Nuclear structure of $^{122}$Xe studied via $\beta^+/\mathrm{EC}$ decay

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Evolution of Nuclear Shape

Collective Model

Shell Model
Spherical
Single particle

Nearly spherical
Surface Vibrate

Shell Model
Spherical
Single particle

Nearly spherical
Surface Vibrate

Ellipsoidal
Deformed
Surface Rotate

Shape changes
More valence nucleons

Closed shell
Mid-shell
Closed shell

Nucleon number
Development of Collectivity

Collective Model

Shell Model

Closed shell

B(E2)≈several W.u.

Mid-shell

B(E2)≈30 W.u.

Nucleon number

B(E2)≈100 W.u.

Enhanced B(E2) rates

Lowering of the collective states
What kind of collective model can describe such nucleus?

$^{122}\text{Xe}$ falls in transitional region.
Recent work on $^{124}$Xe

Showed $O(6)$ broken

Is $^{122}$Xe still $\gamma$-soft nucleus and does it possess $O(6)$ symmetry?
Systematics of the low-lying $0^+$ states in the $^{120}$Xe – $^{130}$Xe isotopes.

**Collectivity in Xe isotopes is actually rather poorly characterized!**

- Collective nuclei have to have these bands
- In-band E2 transitions strong
- Their B(E2) values (quadrupole collectivity)
E2 transitions in Xe-122

Suggested spin $(0)_3^+$

Systematics of the low-lying $0^+$ states in the $^{120}$Xe – $^{130}$Xe isotopes.

**Collectivity in Xe isotopes is actually rather poorly characterized!**

- Third $0^+$ state not confirmed
- Band member $2^+$ state missing
- Important E2 transitions missing

**Important in-band E2 transitions are missing for $^{122}$Xe?**

To answer need to investigate $^{122}$Xe
Experimental setup

TRIUMF-ISAC facility located in Vancouver, Canada.

Two sets of data were collected for short- and long-half-life decays in repeated cycles.

- short cycle run 2s, 20s, 20s, and 0.75s
- long cycle run 20s, 450s, 450s, and 1.5s
**8π spectrometer**

- **Hemisphere of 8π**
- **Moving tape collector**

- 20 HP Ge detectors for γ-ray
- 5 Si(Li) detectors (PACES) for e⁻'s
- Moving tape collector used to transport the beam deposit spot

- γγ coincidence data allowed
  - 160 new transitions
  - more than 100 new levels

---

**PACES**

**SCEPTAR**
Results: Important E2 transitions

- Gated on 818 keV $\gamma$ ray

- Gated on 1385 keV $\gamma$ ray

Counts

$E_\gamma$ (keV)

Counts

$E_\gamma$ (keV)

8$^+$  2217

6$^+$  1467

4$^+$  829

2$^+$  331

0$^+$  331 0

10

10

10

10

10

10

10

10
Results: E2 transitions

Systematics of the low-lying 0+ states.

Collective nuclei

Strong

Weak
Results: Relative $B(E2)$ values

$B(E2) = \frac{9.527 \times 10^6}{E_{\gamma_i}^5 A^{4/3}} \frac{BR_{\gamma_i}}{T_{1/2}^{level}(1 + \alpha_i)}$

$T_{1/2}$ the half-life of the levels missing,

The relative $B(E2)$ values for the key transitions

Systematics of the low-lying $0^+$ states.

Collective nuclei

Strong

Weak

Agrees collective behaviour

Firmly establishes $2^+$ band members

First critical piece of information
Results: Angular Correlation

The probability, per unit solid angle, that two gamma-rays are emitted at an angle $\theta$ is proportional to.

$$W(\theta) = 1 + A_{22} P_2(cos(\theta)) + A_{44} P_4(cos(\theta)) + ...$$

$A_{22}(J_1, J_2, J_3)$ and $A_{44}(J_1, J_2, J_3)$
Results: Angular Correlation

The probability, per unit solid angle, that two gamma-rays are emitted at an angle $\theta$ is proportional to:

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$A_{22}(J_1, J_2, J_3)$ and $A_{44}(J_1, J_2, J_3)$

Angular correlations of 1385 keV transitions gated on 331 keV transition

- Calibration made
- Third $0^+$ state confirmed
Results: Angular Correlation

Angular correlations of 1976 keV transitions gated on 331 keV transition

Angular correlations of 2166 keV transitions gated on 331 keV transition

Angular correlations of 2200 keV transitions gated on 331 keV transition

Old spin $0^+, 1^+, 2^+$

Old spin $1^+$

Angular correlations of 1976 keV transitions gated on 331 keV transition

Angular correlations of 2200 keV transitions gated on 331 keV transition

Angular correlations of 2166 keV transitions gated on 331 keV transition
Key transition observed first time

They will decide γ-softness
γ-soft (in IBM O(6) symmetry)

Not ready to say something about γ-softness

Need to work on transition rate and branching ratio
Conclusion

160 new transitions and 100 new levels have been observed along with the $2^+$ members of $\beta$-vibrational bands. Relative $B(E2)$ values firmly establish the $2^+$ band members.

We have firmly assigned spin value of 0 for 5 new states.

