Nuclear Isomerism
Phil Walker
University of Surrey

on the occasion of the 70th birthday of Geirr Sletten
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HAPPY BIRTHDAY GEIRR !!
What are isomers?
What are isomers?

1917: predicted by Soddy
"different in their stability"

1921: uranium-X isomers
observed by Hahn

1936: isomers explained as
spin traps by von Weizsäcker

excited nuclear states with long half-lives: > 1 ns
Why study isomers?
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At the limits of nuclear binding, isomers may be more stable than ground states.
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\[ ^{270}_{110}\text{Ds} \alpha \text{ decay} \]

- 6 ms isomer at 1 MeV
- 0.1 ms ground state

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\[ ^{270}_{110}\text{Ds } \alpha \text{ decay} \]
6 ms isomer at 1 MeV
0.1 ms ground state

\[ ^{159}_{75}\text{Re } p \text{ decay} \]
21 µs isomer
ground state unknown


Why study isomers?
At the limits of nuclear binding, isomers may be more stable than ground states.

**KEY ROLE OF ANGULAR-MOMENTUM MAGNITUDE AND DIRECTION**

**270\(^{110}\)Ds α decay**
- 6 ms isomer at 1 MeV
- 0.1 ms ground state


**159\(^{75}\)Re p decay**
- 21 μs isomer
- Ground state unknown

Chart of nuclides

adapted from Lund web site
Sletten nuclides
SPONTANEOUSLY FISSIONING ISOMERS
IN U, Np, Pu AND Am ISOTOPES

N. L. LARK†, G. SLETSEN, J. PEDERSEN and S. BJØRNHOLM

The Niels Bohr Institute, University of Copenhagen, Denmark

> 100 citations
Fig. 2. Counter and target configuration used in (d, p delayed fission) coincidence measurements. The spacing between the carbon backed target and the backside of counter II is about 1 mm. The aluminium absorber foils placed between counters I and II allow only protons to go through.
Island of High-Spin Isomers near $N = 82$

J. Pedersen, B. B. Back, (a) F. M. Bernthal, (b) S. Bjørnholm, J. Borggreen, O. Christensen, F. Folkmann, B. Herskind, T. L. Khoo, (a) M. Neiman, F. Fühlhofer, and G. Sletten

Niels Bohr Institute, Risø, DK-4000 Roskilde, Denmark, and Gesellschaft für Schwerionenforschung, D-6100 Darmstadt, Germany

FIG. 1. Schematic diagram of recoil catcher and sixteen-element multiplicity filter apparatus used in search for high-spin isomers.

16 NaI > 100 citations
NUCLEON ALIGNMENT TO VERY HIGH SPINS IN $^{147}$Gd:  
RAPID “ROTATION” OF A FERMION SYSTEM

G. SLETTEN, S. BJØRNHOLM, J. BORGGREEN, J. PEDERSEN
Niels Bohr Institutet, Risø, 4000 Roskilde, Denmark

P. CHOWDHURY ¹, H. EMLING ², D. FREKERS, R.V.F. JANSSENS, T.L. KHOO
Argonne National Laboratory, Argonne, IL 60439, USA

and

Y.H. CHUNG and M. KORTELAHTI
Purdue University, W. Lafayette, IN 47907, USA

$^{14}$NaI + 4 Ge(Li)
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Niels Bohr Institutet, Risø, 4000 Roskilde, Denmark

In this letter we present the results of experiments on \(^{147}\text{Gd}\) where we show that up to \(I = \frac{79}{2} \hbar\) the angular momentum along the yrast line is generated exclusively by the alignment of valence nucleons, which in a pictorial way might be described as the formation of a "Saturn ring" of orbiting particles.

\[ 14 \text{NaI} + 4 \text{Ge(Li)} \]
High-Spin Isomers in W and Os Nuclei; 
Competition between K-Quantization and Triaxiality

