Study of the stability of the gallium isotopes beyond the $N = 50$ neutron shell closure

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– CRIS collaboration –

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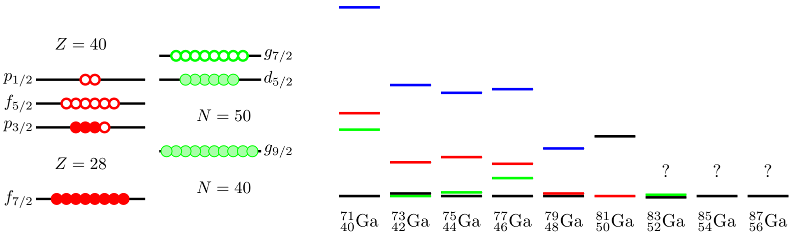
26^{th} June 2013
44^{th} INTC meeting

Level migration in n-rich gallium

leading to quantum inversion in the ground state at $N = 50$



Following the shell model description:

$3/2^-$ 1h in $p_{3/2}$ ⇒ expected ground state

$5/2^-$ 1p-2h in $f_{5/2}$ ⇒ ground state at $N = 50$

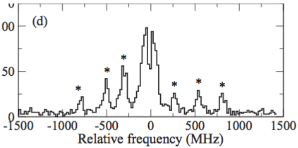
$1/2^-$ 1p-2h in $p_{1/2}$ ⇒ ground state at $N = 42$

$7/2^-$ 2p-1h in $f_{7/2}$

COLLAPS work: B. Cheal et al., PRL 104(2010)252502.

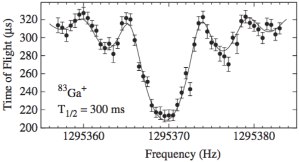
Isomerism at $N = 49$

Spectroscopy of the lightest $N = 49$ isomer



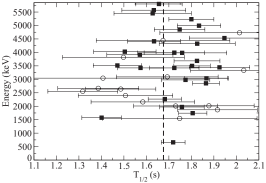
COLLAPS work: Identification of 2 states with spin 3 and 6 $\Rightarrow$ $T_{1/2} \geq 200$ms.

B. Cheal et al., PRC 82(2010)051302(R).



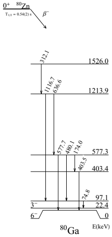
JYFLTRAP work: No evidence for 2 states $\Rightarrow$ $\Delta E < 50$keV.

J. Hakala et al., PRC 101(2008)052502.



^{80}Ga β-decay study at ALTO $\Rightarrow$ $T_{1/2}(I = 3) = 1.9(1)$s & $T_{1/2}(I = 6) = 1.3(2)$s. No pure beam could be studied and the uncertainty on the analysis remains large.

D. Verney et al., PRC 87(2013)054307.

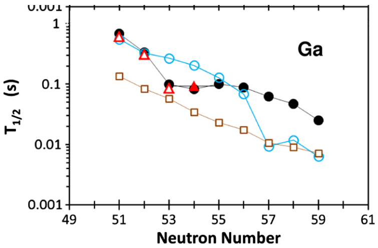


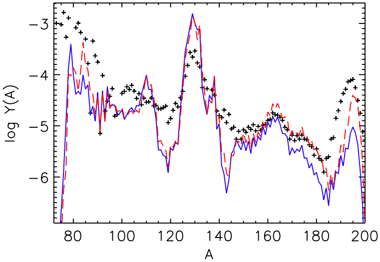
^{80}Zn β-decay study at ISOLDE $\Rightarrow$ Excited level structure in ^{80}Ga determined. $E(I = 3) = 22.4$keV

R. Lică et al., AIP Conf. Proc. 1491(2012)97.

Half-lives beyond $N = 50$

Impact on stellar r process





- Recent β-decay studies of n-rich gallium isotopes from HRIBF: stabilisation of the half-life of gallium at $N = 54$.
- New calculations predict stabilisation up to $N = 56$.
- Possible large impact on r-process calculations.

M. Madurga et al., PRL 109(2012)112501.

P375 - Aim of this proposal

Nuclear structure across $N = 50$

We propose to study the spin, electromagnetic moments and nuclear charge radii of the gallium isotopes with $N \geq 50$ to assert the configuration of their ground state.
⇒ Determine the purity of the ground state of the gallium isotopes beyond $N = 50$.

