overall agreement (fit to all)
(2) jj4b is doing overall extremely well !
(3) JUN45 does not very well reproduce the strong core-polarization observed when adding or removing neutrons to/from \(^{69}\text{Cu}\).
\(\Rightarrow\) related to the too high 5/2 below N=40
too high 1/2 above N=40
(4) a better precision on \(^{61}\text{Cu}\) and a value for \(^{59}\text{Cu}\) will be a very clear proof for the softness of the \(^{56}\text{Ni}\) core !
g-factors of odd-odd Cu isotopes from N=29 to N=45

Conclusions:

1. Overall trend best reproduced by jj4b

2. g-factor is very sensitive to the leading configuration in the wave function

3. Both overestimate the $^{66}\text{Cu}$ value → leading configuration is coupling to $\nu f_{5/2}$, not to $\nu p_{1/2}$

4. Leading proton configuration in $^{72,74}\text{Cu}$ is $\pi f_{5/2}$

The $2^-$ appears at 264/211 keV !!

JUN45, Honma et al., PRC80, 064323, 2009
jj4b, Brown, private communication

quadrupole moments of odd-odd Cu isotopes from N=29 to N=43

JUN45: $c_p=1.6$, $c_n=1.0$
jj4b: $e_p=1.4$, $e_n=1.0$
Energy levels of odd-Cu isotopes from N=28 to N=50

Below N=40:
- 5/2- level ~500 keV high
- 1/2- rather OK, not in 57Cu

Above N=40:
- 5/2- level rather OK
- 1/2- > 800 keV too high

Below N=40:
- 5/2- level in 57Cu too low!
- 5/2- level ~200 keV too low
- 1/2- rather OK

Above N=40:
- 5/2- level rather OK
- 1/2- bit too high in 73,75Cu

Energy levels Cu isotopes beyond N=42

Experiment

Calculated
Ground state spins in odd-Ga isotopes

Normal ground state configuration of odd-Ga isotopes: \( \pi(p_{3/2}^3) \frac{3}{2}^- \)

Prior to our work: firmly assigned \( \frac{3}{2}^- \) value up to \(^{75}\text{Ga}\)
tentatively assigned \( \frac{3}{2}^- \) for \(^{77,79}\text{Ga}\)
no assignment for \(^{81}\text{Ga}\)

This work: measured all g.s. spins from \(^{67}\text{Ga}\) up to \(^{81}\text{Ga}\)
B. Cheal et al., in preparation

Spin changes in \(^{73}\text{Ga} \) (I=1/2) and \(^{81}\text{Ga} \) (I=5/2) !!

\( \Rightarrow \) Need the magnetic and quadrupole moment to understand the structure change !!

Odd-Ga level systematics

Dip in \( 9/2^+ \) energy at \(^{73}\text{Ga} \) (N=42)
(intruder \( \pi g_{9/2} \) leading to onset of deformation around neutron mid-shell at N = 42)

No low-lying spin-1/2 state observed in \(^{73}\text{Ga} \) before.

\( \Rightarrow \) 3/2^- seen in \(^{73}\text{Ga} \) seen in (p,t) reaction study (Vergnes et al., PRC19, 1276, 1971)

\( \Rightarrow \) ½^- g.s. must be near-degenerate with this 3/2^- state (less than 1 keV according to Stefanescu)!!
**g-factors of odd-Ga isotopes**

B. Cheal et al., in preparation

- g.s. wave function dominated by unpaired \( \pi p_{3/2} \) (seniority \( \sigma = 1 \)), in 67,69,71Ga and in 75,77Ga
- g.s. dominated by \( \pi(f_{5/2}) \) configurations in 81Ga, having spin 5/2, but also in 79Ga having spin 3/2 (with mixed \( \pi(p_{3/2}^2 f_{5/2} \otimes 2^+ \) and \( \pi(f_{5/2}^3, \sigma = 3)_{3/2} \) as leading configurations)!!
- g.s very mixed in 73Ga: \( \pi(p_{3/2}^3, \sigma = 3)_{1/2} \) with \( \pi p_{1/2} \) and \( \pi f_{5/2} \otimes 2^+ \)
- the 73Ga g.s. g-factor \( g_{exp} = 0.418(4) \) is very close to \( g_n \sim Z/A \sim 0.44 \)

**quadrupole moments of odd-Ga isotopes**

B. Cheal et al., in preparation

- **Shape changes**

  (1) around 73Ga
  
  - Below \( N = 42 \) (36,38,40): \( Q > 0 \)
    main configuration: \( Q(p_{3/2})^3 = Q(p_{3/2}^{-1}) \)
    (hole configuration has a positive Q-moment)
  
  - Above \( N = 42 \) (44,46): \( Q < 0 \)
    main configuration: \( p_{3/2}^{-1} (f_{5/2}^2 p_{1/2})_2 \)
    (particle configuration has a negative Q-moment)

(2) In 79Ga

  positive Q-moment: particle-like must be the leading configuration
  
  - mixing between \( (p_{3/2}^2 \pi f_{5/2} \otimes 2^+)_{3/2} \) and \( (f_{5/2}^3)_{3/2} \) configurations
Comparing magnetic moments to JUN45 and jj4b

B. Cheal et al., in preparation

Both interactions predict g.s. structure of $^{79}$Ga around 250-300 keV.