J. Pedersen, B.B. Back*, S. Bjørnholm, J. Borggreen, and G. Sletten
The Niels Bohr Institute, Roskilde, Denmark

F. Azgui, H. Emling, H. Grein, G. Seiler-Clark, W. Spreng, and H.J. Wollersheim
Gesellschaft für Schwerionenforschung, Darmstadt, Federal Republic of Germany

P. Walker
Nuclear Structure Facility, Daresbury, United Kingdom
10 NaI + 2 Ge(Li) (one suppressed)
DECAY OF HIGH-SPIN ISOMERS IN Os NUCLEI
BY BARRIER PENETRATION

P CHOWDHURY¹, B FABRICIUS², C CHRISTENSEN, F AZGUI³,
S BJØRNHOLM, J BORGGREEN, A HOLM, J PEDERSEN and G SLETTE

Niels Bohr Institute, DK-4000 Roskilde, Denmark

M A BENTLEY, D HOWE, A R MOKHTAR, J D MORRISON
and J F SHARPEY-SCHAFER

Oliver Lodge Laboratory, University of Liverpool, Liverpool L69 3BX, United Kingdom

P M WALKER

Department of Physics, University of Surrey, Guildford GU2 5XH, United Kingdom

R M LIEDER

Institut fur Kernphysik, Kernforschungsanlage Julich, D-5170 Julich, West Germany

> 70 citations
TESSA 3 (50 BGO + 12 Ge suppressed) with bunched beam of $^{36}\text{S}$

$T_{1/2} = 130$ ns

6-quasiparticle isomer at 7 MeV

bypassing

beam current: on 5 ns
off 200 ns
gamma-ray coincidence spectrum

counts

Energy (keV)

623 + 712 + 796 keV gate

25^+

130 ns

bypassing
$^{238}\text{U}$

Deformation $\epsilon_2$

Potential Energy

$^{182}\text{Os}$

Deformation $\gamma$
Short note

Seven and nine quasi-particle $K$-isomers in $^{175}$Hf

N.L. Gjørup$^1$, M.A. Bentley$^{2,a}$, B. Fabricius$^{1,b}$, A. Holm$^1$, J.F. Sharpey-Schafer$^2$, G. Sletten$^1$, and P.M. Walker$^3$

$^1$ The Niels Bohr Institute, DK-4000 Roskilde, Denmark
$^2$ Oliver Lodge Laboratory, University of Liverpool, Liverpool L69 3BX, United Kingdom
$^3$ Department of Physics, University of Surrey, Guildford GU2 5XH, United Kingdom

$^a$ Present address: SERC, Daresbury Laboratory, Warrington WA4 4AD, United Kingdom

$^b$ Present address: Department of Nuclear Physics, Australian National University, Canberra ACT 2601, Australia
9-quasiparticle isomer at 7.5 MeV

ESSA 30 (30 Ge suppressed)
recoil shadow

5-quasiparticle isomer at 3 MeV
bunched $^{48}$Ca beam

$\tau > 10$ ns

$bypassing$

7455 keV

$^{175}$Hf $^{103}$

3015 keV

$^{74}$Ga beam

$\tau = 1.2$ µs

$5/2^-$
$^{175}$Hf rotational bands based on 9-qp states

Kondev et al., to be published

Gammasphere 100 Ge suppressed

"analysis of a number of high-seniority bands shows that they behave as if the nuclei rotate in the unpaired state"

**bypassing transitions**

<table>
<thead>
<tr>
<th>nuclide</th>
<th>$K^\pi$</th>
<th>bypassing intensity</th>
<th>quasiparticle change</th>
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<tr>
<td>$^{182}$Os</td>
<td>$25^+$</td>
<td>2 %</td>
<td>6 → 0</td>
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<td>$^{174}$Hf</td>
<td>$14^+$</td>
<td>1 %</td>
<td>4 → 0</td>
</tr>
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<td>$^{175}$Hf</td>
<td>$57/2^-$</td>
<td>&gt;50 %</td>
<td>9 → 5</td>
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<td>$35/2^-$</td>
<td>95 %</td>
<td>5 → 1</td>
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Do we understand the $K$-composition of S-bands?

