Investigation of low-lying collective excitations in Mo-96

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E.T. Gregor
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Background
Isovector states

Without interaction

\[
\begin{pmatrix}
H_0 & 0 \\
0 & H_0
\end{pmatrix}
\begin{pmatrix}
\Psi_1 \\
\Psi_2
\end{pmatrix} = E_i
\begin{pmatrix}
\Psi_1 \\
\Psi_2
\end{pmatrix}
\]

Adapted from K. Heyde, J. Sau, PRC 33, 1050 (1986)
Background
Isovector states

\[
\begin{pmatrix}
H_0 & 0 \\
0 & H_0
\end{pmatrix}
\begin{pmatrix}
\Psi_1 \\
\Psi_2
\end{pmatrix} = E_i
\begin{pmatrix}
\Psi_1 \\
\Psi_2
\end{pmatrix}
\]

Without interaction

\[
\begin{pmatrix}
H_0 & V_{12} \\
V_{12} & H_0
\end{pmatrix}
\begin{pmatrix}
\Psi_1 \\
\Psi_2
\end{pmatrix} = E_i'
\begin{pmatrix}
\Psi_1 \\
\Psi_2
\end{pmatrix}
\]

With interaction

\[
\beta |\Psi_1\rangle - \alpha |\Psi_2\rangle = \beta |\Psi_1\rangle + e^{i\pi} \alpha |\Psi_2\rangle
\]

Adjusted from K. Heyde, J. Sau, PRC 33, 1050 (1986)
Background
Isovector states

M. Scheck et al., PRC 81, 064305 (2010)
Background
Isovector states

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Background
Why 96-Mo?

\[ \begin{align*}
3s_{1/2}^+ & \quad \text{---------------------} \\
2d_{3/2}^+ & \quad \text{---------------------} \\
1h_{11/2}^- & \quad \text{---------------------} \\
1g_{7/2}^+ & \quad \text{---------------------} \\
\end{align*} \]

\[ E_F - - - \quad \frac{2d_{5/2}^+}{\nu} \quad - - - \quad \frac{1g_{9/2}^+}{\pi} \quad 2p_{1/2}^- \]

\[ \quad \frac{1f_{5/2}^-}{\pi} \quad 2p_{3/2}^- \]
Background
Why 96-Mo?

\[ \Psi_{\pi}^{3-} = \alpha \left[ g_{9/2}^{+}, p_{3/2}^{-} \right]_{3-} + \beta \left[ g_{9/2}^{+}, f_{5/2}^{-} \right]_{3-} \]

\[ \Psi_{\nu}^{3-} = \alpha \left[ h_{11/2}^{-}, d_{5/2}^{+} \right]_{3-} + \beta \left[ h_{11/2}^{-}, g_{7/2}^{+} \right]_{3-} \]
Background
Why 96-Mo?

- First and second $3^-$-state in $^{96}$Mo at 2234 and 3178 keV respectively
- Proton and neutron $3^-$-states in-between
- Publication in preparation!

Data from BNL’s ENSDF

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Background

Transition strengths

\[ B \left( \frac{M}{E}, \lambda, J_i \rightarrow J_f \right) = (2J + 1)^{-1} |\langle \Psi_f || \left( \frac{M}{E} \lambda \right) || \Psi_i \rangle|^2 \]

\[ B (M1) = C_{M1} \frac{I_{rel} [\%/100]}{\tau \left( E_{\gamma} [MeV] \right)^{(2L+1)}} \frac{1}{1 + \delta^2} \]

\[ B (E2) = C_{E2} \frac{I_{rel} [\%/100]}{\tau \left( E_{\gamma} [MeV] \right)^{(2L+1)} \delta^2} \frac{1}{1 + \delta^2} \]
Background

Transition strengths

\[ B \left( \frac{M}{E} \lambda, J_i \rightarrow J_f \right) = (2J + 1)^{-1} |\langle \Psi_f | \left( \frac{M}{E} \lambda \right) | \Psi_i \rangle|^2 \]

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\[ B (E2) = C_{E2} \frac{I_{rel} [%/100]}{\tau (E_{\gamma} [MeV])^{(2L+1)} 1 + \delta^2} \]

Follow-up experiment? (GAMS)

Gamma-spectroscopy

Multipole and mixing ratio from angular correlation (see there)
Background
Neutron capture

\[ J_{\text{even,capture}}^\pi = J_{\text{odd,ground}}^\pi \pm 1/2 \]

Meaning for \(^{95/96}\text{Mo}\\):

\[ \frac{5}{2}^+ \pm \frac{1}{2} = 2^+, 3^+ \]

\[ E_{\text{NCS}} = 9154.32 \text{ keV} \]
Experiment

• Neutrons from ILL’s high flux reactor
• Neutron capture on $^{95}$Mo
• Thermal neutron flux of $10^8$ n/cm²
• Decays measured with EXOGAM
  • 8 Ge-clover detectors with BGO suppression shields
• Measured for approx. two nights (~20h)

ILL Réacteur à haut flux – Rapport transaprence et sécurité nucléaire
EXOGAM homepage

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Experiment
Determining multipolarity

O. Kaleja, BSc thesis
• In a cascade of two decays, the angular distribution of the second ray is measured relative to the first
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The angular distributed is fitted to the following formula...

\[ W(\theta) = a_0 + a_2 P_2(\cos\theta) + a_4 P_4(\cos\theta) \]

K. Krane, Introductory Nuclear Physics
In a cascade of two decays, the angular distribution of the second ray is measured relative to the first.

The angular distribution is fitted to the following formula...

$$W(\theta) = a_0 + a_2 P_2(\cos\theta) + a_4 P_4(\cos\theta)$$

..obtaining the coefficients $a_2$ and $a_4$

$$a_n = B_n(L_1, L'_1, \delta_1, j_1, j) \cdot A_n(L_2, L'_2, \delta_2, j_2, j)$$

J. Beller, PhD thesis
In a cascade of two decays, the angular distribution of the second ray is measured relative to the first. The angular distribution is fitted to the following formula:

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obtaining the coefficients \(a_2\) and \(a_4\)

\[ a_n = B_n(L_1, L'_1, \delta_1, j_1, j) \cdot A_n(L_2, L'_2, \delta_2, j_2, j) \]

From which multipolarity and multipole mixing factors can be obtained.
(Very) Preliminary Results
Direct decay of the first $3^-$-state
(Very) Preliminary Results

Direct decay of the first $3^-$-state
(Very) Preliminary Results
Direct decay of the first $3^{-}$-state
(Very) Preliminary Results

The $2^{+}_{ms}$-state
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The $2^+_{ms}$-state

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(Very) Preliminary Results

The $2^+_{ms}$-state

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(Very) Preliminary Results

Decay of the candidate

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(Very) Preliminary Results
Decay of the candidate
(Very) Preliminary Results

Decay of the candidate
(Very) Preliminary Results

$J^\pi$ of the neutron capture state

Crate: 0, Adc: 0

No obvious direct decays from the neutron capture state to any $J=1$ state, but several decays to $J=2, 3, 4$ states

$\rightarrow$ Neutron capture state probably has $J=3$
• Mixed-symmetric states provide a probe for proton-neutron interaction
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• The second $3^-$-state in $^{96}$Mo is a candidate
• Mixed-symmetric states provide a probe for proton-neutron interaction
• The second $3^-$-state in $^{96}$Mo is a candidate
• Neutron capture experiment performed
...and Outlook

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