Comparing quadrupole moments to JUN45 and jj4b

B. Cheal et al., in preparation

Conclusions: (1) jj4b has better overall agreement for the magnetic moments!
(2) In jj4b the quadrupole moment of 69Ga and 71Ga has wrong sign
   → too fast emptying of the p3/2 orbital?
   (indeed, lowest 3/2- has leading $p_{3/2}^2$ configuration,
    while the first-excited 3/2 has a leading $p_{3/2}^2$ configuration)
   → check if this Q-moment and mu-moment better fit data!
Comparing experimental levels to JUN45 and jj4b

Real ground state!

Real ground state ???
To be checked by moments!

Reduction of the N=28 gap below $^{48}\text{Ca}$

Evidence for N=28 gap reduction below $^{48}\text{Ca}$, in
- in Ar isotopes
- in S isotopes

N=27 isotones
Experimental 7/2⁻ and 3/2⁻

From Gaudefroy et al., PRL 102 (2009):
→ 7/2⁻ isomer in $^{43}\text{S}$ is dominated by $\nu_{f7/2}$ (from g-factor)
→ very good agreement with sd-pf-U interaction
→ suggested g.s. of $^{43}\text{S}$: a collective 3/2⁻ state dominated by $\nu_{p3/2}$

→ $^{44}\text{Cl}$ between $^{45}\text{Ar}$ and $^{43}\text{S}$

$\nu_{7/2}$
Near-degeneracy of $\pi s_{1/2}$ and $\pi d_{3/2}$ near $N=28$

$\pi d_{3/2}$

$N=22$ $N=24$ $N=26$ $N=28$

Calculation: sdpf-U interaction
(Nowacki and Poves, PRC79 (2009))

protons in sd orbits
neutrons in pf orbits
$g_s^{\text{eff}}=0.75g_s$

GOOD AGREEMENT:
Ground state spin 2 confirmed
VERY MIXED WAVE FUNCTION CONFIRMED

$\beta$-NMR on $^{44}$Cl(NaCl)

$|g|=0.27487(16)$

Fragmentation of $^{48}$Ca beam, 2 $\mu$A
$\rightarrow$ select polarized beams at LISE-GANIL for $\beta$-Nuclear Magnetic Resonance

M. De Rydt et al., PRC 2010, submitted

$\rightarrow$ Hardly no experimental information available on $^{44}$Cl
- knock-out reaction from $^{45}$Cl (PRC79, 2009) suggests 2- g.s. with significant contribution from $\nu p_{3/2}$ in the wave function
- no excited states known.

Normal $^{44}$Cl g.s. configuration = $(\pi d_{3/2}\nu f_{7/2}^{-1}) 2,3,4,5$-
Mixed with $(\pi d_{3/2}\nu p_{3/2}) 0,1,2,3$-
$(\pi s_{1/2}\nu p_{3/2}) 1,2$ $\rightarrow$ pushes 2- down in energy
$\rightarrow$ lowers the g-factor

$^{44}$Cl is in between $^{43}$Cl and $^{45}$Cl

$^{44}$Cl ground state presumably dominated by $\pi s_{1/2}$ configurations

$^{43}$Cl and $^{45}$Cl have probably 1/2+ ground state
(A. Gade, PRC 74(2006)034322)

$\rightarrow$ 1.5\% experimental information available on $^{44}$Cl
$\rightarrow$ 2- g.s. with significant contribution from $\nu p_{3/2}$ in the wave function
- no excited states known.

Normal $^{44}$Cl g.s. configuration = $(\pi d_{3/2}\nu f_{7/2}^{-1}) 2,3,4,5$-
Mixed with $(\pi d_{3/2}\nu p_{3/2}) 0,1,2,3$-
$(\pi s_{1/2}\nu p_{3/2}) 1,2$ $\rightarrow$ pushes 2- down in energy
$\rightarrow$ lowers the g-factor

$\rightarrow$ 1.5\% experimental information available on $^{44}$Cl
$\rightarrow$ 2- g.s. with significant contribution from $\nu p_{3/2}$ in the wave function
- no excited states known.
Conclusions

(1) **Knowing magnetic moments and quadrupole moments** in a series of isotopes or isotones is extremely helpful to understand the structural changes in isotopes far from stability!

(2) **Measurements** of the g.s. spin is needed in these exotic regions, because theories are not sufficiently well developed to make predictions!

(3) Measured g.s. spin values are crucial for further assigning spins of excited levels.

(4) **Measuring the sign of the g-factor** (magnetic moment) is crucial for interpretation of the mixed g.s. structures (less critical for isomeric states that are mostly of single particle nature)

---

M. De Rydt et al., PLB 678, 344 (2009)

T. Nagatomo, H. Ueno et al., preliminary