i.e. do we understand the orientation of the angular-momentum vector?
CONNECTION BETWEEN BACKBENDING AND HIGH-SPIN ISOMER DECAY IN $^{179}$W

F. BERNTHAL$^1$, B.B. BACK$^2$, O. BAKANDER, J. BORGGREEN, J. PEDERSEN and G. SLETKEN

Niels Bohr Institutet, Risø, DK-4000 Roskilde, Denmark

and

H. BEUSCHER, D. HAENNI and R. LIEDER

KFA, D-517 Jülich, Germany


Intrinsic Excitations as Yrast Structures in $^{179}$W above $I \sim 35/2 \hbar$

J. Pedersen, S. Bjørnholm, J. Borggreen, J. Kownacki$^*$ and G. Sletten

The Niels Bohr Institute, DK-4000 Roskilde, Denmark
$^{179}$W

1983

14 NaI + 4 Ge(Li)

bypassing
bypassing
179-W

31/2 –

33/2 –

3030.0

2738.9

597.6

2441.8

2141.3

565.4

1853.4

1575.9

511.3

25/2 +

4291

2057

406.4

241.5

415.7

508.6

671.1

27/2 +

2271.7

511.2

266.2

2137.8

264.4

1873.5

505.8

1632.0

206.7

375 ns

74 W

105

710 ns

3348.7

35/2 –
CAESAR: 6 Ge suppressed bunched and chopped beam

Walker et al. PRL67 (1991) 433
\[ ^{174}_{74} \text{W} \]

GAMMASPHERE


bandhead?
not an isomer
K unknown
$^{174}$W B(E2) ratios

<table>
<thead>
<tr>
<th>$K_i^{\pi}$</th>
<th>$T^\gamma_{\text{out}} / T^\gamma_{\text{in}}$</th>
<th>$B(E2)<em>{\text{out}} / B(E2)</em>{\text{in}}$ (expt.)</th>
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<td>$18^+_{g}$</td>
<td>0.53(5)</td>
<td>1.36(13)</td>
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<td>$18^+_{s}$</td>
<td>9.46(86)</td>
<td>2.54(23)</td>
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$E2$ transitions

### $^{174}\text{W} \text{ B(E2) ratios}$

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$\Rightarrow K_s = 8 \pm 1$

---

**E2 transitions**

if \( K_1 = K_2 \), then \( c = 1 \), and \( R[B(E2)]_s = R[B(E2)]_g \)
\[ K = \Omega_1 + \Omega_2 \]

for 2 \( i_{13/2} \) neutrons
even-even nuclides

\[ K = |\Omega_1 - \Omega_2| \]

\[ ^{174}\text{W}, K = 8 \]
bandhead?

\[ ^{184}\text{Os}, K = 10 \]
isomer bandhead

full line: \( K = \Omega_1 + \Omega_2 \) for 2 \( i_{13/2} \) neutrons even-even nuclides

\[ K = |\Omega_1 - \Omega_2| \]

\( ^{174}\text{W}, K = 8 \) bandhead?

\( ^{184}\text{Os}, K = 10 \) isomer bandhead

high-K band crossings!

