DSAM lifetime measurements at ReA

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Evolution of halo properties

- N=8 p-shell
- N=28 pf-shell
- N>40 gds-shell
- N=20 sd-shell
- Island of inversion
- New magic N=16
- \( ^{11}\text{Li}, \ ^{11}\text{Be} \)
- \( ^{19}\text{C}, \ ^{22}\text{C} \)
- Large E1 \( s_{1/2} \)-wave
- Large E2?

T. Nakamura et al., PRL112(14)142501
N. Kobayashi et al., PRL112(14)242501
G. Hagen et al., PRL111(13)132501

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Transition rates (level lifetimes) and halo properties

<table>
<thead>
<tr>
<th>Type of halo</th>
<th>Configuration of valence neutron</th>
<th>B(E1) established</th>
<th>B(M1) - to be established</th>
<th>B(E2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spherical</td>
<td>Pure $s_{1/2} + \text{core (0}^+\text{)}$</td>
<td>○</td>
<td>×</td>
<td>△</td>
</tr>
<tr>
<td>Deformed</td>
<td>Mixed $(sd) or (pf) + \text{core}$</td>
<td>○</td>
<td>○ ¹</td>
<td>○</td>
</tr>
</tbody>
</table>

Large B(E1) – evidence for halo / skin

$^{11}\text{Be} (1/2^+ \rightarrow 1/2^-)$: 0.1 e²fm², 0.36 W.u.

$^{68}\text{Ni} \text{ PDR}: 1.2e^2\text{fm}^2, 1\text{W.u. (5% of EWSR)}$

O. Wieland et al., PRL102(09)092502

One of the most hindered M1 strengths found for one neutron halo nucleus $^{19}$C.

A comparison with shell model calculations suggests the s-wave prevalence in both the ground ($1/2^+$) and excited ($3/2^+$) states in $^{19}$C, characteristic of halo structure, causes a diminished magnetic response.

$^{17}$C: D.Smalley, H.Iwasaki, P.Navratil, R.Roth et al., effects of 3NF, continuum in NCSM(C), submitted

Evolution of halo properties

N=8 p-shell

N=28 pf-shell

N>40 gds-shell

E0, E? Efimov?

11Li, 11Be

19C, 22C

Large E1 s1/2-wave

Large E2 p-wave

N=20 sd-shell

island of inversion

new magic N=16

T.Nakamura et al., PRL112(14)142501
N.Kobayashi et al., PRL112(14)242501
G.Hagen et al., PRL111(13)132501

11Be

62Ca?
Evolution from stable Sn to exotic Ca

Lowering of the $3S_{1/2}$ state near the dripline?

![Diagram showing the energy level diagram with states and labels, including $60^{Ca}$, $2S_{1/2}$, $1S_{1/2}$, and N>40 gds-shell.]

A.Ozawa et al., PRL84(00)5493, C.R.Hoffman et al., PRC89(14)061305(R)
Level Schemes in N=69 isotones

$^{17}$C, $^{19}$C
($Z=6,N=11,13$) → $^{117}$Sn, $^{119}$Sn ($Z=50, N=67,69$)
$^{115}$Cd, $^{117}$Cd ($Z=48, N=67,69$)
$^{107}$Zr, $^{109}$Zr ($Z=40, N=67,69$)

$I$-forbidden M1 transitions and pseudospin symmetry, P. von Neumann-Cosel, J.N.Ginocchio, PRC62 (00) 014308
Level Schemes in N=67 isotones

\[ ^{17}\text{C},^{19}\text{C} \quad (Z=6,N=11,13) \rightarrow \quad ^{117}\text{Sn}, \quad ^{119}\text{Sn} \; (Z=50, \; N=67,69) \]

\[ ^{115}\text{Cd}, \quad ^{117}\text{Cd} \; (Z=48, \; N=67,69) \]

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Forbidden M1 transitions and pseudospin symmetry, P. von Neumann-Cosel, J.N. Ginocchio, PRC62 (00) 014308
Direct reactions \((p,d),(d,p)\) … with ReA beams + DSAM

- Measure recoils (energy, angle) – tag reactions, Q value
  \((p,d) \, Q = -8\text{MeV} \, (\text{ReA9-A12}) : \, (d,p) \, Q>0\text{MeV} \, (\text{ReA6})

- Momentum matching – selective to specific states \((l)\)
DSAM with GRETINA at ReA in inverse kinematics – to measure sub-\(\mu s\) lifetimes of exotic nuclei

\[118\text{Sn}(p,d) \text{ at } 10\text{AMeV}\]

\[117\text{Sn}\]

Target stopper

50\(\mu\)m 20\(\mu\)m

CH\(_2\) Ta

1000keV

200keV

117\(\text{Sn}\)

ReA3 upgrade workshop
300 counts in one experiment
- $10^5$ beam $\times$ 1 mb (or $10^4$ beam $\times$ 10 mb)

Physics opportunities:
- I-forbidden M1 measurement (pseudospin partners)
- E2 transitions (for higher-lying states, symmetries)
- Collective M1, E3 transitions
Summary

- Spectroscopy and lifetime measurements at ReA6/ReA9/Re12 (above Coulomb barrier) are discussed.

- The behavior of the 3s orbital is discussed as a key observable to investigate the shell evolution from stable Sn to exotic Ca.

- As a possible probe, sub-ps lifetime measurements based on DSAM technique with ReA beams are proposed to study the l-forbidden M1 transitions. Similar experimental approaches can be used in various spectroscopic studies on low-lying structure of exotic nuclei.
Thank you, and...
This workshop will be the kickoff for a whitepaper outlining the science opportunities at the ReA facility. All speakers and those who are interested are invited to send a 1-page document describing their science interests.

Schedule:

August 20  ReA3 upgrade workshop
August 31  organizer(s) will contact with you
September 30  deadline for the 1-page draft
November 30  first draft for whitepaper
January, 2016  final version

Presentation slides and any updates for whitepaper preparation, ReA project, etc will be posted at

https://people.nscl.msu.edu/~iwasaki/rea6.html
Outline of the whitepaper (tentative)

- Introduction and Executive Summary

- Physics Opportunities at ReA ← discussed today in workshop
  - Structure of exotic nuclei
    shell and shape evolution, collective phenomena, high-spin states, nuclear clustering, weakly-bound system
  - Reaction dynamics at and above Coulomb barrier
    fusion, direct reactions, multi-fragmentation, isospin equilibration (EOS)
  - Heavy and super-heavy element studies
    multi-nucleon transfer reactions, chemical studies of neutron-rich SHEs
  - Nuclear astrophysics
    transfer reactions, ANC,
  - other applications
    particle emission of compound nuclei, photon strength function, …

- ReA6/ReA9/ReA12 facility
  - conceptual design
  - possible ideas for major equipment
  - cost estimates and time lines for the ReA and associated infrastructure
Thank you