Systematics of nuclear charge radii and deformation in the $Z \approx 40$, $N \approx 60$ region

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Talk layout

- Collinear laser spectroscopy
- Isotope Shift and Hyperfine Structure
- Nuclear Deformation
- Deformation across the $N \approx 60$ region
- Molybdenum
- Summary
Collinear laser spectroscopy

- Laser spectroscopy involves stimulating transitions between atomic energy levels

A spectrum is then formed by counting the number of the emitted photons as a function of laser frequency.

The exact value of the atomic energy levels is determined by the atoms’ nucleus.

\[ E = E_2 - E_1 = h\nu \]
Features of interest

- **Isotope Shift**: The shift in frequency between two isotopes can be used to extract the mean-square charge radius of the nucleus.

- **Hyperfine Structure**: The spacing of the hyperfine structure lines can be used to determine the magnetic dipole and electric quadrupole moments of the nucleus.
Nuclear shape and deformation

- Mean-square charge radius is a model independent quantity that provides insight into nuclear size and deformation

\[ \langle r^2 \rangle = \langle r^2 \rangle_{sph} + \langle r^2 \rangle_{sph} \frac{5}{4 \pi} \langle \beta_s^2 \rangle \]

- The mean-square quadrupole deformation parameter, \( \langle \beta_s^2 \rangle \), is dependent on both static deformation and collective nuclear vibrations (dynamic deformation)

- Electric quadrupole moment can be used to determine the shape of the nucleus

\[ Q_0 = \frac{5Z \langle r^2 \rangle_{sph}}{\sqrt{5\pi}} \langle \beta_s \rangle \left(1 + 0.36 \langle \beta_s \rangle \right) \]

\[ Q_s = Q_0 \frac{I(2I - 1)}{(I + 1)(2I + 3)} \]

- The mean quadrupole deformation parameter, \( \langle \beta_s \rangle \), is dependent on only static deformation
• Quadrupole deformation parameter can be used to determine the shape and dynamical properties of the deformation

\[ \beta_2 \leq 0 \]
Oblate deformation

\[ \beta_2 > 0 \]
Prolate deformation

• If \( \langle \beta_2^2 \rangle \) is larger than \( \langle \beta_2 \rangle^2 \) the nucleus exhibits “soft” dynamic deformation

• If \( \langle \beta_2^2 \rangle \) is equal to \( \langle \beta_2 \rangle^2 \) the nucleus exhibits rigid static deformation
Decrease in $<r^2>$ at N = 50 shell closure

$r^2$ increases gradually across 50<N<60 region but at a greater rate than that expected for increase in radius due to volume changes

For elements Z = 37 to Z = 41 a sudden onset of deformation occurs at N = 60 with the effect being most prominent in yttrium (Z = 39)
<r^2> increases gradually across 50<N<60 region

Deformation increases gradually across N=60 with NO sudden onset of deformation

Deformation reaches similar levels as that exhibited in other neighbouring elements

Increase of deformation shows evidence of levelling off at N = 66
Nature of deformation across the region

- Isotopes exhibit soft dynamic deformation in 50<N<60 region
- Deformation becomes rigid/static after N = 60
- $<\beta_2>$ is slightly negative for N<60 indicating a weakly oblate deformation of the nucleus
- $<\beta_2>$ is positive for N>60 indicating a strongly prolate deformation of the nucleus
Summary

• The onset of deformation at N = 60 for elements in the Z = 40 region is not observed for Molybdenum

• The rate of increase in mean square charge radius is observed to flatten off at N = 66

• Further measurements of Mo are required using a transition that would enable the quadrupole moment to be extracted and the dynamic nature of the deformation of its nucleus determined
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References:


Experimental Setup

- Laser beam
- Interaction region
- Cooler/buncher
- Beam switchyard
- 55° dipole magnet
- Ion guide
- Beam from K130 cyclotron
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