Summary

Types of isomerism: shape isomers, spin traps, K isomers

Technical developments: recoil shadow, beam pulsing, detector arrays

K-forbidden transitions: importance of $t$-bands
Summary

Types of isomerism: shape isomers, spin traps, K isomers

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K-forbidden transitions: importance of \( t\)-bands

**KEY ROLE OF ANGULAR-MOMENTUM MAGNITUDE AND DIRECTION**
Summary

Types of isomerism: shape isomers, spin traps, K isomers

Technical developments: recoil shadow, beam pulsing, detector arrays

K-forbidden transitions: importance of \( t\)-bands

**KEY ROLE OF ANGULAR-MOMENTUM MAGNITUDE AND DIRECTION**

Thank you, Geirr, for many years of friendship and physics!
"what I tell you three times is true"
from Lewis Carroll, The Hunting of the Snark
Saturn's rings !!
K values at bandcrossings

<table>
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<tr>
<th></th>
<th>I (h)</th>
<th>R[B(E2)]_s</th>
<th>R[B(E2)]_g</th>
<th>V (keV)</th>
<th>&lt;K_s&gt;</th>
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<tr>
<td>^{154}Gd_{90}</td>
<td>18</td>
<td>0.66 ± 0.03</td>
<td>0.63 ± 0.03</td>
<td>24.3^{+0.3}_{-0.2}</td>
<td>2.2^{+1.3}_{-2.2}</td>
</tr>
<tr>
<td>^{164}Yb_{94}</td>
<td>16</td>
<td>3.09 ± 0.75</td>
<td>3.76 ± 0.34</td>
<td>93.6^{+0.1}_{-0.2}</td>
<td>&lt;3</td>
</tr>
<tr>
<td>^{174}W_{100}</td>
<td>18</td>
<td>2.54 ± 0.23</td>
<td>1.36 ± 0.13</td>
<td>62.2 ± 0.6</td>
<td>^{8.1}_{-0.9}</td>
</tr>
<tr>
<td>^{176}W_{102}</td>
<td>18</td>
<td>1.20 ± 0.37</td>
<td>0.97 ± 0.16</td>
<td>29.3^{+0.8}_{-1.1}</td>
<td>^{5.7}_{-5.7}</td>
</tr>
<tr>
<td>^{178}Os_{102}</td>
<td>18</td>
<td>0.85 ± 0.18</td>
<td>0.62 ± 0.20</td>
<td>29.8^{+1.5}_{-1.8}</td>
<td>^{6.7}_{-6.7}</td>
</tr>
<tr>
<td>^{184}Os_{108}</td>
<td>16</td>
<td>1.12 ± 0.07</td>
<td>0.71 ± 0.04</td>
<td>44.6 ± 0.4</td>
<td>8.1^{+0.7}_{-0.8}</td>
</tr>
</tbody>
</table>

90 ≤ N ≤ 110 and 60 ≤ Z ≤ 76

\[ E_{4^+_1}/E_{2^+_1} > 3 \] (compared to the rigid-rotor limit of 3^{1/3}_3)

Since the $K$ values of the ground-state band and the $s$-band are believed to be zero or approximately zero, the degree of $K$-forbiddenness for the observed transitions is extremely large.

\[ B(E2; I \rightarrow I - 2) = \frac{5}{16\pi} \langle I \ 2 \ 0 \ | I - 2 \ 0 \rangle^2 Q^2 \]

for $^{172}$Hf ($N = 100$)


for $^{174}$W ($N = 100$)

...the alignment of two $i_{13/2}$ neutrons, has been identified over a considerable range of spin (8–26ℏ) and interpreted as an $s$-band ($K = 0$) structure.

\(^{172}\text{Hf}\) yrast band

\[ Q_0 \text{ (eb)} \]

\[ I_i = 20 \quad 22 \quad 24 \quad 26 \quad 28 \]

\[ \hbar \omega \text{ (MeV)} \]

$^{172}$Hf yrast band

![Graph showing Q₀ (eb) vs. $\hbar\omega$ (MeV) for $I_i = 20, 22, 24, 26, 28$.]

[Corrected for K = 8]

[Jain et al., Rev. Mod. Phys. 62 (1990) 393]
Multiphonon Vibrations at High Angular Momentum in $^{182}$Os


TIDAL WAVES

$^{182}$Os $\kappa=25^+ 130$ ns