Precision mass cartography of the island of inversion

TITAN mass measurement of $^{29,30}\text{Al}$

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Motivation for S1240

view on the island of inversion through $S_{2n}$

$$S_{2n} = m(Z, N - 2) + 2m_n - m(Z, N)$$

![Diagram showing the island of inversion with various elements and their binding energies](image-url)
Returning to the $S_{2n}$ plot, it is interesting to examine the case of $N = 28$ for more exotic nuclides. While the case of Ar is still not determined, Cl would appear to fall victim to the disappearance of the $N = 28$ shell. These masses were obtained from measurements made at GANIL using the SPEG energy-loss spectrometer [Sara00].

The relative strength of the difference in binding energy before and after a purported magic number can be quantified by a quantity defined as the shell gap:

$$\Delta = S_{2n}(Z,N) - S_{2n}(Z,N+2)$$

In the figure (left) the shell gap is plotted versus $Z$ for the cases of $N = 20$ and 28. The prominent features of this plot are the peaks for nuclides having $N = Z$. This shows the exceptional binding of such nuclides due to proton-neutron pairing (sometimes called the Wigner effect). Another peak can be seen for $N = 28$ and $Z = 20$ (the doubly-magic nuclide $^{48}$Ca). The shell gap nicely illustrates the magic number disappearance for $N = 20$, being greatly diminished below $Z = 15$ (to the point of being “quenched” at $Z = 13$) from its nominal value of 4-5 MeV. The unfilled $N = 28$ shell-gap point for $Z = 17$ was obtained from recent mass measurements with SPEG using fragmentation [Jura07]. Such measurements so far from stability are indeed impressive, however the uncertainty associated with the results is unfortunately too large to report the disappearance of the $N = 28$ shell. In fact, the error bars of the $N = 20$ shell gap values for sodium and magnesium do not rule out the possibility of a reincarnation of this magic number! It may well be within the possibilities of nature for the doubly magic $^{26}$O nuclide to exist. A recent reaction mass measurement was performed at MSU for $^{25}$O that highlights the emergence of an $N = 16$ shell [Hoff08] and shows that important theoretical work remains to be done to explain the nuclear binding of this region. It is therefore of great interest to complement this work by a more refined mapping of the shell gap behavior to help further understand the delicate properties on which shell structure rests.
Motivation for S1240

\[ \Delta = S_{2n}(Z,N)-S_{2n}(Z,N+2) \]

\[ N = 20 \]

\[ N = 28 \]

\[ \text{neutron shell gap (MeV)} \]

\[ Z = 10, 12, 14, 16, 18, 20, 22 \]

\[ \text{Proton Number } Z \]


ESPE

\[ N = 20 \]

\[ 16 \]

\[ 20 \]

\[ 0d_{3/2} \]

\[ 1S_{1/2} \]

\[ 0d_{5/2} \]
Motivation for S1240

\[ \Delta = S_{2n}(Z,N) - S_{2n}(Z,N+2) \]

neutron shell gap (MeV)

\[ N = 20 \]

\[ N = 28 \]

reappearance of magic number?

Motivation for S1240

TITAN: Sept. ’09:
MPET Vacuum for HCI

\[ \frac{\delta m}{m} \approx \frac{m}{q \cdot B \cdot T_{RF} \cdot \sqrt{N_{ion}}} \]

\[ ^{39}\text{K}^{4+} @ 5.7 \cdot 10^{-10} \text{ Torr} \]

\[ \begin{array}{|c|c|c|c|}
\hline
T_{rf} & \text{scans} & \Delta \nu & \text{exp } \Delta \nu \\
[ms] & & [Hz] & [Hz] \\
\hline
8 & 100 & 2.607 & \\
197 & 200 & 0.096 & 0.074 \\
497 & 199* & 0.094< & 0.030 \\
\hline
\end{array} \]

\[ \Rightarrow \text{ for further HCI: better vacuum required} \]
MPET baking

3.7 \times 10^{-11} \text{ Torr (on both sides)}
Shorts after baking
**Advantages:**

- 2 independent detection systems
- detector repair without venting MPET
- independent baking possible
Accuracy check

- before beamtime
- $^{39}\text{K}$ vs $^{23}\text{Na}$
- literature: new FSU data

\[ R = R_{\text{meas}} \left(1 + \left(\frac{\Delta R}{R}\right)_{\text{mds}} \Delta A\right) \]

mass dep. shift: 0.8(2) keV over $\Delta A=16$
Accuracy check II:

- $^{27}$Al from ISAC
- use $^{27}$Al to optimize trapping parameters and scale from there for radioactives
- reference: $^{23}$Na

mass dep. shift: 0.3(4) keV over $\Delta A=4$
$^{29}\text{Al}$ complete data:

preliminary
$^{29}$Al complete data:

- 1 Hz, no dip.
- 1 Hz, incomplete dip, but no dip applied.
- 10 Hz, incomplete dip.
- 10 Hz, 47 ms dip cycle (45 ms dip).
- 10 Hz, correct dip.
- 10 Hz, incomplete dip mod. cycle (45 ms dip).

Preliminary
$^{29}$Al complete data:

1 Hz, no dip.

1 Hz, incomplete dip.

10 Hz, incomplete dip.

10 Hz, 47 ms dip cycle but no dip applied.

10 Hz, correct dip.

10 Hz, 47 ms dip cycle (45 ms dip).

1 Hz, correct dip.

$!!?i?$ systematic effect $!!?$

Preliminary
preliminary
• 30,000 ions/sec at the channeltron but hardly anything at MPET MCP (ca. 400 counts in 1/2h)

preliminary
Transfer Efficiency

normal condition:

\[ T_{1/2} = 24 \text{ ms} \]

\~30-300 ions/s

terrible transfer efficiency through RFQ:

- ‘chemistry’ He ↔ Al?
- low pressure in gas bottle \( \rightarrow \) more contamination in gas
- RF problem

• needs further investigation & repair !!!
\\[^{28}\text{Na}\]

- 2,000 ions/sec at the channeltron
- 380 ions in 2 1/2 h

\[\Rightarrow\] we were able to trap
- but no (real) reasonacne

**Info:**
- Ions: 382
- MCA: \([151, 351]\)
- O. error 0.5 [\(\mu s\)]
- Mean TOF 51.4 [\(\mu s\)]
- Rec. time error: 8.814 [\(\mu s\)]
Conclusion

- *after baking, repair & upgrade:* MPET online again
- but serious problems with RFQ transfer efficiency
- mass of $^{29,30}\text{Al}$ measured
TITAN collaboration

- **The TITAN Group**: Jens Dilling, Paul Delheij, Gerald Gwinner, Melvin Good, Alain Lapierre, David Lunney, Mathew Pearson, Ryan Ringle, Maxime Brodeur, Ernesto Mané, Vladimir Ryjkov, Martin C. Simon, Thomas Brunner, Usman Chowdhury, Benjamin Eberhart, Stephan Ettenauer, Aaron Gallant, Vanessa Simon, Mathew Smith

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And the rest of the TITAN collaboration....