Isomerism in odd-odd gallium isotopes

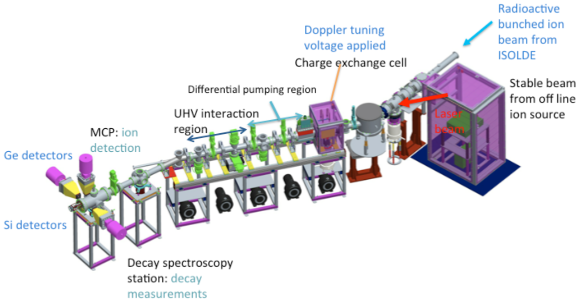
We will study the decay of isomerically pure samples of ^{80g,m}Ga to ^{80}Ge to determine their respective half-lives and feeding patterns.
⇒ These data will complete the existing spectroscopic information on this nucleus and assert the shape coexistence between spherical and triaxial shapes in the vicinity of ^{78}Ni.

Half-lives of n-rich gallium isotopes

We propose to measure the half-life of the n-rich gallium isotopes with $N \geq 50$ to confirm the recently measured values and extend the measurement to the more n-rich isotope.
⇒ These new data will then challenge the most recent calculations and impacts on r-process calculations.

CRIS

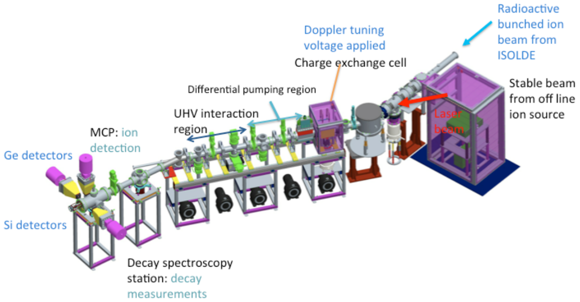
Collinear Resonance Ionisation Spectroscopy



Layout of the CRIS beam line

- Bunches are delivered from the ISOLDE HRS ISCOOL at 40 keV;
- Ions are neutralised in a potassium charge exchange cell operated at 10^{-6} mbar;
- Non-neutralised ions are deflected away while the atoms drift through the interaction region, maintained at $< 10^{-9}$ mbar;
- Lasers are sent through the interaction region;
- Re-ionised isotopes are deflected towards an MCP or a decay spectroscopy station.

CRIS
Collinear Resonance Ionisation Spectroscopy



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IS471

Review of the 2012 CRIS campaign

Successful IS471 beam times (Aug'12 & Oct'12) have allowed to study 17 hyperfine structures in francium, including 9 new isotopes and 4 isomers.

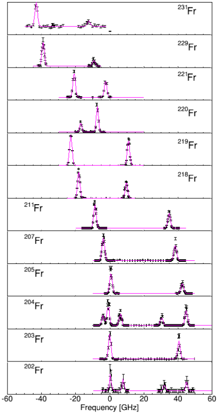
High efficiency

- Neutralization efficiency of 50%;
- Total efficiency for resonant ions of 1% has been reached in Fr;
- ^{202}Fr has been effortlessly measured with 100 ions per second.

High purity

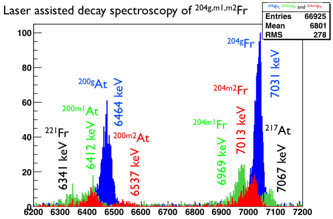
- Total collisional background efficiency of 1:300 000 at a pressure of $8 \cdot 10^{-9}$mbar;
- Background-free measurement in the most exotic cases (e.g. 100 per s ^{202}Fr vs. $\sim 10^4$ per s ^{202}Tl);

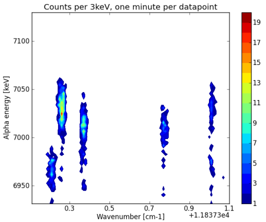
⇒ 99.98% purity on isomer selection.



DALAS & LANDS

Decay-Assisted LAser Spectroscopy & Laser-Assisted Nuclear Decay Spectroscopy



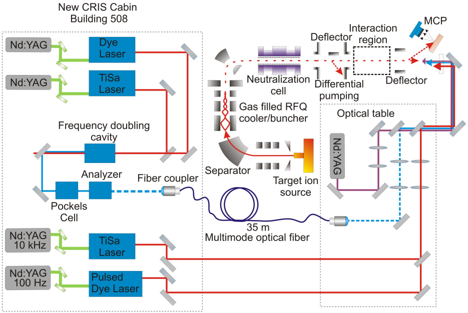


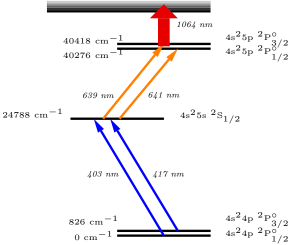
Isomeric sample production

- Scans on the MCP reveals the components;
- Each component is sent to the DSS to observe the respective $[\alpha]$ decay;
- The peaks in the hyperfine structure can then be associated with their respective states.
- Spectroscopy can then be performed on purified beams of isomer (corresponding to a mass resolving power $M/\Delta M \sim 5 \cdot 10^6$ for the case of ^{204}Fr).

