Laser spectroscopy of gallium isotopes using ISCOOL
Optical measurements in the region

→ spins, $\mu$, $Q_s$, $\delta<r^2>$
Physics motivation

Otsuka (PRL 95 232502):

Tensor force **attractive** between $L+1/2$ and $L-1/2$

(esp with $\sim$radial wavef$^n$)

Does $5/2$ replace $3/2$ as gs in Ga? **When?**

Use laser spectroscopy to measure the gs spins...
Laser spectroscopy at Collaps

RILIS

532 nm
34782 cm⁻¹
288 nm
826 cm⁻¹
295 nm
0 cm⁻¹

Magnets

p-n converter

Protons

p-n converter

288 nm
295 nm
532 nm

RILIS

MAGNETS

ISCOOL

Proton Beam

Charge exchange

Applied Doppler tuning voltage

PMT
ISCOOL for cooling & bunching

Photon background dominated by continuous laser scatter

End plate potential

Accumulate

Release

200ms PMT

6μs gate
Example spectrum - $^{76}$Ga

Ungated

Gated (64$\mu$s - 70$\mu$s)

Time of flight (50ms accumulation)

Background suppression

50ms / 6$\mu$s = $\sim$10$^4$
417nm Ga I spectra

$826\text{ cm}^{-1}$ $3d^{10}4s^24p^2 \, ^2P_{3/2} \rightarrow 24789\text{ cm}^{-1}$ $4s^25s \, ^2S_{1/2}$
The strange case of $^{73}\text{Ga}$

All odd-$A$ states previously assigned $I=3/2$

$\pi(p_{3/2})^3$ - hole state

$\text{Au/Al} \neq 5.59(2)$
403nm ($^{2}P_{1/2} \rightarrow ^{2}S_{1/2}$) transition

\[ F=1 \rightarrow F=0 \]

\[ J=1/2 \]

\[ I=3/2 \] → Must be spin 1/2
Intensity distribution (403nm)

- Number of peaks
- Intensity distribution
- \( \text{Au}^{(2S_{1/2})}:\text{Al}^{(2P_{3/2})} \) ratio
Gallium level systematics

No low-lying spin-1/2 state observed in $^{73}\text{Ga}$

Dip in 9/2 energy at this point (onset of deformation)

I. Stefanescu et al. PRC 79, 064302 (2009)
Shell model predictions

Pairing + QQ using a valence space made up from nucleons occupying the $g_{9/2}$, $p_{1/2}$, $p_{3/2}$ and $f_{5/2}$ orbitals

N. Yoshinaga, K. Higashiyama, and P. H. Regan
PRC 78 044320 (2008)
Searching for the $I=5/2...$

Four $^{81}\text{Ga}$ spectra:-

<table>
<thead>
<tr>
<th>$A$</th>
<th>Data Set</th>
<th>$I=3/2$</th>
<th>$I=5/2$</th>
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<tr>
<td>79</td>
<td>1</td>
<td>299</td>
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<tr>
<td>79</td>
<td>2</td>
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<td>81</td>
<td>4</td>
<td>402</td>
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</table>

$^{75,77,79}\text{Ga}$ are $I=3/2$

$^{81}\text{Ga}$ is $I=5/2$
Odd-odd Ga isotopes

Isomeric state discovered in $^{80}\text{Ga}$

$\ell = 3$

Can assign as $\ell = 2$

Agrees with ABMR

No detectable splitting
Gallium nuclear moments

g-factors

\[ Q_s \]

- g-factors of \(^{75,77}\text{Ga}\) similar to \(^{67,69,71}\text{Ga}\)
  - but different structure (\(Q < 0\))
- Staggering of quadrupole moments \(^{75,76,77,78}\text{Ga}\)
Comparison with theory (Energy)

JUN45 - M. Honma
Low $I=\frac{1}{2}$ state in $^{73}\text{Ga}$

jj44b - B.A. Brown
Spin inversion

Experimental $1/2^-, 3/2^-, 5/2^-, 7/2^-$
Theory - nuclear moments

Magnetic dipole

Electric quadrupole

Fails for $^{79}$Ga in particular ....
Theory - nuclear moments

Magnetic dipole  Electric quadrupole

“Second” 3/2 states  ..or the gs?
Isotope shift data

Need to calculate atomic factors...

\[ \delta \nu^{A,A'} = M_i \frac{A' - A}{AA'} + F_i \delta \langle r^2 \rangle^{A,A'} \]
Summary and outlook

• Inversion seen between \(^{79}\)Ga and \(^{81}\)Ga
• \(^{73}\)Ga is \(I = 1/2\) (not \(I = 3/2\))
• Spins also confirmed for \(^{76,77,78,79,80,81}\)Ga
• Isomeric state discovered in \(^{80}\)Ga
• Theoretical predictions of moments
• Analysis of charge radii data

See talk by Pieter Vingerhoets (Cu) isotopes
Collaborating institutions

Manchester, UK
KU Leuven, Belgium
Birmingham, UK
ISOLDE, CERN
Jyväskylä, Finland
Orsay, France
Heidelberg, Germany
Mainz, Germany
New York, USA
## Beta_2 values

<table>
<thead>
<tr>
<th>Value</th>
<th>Delta</th>
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