Evolution of Neutron hole states in N=50 closed shells

$^{84}\text{Se}(p,d)^{83}\text{Se}$
$^{86}\text{Kr}(p,d)^{85}\text{Kr}$

Beam time: 19$^{\text{th}}$ - 28$^{\text{th}}$ May, 2010

Experiment # 06035: HiRA group

• $^{56}\text{Ni}(p,d)^{55}\text{Ni}$
• $^{56}\text{Ni}(d,3\text{He})^{55}\text{Co}$

Beam time: 1$^{\text{st}}$ - 10$^{\text{th}}$ June, 2010

Evolution of neutron (p,d) and proton (d,3He) hole states in the “doubly” magic nucleus $^{56}\text{Ni}$
Physics goal:

**Spectroscopic factor (SF):** quantifies the nature and occupancy of the single particle orbits in a nucleus.

- $^{56}\text{Ni}(p,d)^{55}\text{Ni} \rightarrow$ Measurement of Neutron SF factor of $^{56}\text{Ni}$
- $^{56}\text{Ni}(d,^3\text{He})^{55}\text{Co} \rightarrow$ Measurement of Proton SF factor of $^{56}\text{Ni}$

SF from Independent Particle Model = 8

$$SF = \left(\frac{d\sigma}{d\Omega}\right)_{Exp} \div \left(\frac{d\sigma}{d\Omega}\right)_{RM}$$

We will answer the question:
Is $N=Z=28$ closed shell?
• $^{56}\text{Ni}(p,d)^{55}\text{Ni} \rightarrow$ Beam energy 35 MeV/A data exists (Expt # 05133; thesis Alisher)

• New measurement at 75 MeV/A to look for the energy dependence of SF

• $^{56}\text{Ni}(d,3\text{He})^{55}\text{Co} \rightarrow$ New Measurement

• Neutron SF & Proton SF are same?
Experimental set up

- Beam energy: 75 MeV/A

Detect light particles (p,d,t, $^3$He) in HiRA

Detect residues in S800

Tower configuration:
- DE+E+CsI in each telescope
- 20 telescopes and 5 towers
- target – HiRA distance: 50 cm

-- Two MCP separated by 40 cm for beam tracking
- MCP1 to target distance 10 cm
Kinematics

Ni$_{56}$(p,d)$_{55}$Ni

Cross section (mb/sr)

Lab angle (deg)

Ni$_{56}$(d,3He)$_{55}$Co

Cross section (mb/sr)

Lab angle (deg)

HiRA Efficiency

Efficiency

$\theta$ (lab)

Total energy (MeV)

Lab angle (deg)
Punch through

E = 80 MeV/A

Lab angle (deg)

Total energy (MeV)

Punch thru for $^3$He in dE

Punch thru for $^2$H in E

Punch thru for $^3$He in dE

HiRA Efficiency

HiRA punch through summary

<table>
<thead>
<tr>
<th>Particle</th>
<th>65 micron dE Si (MeV)</th>
<th>1.5 mm E Si (MeV)</th>
<th>4 cm CsI (MeV)</th>
<th>Loss in Si (1.5 mm) (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>p</td>
<td>2.45</td>
<td>15.6</td>
<td>115.8</td>
<td>1.84</td>
</tr>
<tr>
<td>d</td>
<td>3.17</td>
<td>20.9</td>
<td>154.8</td>
<td>2.48</td>
</tr>
<tr>
<td>t</td>
<td>3.68</td>
<td>24.8</td>
<td>183.4</td>
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<td>$^3$He</td>
<td>8.72</td>
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<td>411.1</td>
<td>6.53</td>
</tr>
</tbody>
</table>
Energy deposited by the particles in HiRA

For 3He Etot @ 45 deg ~ 22 MeV
Loss in dE ~ 3MeV
No dE in telescope position 10 & 15
Efficiency without telescopes in position 10 & 15
### 56Ni(d,3He)55Co

<table>
<thead>
<tr>
<th>$E_{\text{level}}$ (keV)</th>
<th>$J\pi$</th>
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<tbody>
<tr>
<td>0.0</td>
<td>7/2-</td>
</tr>
<tr>
<td>2165.89</td>
<td>3/2-</td>
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<tr>
<td>2089</td>
<td></td>
</tr>
<tr>
<td>2462</td>
<td></td>
</tr>
<tr>
<td>2839</td>
<td></td>
</tr>
<tr>
<td>2882.1</td>
<td>11/2-</td>
</tr>
<tr>
<td>3185.6</td>
<td>1/2+</td>
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### 56Ni(p,t)54Ni

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<td>0+</td>
</tr>
<tr>
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<td>2+</td>
</tr>
<tr>
<td>2000</td>
<td></td>
</tr>
</tbody>
</table>
1st peak at 75 MeV/A beam → 10-40° → ~7-15 MeV of $^3$He

Energy loss of 15 MeV $^3$He in 65 micron Si ~ 4 MeV

Maximum energy to be measured in E ~ 11 MeV

Punch-through energy of $^3$He in dE = 8.8 MeV
Punch-through for E is ~55 MeV
## HiRA punch through summary

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<td>4He</td>
<td>9.69</td>
<td>62.1</td>
<td>462.3</td>
<td>7.34</td>
</tr>
<tr>
<td>6He</td>
<td>11.21</td>
<td>74.0</td>
<td>548.3</td>
<td>8.72</td>
</tr>
<tr>
<td>8He</td>
<td>12.36</td>
<td>83.6</td>
<td>619.1</td>
<td>9.89</td>
</tr>
</tbody>
</table>
Cross section (mb/sr)