We have observed the key transition which will help to test $\gamma$-softness. Angular correlation analysis will be continued for all new states. The conversion electron data will be also analyzed.
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thank you!
Introduction

<table>
<thead>
<tr>
<th>Q_0-n</th>
<th>BE/A</th>
<th>(BE-LDM Fit)/A</th>
<th>E_{1st ex. st.}</th>
<th>E_{2+}</th>
<th>E_{3-}</th>
<th>E_{4+}</th>
<th>E_{4+}/E_{2+}</th>
<th>B(E2)<em>{42}/B(E2)</em>{20}</th>
<th>σ(n,γ)</th>
<th>σ(n,F)</th>
</tr>
</thead>
</table>

122\text{Xe}

122\text{Xe} is an even-even deformed collective nucleus.

Collective model

Shell model

Vibration and Rotation
- Energy of the first 2+ state
- E2 transition strengths
- 0+ states (shape coexistence)
Evolution of Nuclear Structure

Collective Model

Shell Model

Closed shell

Mid-shell

Lowering of the collective states

Closed shell
Evolution of collectivity

- 3D landscape plot
- First $2^+$ state energy
- Xe centrally located
- Smooth evolution of collectivity
- $Z>50$ and $N<82$

However collectivity in this region is actually rather poorly characterized!
The $\beta$ vibration corresponds to fluctuations in the quadrupole deformation $\beta$.

The $\gamma$ vibration corresponds to oscillations in $\gamma$.

$^{122}\text{Xe}$ is in transitional region from vibrational toward rotational.
\gamma\text{-soft (in IBM O}(6)\text{ symmetry)}

\gamma\text{-soft, O}(6)\text{ symmetry (theo)}

\[ E_{rot}(J) = \frac{\hbar^2}{2I} [J(J + 1) - K(K + 1)] \]

J=K, K+1, K+2, ...

E2:E4:E6:E8= 1 : 2.5 : 4.5 : 7

\gamma\text{-soft (in IBM O(6) symmetry)}

\gamma\text{-soft, O(6) symmetry (theo)}

\[
\begin{align*}
8^+ & \quad \rightarrow \quad 6^+ \quad \rightarrow \quad 2^+ \quad \rightarrow \quad 4^+ \\
6^+ & \quad \rightarrow \quad 4^+ \quad \rightarrow \quad 0^+ \quad \text{K=0} \\
4^+ & \quad \rightarrow \quad \gamma \quad 2^+ \\
2^+ & \\
0^+ &
\end{align*}
\]

\[
E_{rot}(J) = \frac{\hbar^2}{2I} [J(J + 1) - K(K + 1)]
\]
J=K, K+1, K+2, ...

E2:E4:E6:E8= 1 : 2.5 : 4.5 : 7

\[
\begin{align*}
8^+ & \quad 6^+ \quad 4^+ \quad 2^+ \\
6^+ & \quad 4^+ \quad 2^+ \\
4^+ & \quad 2^+ \\
2^+ & \\
0^+ &
\end{align*}
\]

\begin{itemize}
  \item Energy levels agree
  \item Levels spacing matches very good
  \item E2:E4:E6:E8= 1 : 2.5 : 4.4 : 6.7
  \item But third 2\textsuperscript{+} state of K=0 band lower
\end{itemize}


Xe isotopes manifest O(6) symmetry

- IBM version of deformed, axially-asymmetric but $\gamma$-soft rotor
- IBM (Algebraic model)
- Energies and interactions of fermion pairs

- Recent work on $^{124}$Xe
- Showed $O(6)$ broken


Is $^{122}$Xe still $\gamma$-soft nucleus and does it possess $O(6)$ symmetry?
How do we test $\gamma$-softness

### $\gamma$-soft or $O(6)$ nucleus

<table>
<thead>
<tr>
<th>6$^+$</th>
<th>4$^+$</th>
<th>2$^+$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3$^+$</td>
<td>0$^+$</td>
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</table>

#### Alaga rule

\[
\frac{B(E2 : J_i \rightarrow J_f)}{B(E2 : J_i \rightarrow J'_f)} = \frac{\langle J_i K_i 2\Delta K | J_f K_f \rangle^2}{\langle J_i K_i 2\Delta K | J'_f K_f \rangle^2}
\]

For example:

\[
\frac{B(E2 : 2^+_2 \rightarrow 2^+_1)}{B(E2 : 2^+_2 \rightarrow 0^+_1)} \rightarrow \infty
\]

\[
\frac{B(E2 : 0^+_2 \rightarrow 2^+_2)}{B(E2 : 0^+_2 \rightarrow 2^+_1)} \rightarrow \infty
\]

### Deformation parameters

- $\beta$ extend of quadrupole deformation $\beta$.
- $\gamma$ gives the degree of axial asymmetry.

### Alaga rule can be used to

- assign $K$ quantum numbers to different intrinsic excitations
- account band mixing effects

- Either both intra-band or both inter-band with the same initial and final bands.
- Intrinsic matrix element will clearly be identical for both transitions.
Results: Level scheme extension

Old level scheme of $^{122}$Xe

Preliminary level scheme of $^{122}$Xe from short runs of this work

Preliminary level scheme of $^{122}$Xe from long runs of this work

- 160 new transitions
- 100 new levels
Angular correlations of 1894 keV transitions gated on 331 keV transition

Results: Angular Correlation

University of Guelph