New laser setup

CRIS at high resolution



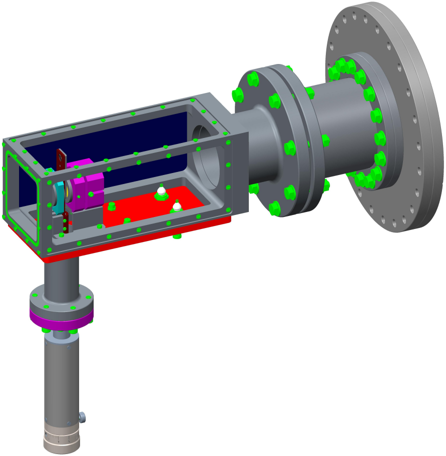


CRIS performances

- IS471 resolution was limited by the laser linewidth (1.2 GHz).
- Recent off-line tests with K have demonstrated the possible operation with high-resolution continuous-wave laser (25 MHz) in saturation.
- A CW MATISSE laser (dye/Ti:Sa) has been delivered. A pulsed Dye laser from the Photon Science Institute of the University of Manchester will soon complete the setup.

New decay spectroscopy station

Close geometry setup



- Exisiting DSS for α-particle identification.
- New DSS with few C foils, 2 silicon detectors, close geometry for germanium detectors.
- Can be fitted with a tape for β-decay studies.

Beam time request

and requirements from ISOLDE

	Run 1		Run 2
	^{80}Ga	$^{82-84}$Ga	$^{85-87}$Ga
on-line setup	3 shifts		3 shifts
Laser spectroscopy	1 shift	6 shifts	9 shifts
LANDS	4 shifts	3 shifts	3 shifts
TOTAL	18 shifts		15 shifts

Isotope	$T_{1/2}$ [s]	Yields [$/\mu$C]
^{80}Ga	1.7	5.2×10^5
^{81}Ga	1.22	3.2×10^5
^{82}Ga	0.6	5.0×10^4
^{83}Ga	0.31	7.5×10^3
^{84}Ga	0.085	1.3×10^2
^{85}Ga	0.093	2.0×10^1
^{86}Ga	$\sim$ 0.1	2.5×10^0
^{87}Ga	$\sim$ 0.06	

Operation

- UC_x target + n-converter
- RILIS on Ga
- HRS + ISCOOL (50-100 Hz)
- ISOLDE's HPGe detector
- ISOLDE's DigiDAQ

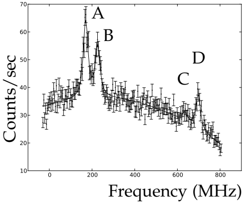
Yields of isobaric Rb & Sr ranges from 10^5 to 10^7 $/\mu$C with protons on target. Those can be suppressed by making use of the neutron-converter to suppress the proton-induced fragmentation cross-section (yielding Rb & Sr) and benefit from neutron-induced fission (producing Ga). Chemical selectivity of a quartz transfer line can alternatively be used to suppress Rb & Sr.

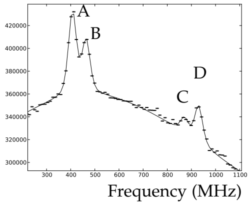
Thanks to its high selectivity, the CRIS experiment does not have high purity requirements. It is however limited in total beam intensity by the acceptance of ISCOOL.

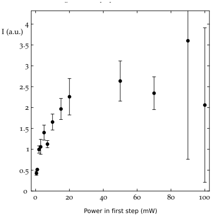
High-resolution test
ABU K RIS

Spring 2013 - High-resolution CW laser test in Atomic Beam Unit with K

- Comparison between fluorescence and RIS.
- Saturation was reached for CW - RIS.
- 25 MHz resolution can be achieved with RIS.







R. de Groote, M.Sc. Thesis, KU Leuven (2013).