56Ni(d,3He)55Co

CM angle (deg)
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<tr>
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</tr>
<tr>
<td>2165.89 5</td>
<td>3/2−</td>
</tr>
<tr>
<td>2665.85 3</td>
<td>3/2−</td>
</tr>
<tr>
<td>2699.48 6</td>
<td>5/2−</td>
</tr>
<tr>
<td>2910.50 6</td>
<td>7/2−</td>
</tr>
<tr>
<td>2922.25 12</td>
<td>1/2+</td>
</tr>
<tr>
<td>2939.16 8</td>
<td>1/2−</td>
</tr>
<tr>
<td>2960.1 4</td>
<td></td>
</tr>
<tr>
<td>2973.47 20</td>
<td>11/2−</td>
</tr>
<tr>
<td>2976.34 18</td>
<td>9/2−,(7/2)</td>
</tr>
<tr>
<td>2990 80</td>
<td>(3/2)−</td>
</tr>
<tr>
<td>3305.11 7</td>
<td>5/2−</td>
</tr>
<tr>
<td>3323.23 10</td>
<td>1/2−</td>
</tr>
</tbody>
</table>

Alisher’s expt
To Do: Before Experiment:

- Alpha source calibrations of E
- Alpha source calibrations of DE
- Pin source calibration of E
- Pulser ramp calibration of DE, EF, EB and CsI
- Optical Alignment with cross-hair to determine the position of the reaction target and MCP target/Mask – chamber installation
- TDC (S800 and MCP) calibrations
- Pulser ramp for MCP/QDC to match the high gain and low gain.
To Do: After Experiment:

- Position measurement of HiRA, target and MCP foil + Mask using romar arm
- Position measurement of target and MCP foil + Mask using LBAS and references
- Alpha source calibrations of DE
- Pin source calibration of E
- Take out DE, do alpha source calibrations of EF and EB
- Pulser ramp calibration of DE, EF, EB and CsI
- TDC (S800 and MCP) calibrations
- Pulser ramp for MCP/QDC to match the high gain and low gain
To Do: During Experiment:

- Data Run
- Unreacted Beam (also whether the A1900 setting is changed)
- CDRC mask calibration (CRDC1 and 2)
- Reaction target mask (5 holes) calibration
- MCP mask calibration (defocused beam, if it takes a while to tune the beam, then just move the MCP mask for more hole coverage)
- Alpha calibration when there is no beam
- Background measurement at the end of experiment
- Magicity of $^{48}\text{Ca}$ suggests good closed shell.
- Recent measurement of magnetic moment of $^{57}\text{Cu}$ implies shell breaking of N=28 in the core.
Magicity of $^{42}$Si suggests that N=28 is a good closed shell

Nuclear Magnetic Moment of the $^{57}$Cu Ground State

K. Minamisono,$^{1}$ P. F. Mantica,$^{1,2}$ T. J. Mertzimekis,$^{1}$ A. D. Davies,$^{1,3}$ M. Hass,$^{4}$ J. Pereira,$^{1}$ J. S. Pinter,$^{1,2}$ W. F. Rogers,$^{5}$ J. B. Stoker,$^{1,2}$ B. E. Tomlin,$^{1,2}$ and R. R. Weerasiri$^{1,2}$

$^{1}$National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824, USA
$^{2}$Department of Chemistry, Michigan State University, East Lansing, Michigan 48824, USA
$^{3}$Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824, USA
$^{4}$Department of Particle Physics, Weizmann Institute, 76100 Rehovot, Israel
$^{5}$Department of Physics, Westmont College, Santa Barbara, California 93108, USA

(Received 21 December 2005; published 17 March 2006)

The nuclear magnetic moment of the ground state of $^{57}$Cu($I^\pi = 3/2^-$, $T_{1/2} = 196.3$ ms) has been measured to be $|\mu(^{57}\text{Cu})| = (2.00 \pm 0.05)\mu_N$ using the $\beta$-NMR technique. Together with the known magnetic moment of the mirror partner $^{57}$Ni, the spin expectation value was extracted as $\langle \Sigma \sigma_z \rangle = -0.78 \pm 0.13$. This is the heaviest isospin $T = 1/2$ mirror pair above the $^{40}$Ca region for which both ground state magnetic moments have been determined. The discrepancy between the present results and shell-model calculations in the full $f_{p}$ shell giving $\mu(^{57}\text{Cu}) = 2.4\mu_N$ and $\langle \Sigma \sigma_z \rangle \sim 0.5$ implies significant shell breaking at $^{56}$Ni with the neutron number $N = 28$.

M measurement of the nuclear magnetic moment of the ground state of $^{57}$Cu which could be viewed as a valence proton outside a closed $^{56}$Ni core suggests significant shell breaking of N=28 in the core.
To do: 30th April

1. Alpha source test: Dan, Zibi, Bill
2. Fix the dE motherboard and chip: Dan
3. Get the CsI ribbon cable: Mike
4. Making the CsI cable: Mike
5. Put CsI shaper into HiRA lab and test: Ali
6. Bias cable adaptar
7. Protector circuit hook up to interlock system: Tilak/Mike
8. Clear up and check grounding: Bill
9. Close up the PLC box, check the readout with cables: Mike/Bill
10. Reshiled the dE cables: Patrick/Tilak
11. Install the other HiRA telescope: Tilak & Ali
12. Put dE motherboards/preamp at the top of the chamber and test with pulser
13. Make 34 Pin male to male cable: Mike
14. Make decision on gain setting for dE & E: Tilak, Betty