Lifetime measurements with fast-timing arrays

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Overview

- Shell structure helps lay out a roadmap of interesting structural features

- Experimentally determined properties described in terms of shell structure

- Large-scale shell model calculations and ab initio calculations (NCSM, IM-SRG, and their merger) have exciting prospects as they move towards expanding our understanding of medium-mass nuclei
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- Shell structure helps lay out a roadmap of interesting structural features

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Shell Evolution

- Many shell model calculations predict a modified shell structure in nuclei away from the $\beta$-stability line.

FRIB Nuclei

- FRIB will enable the study of many exotic nuclei
- Even for nuclei near the extremes of the FRIB production rates, $\beta$-decay studies are a viable means for determining their low-lying properties

M. Thoennessen, Nuclear Data Sheets **118**, 85 – 90 (2014)
Energy Systematics

- Need to go beyond energy systematics to measuring transition strengths and comparing with large-scale theoretical calculations

Lifetimes around the nuclear chart

- A lot of useful information can be determined through measuring lifetimes all throughout the nuclear chart.

M. Thoennessen, Nuclear Data Sheets 118, 85 – 90 (2014)
Lifetimes of proton-rich nuclei

$^{94}\text{Ru},^{96}\text{Pd}$

M. Thoennessen, Nuclear Data Sheets 118, 85 – 90 (2014)
Lifetimes of neutron-rich nuclei

M. Thoennessen, Nuclear Data Sheets 118, 85 – 90 (2014)

Predicted Shape Coexistence in $^{70}\text{Ni}$

- MCSM calculations also predict shape coexistence in $^{70}\text{Ni}$
  - Deepening of the prolate potential well


- $^{68}\text{Ni}$
- $^{70}\text{Ni}$
Fragmentation of a fast-moving, heavy, stable beam on a thin stable target
• $^{76}$Ge beam at ~130 MeV/A
• 282 $\mu$g/cm$^2$ $^9$Be target
NSCL Experiment: Detection Systems

• Use beta decay to populate excited states of exotic nuclei near $A = 68$
• Combine detection systems to simultaneously achieve fast timing information and high-resolution energy measurements

Central Implantation Detectors: Implanted ions from beam and beta decays


Ions identified event-by-event are implanted. Position and arrival time recorded for all implanted ions

Some characteristic time later a decay is detected. Position and time of decay recorded.

• Decays are correlated to ions using spatial and temporal information
• Time scales: Beta decay: $\sim 10^{-3}$ s, Gamma decay: $\sim 10^{-15}$ to $10^{-9}$ s
Central Implantation Detectors: Implanted ions from beam and beta decays


B.P. Crider, C.J. Prokop, S.N. Liddick et al., (in prep.)

$^68\text{Cu}$ $\beta^-$ $^{2+}$ 1077.4 $^{2+}$ 1077.4-keV $\gamma$ ray $^68\text{Zn}$

$^{70}\text{Co}$ \[\beta^-\] \[6^+ \rightarrow 2677\text{ keV} \rightarrow 1.05(3)\text{ ns} \[1\] \rightarrow \[4^+ \rightarrow 2229\text{ keV} \rightarrow \]

$^{70}\text{Ni}$

448-keV $\gamma$ ray

$^{68}\text{Zn}$ 1077 keV $t_{1/2}(\text{lit.}) = 1.61(2)\text{ ps}$

$^{70}\text{Ni}$ 448 keV $t_{1/2}(\text{exp.}) = 1.04(24)\text{ ns}$ $t_{1/2}(\text{lit.}) = 1.05(3)\text{ ns}$

Ni 478 keV $t_{1/2} = 0.57(5)\text{ ns}$

$^{70}\text{Ni}$ 307 keV $t_{1/2} = 1.6^{+1.2}_{-0.8}\text{ ns}$

Lifetime Results

Correlated decays into $^{70}\text{Ni}$
Lifetime Results

\[478 \text{ keV}\]

Lifetime Results

Putting it all together for $^{68,70}$Ni...


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Lifetime of the $0_2^+$ in $^{68}\text{Ni}$

C.J. Prokop, B.P. Crider, S.N. Liddick et al., (in prep.)
Conclusions

• FRIB opens up a large number of nuclei for which $\beta$-decay experiments can provide many details on their low-lying structure.

• Lifetime measurements leading to transition strength determinations are critical for understanding the underlying configurations of excited nuclear states.

• A recent experiment at NSCL coupling fast-timing and high-resolution detection systems has enabled an expansion of the information in $^{68,70}\text{Ni}$. 
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Collaborators

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