Studio della forza di pairing nel meccanismo di trasferimento di neutroni con lo spettrometro MAGNEX

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Particle-Particle correlations in nuclei

Pairing Vibrations

Strong excitation of the $0^+$ ground states

Harmonic behaviour of the excitations

Eigenstates of a general harmonic oscillator in a gauge space with $\Delta N = \pm 2$ and $\Delta L = 0$

Analogy between shape and pairing vibrations

- (p,t) and (t,p) reactions on Sn and Pb targets

$\Delta N = -2 \quad \Delta N = +2$


Particle-Particle correlations

Analogy between p-h, p-p and h-h excitations

Collective p-h excitations ➔ Giant Resonances

Collective p-p or h-h excitations ➔ Giant Pairing Vibrations (GPV)

Predicted properties of the GPV (heavy nuclei)

- Excitation Energy ~ 15 – 20 MeV
- FWHM ~ 7.8 A^{-1/3}
- Collective nature
- L = 0 angular momentum transfer

Recent theoretical studies on light nuclei

- E.Khan et al., PRC 69, 014314 (2004)
- B.Avez et al., PRC 78, 044318 (2008)

NEVER OBSERVED
The role of the reaction mechanism

- **GPV** requires $L = 0$ transfer!

- In transfer reactions typically **large amount of** linear and **angular momentum is transferred**
The role of the incident energy

Near the Coulomb barrier the angular momentum transfer is minimized

Drawback:

1. The angular distributions are peaked at the grazing angle and are not sensitive to the structure of the populated states
2. Q-value matching rules typically suppress the cross section at high excitation energy where the GPV is expected

At high incident energy the mechanism is characterized by a large amount of angular momentum transfer and by deep inelastic collisions

At energies between 5 and 10 times the Coulomb barrier the angular distributions are sensitive to the final populated states

The role of the involved nuclei

• **Brink’s matching conditions**  
  
  \[ \Delta k = k_0 - \lambda_1 / R_1 - \lambda_2 / R_2 \approx 0 \]
  \[ \Delta L = \lambda_2 - \lambda_1 + \frac{1}{2} k_0 (R_1 - R_2) + Q_{\text{eff}} R / \hbar \nu \approx 0 \]
  
  \[ l_1 + \lambda_1 = \text{even} \]
  \[ l_2 + \lambda_2 = \text{even} \]

  \[ k_0 = mv / \hbar \]
  \[ Q_{\text{eff}} = Q - (Z_1^{f} Z_2^{f} - Z_1^{i} Z_2^{i}) \]

• The survival of a **preformed pair** in a transfer process is favored when the initial and final orbitals are the same
The $^{13}\text{C}(^{18}\text{O},^{16}\text{O})^{15}\text{C}$ reaction at 84MeV

$^{18}\text{O}^6+$ Tandem beam at $E_{inc} = 84$ MeV (7.5 times above the Coulomb barrier)

$^{13}\text{C}$ self-supporting target 99% enriched, thickness 50 µg/cm$^2$

$^{16}\text{O}$ ejectiles momentum analysed by the MAGNEX spectrometer (LNS – Catania)

Three angular settings ($\Omega \sim 50$ msr) \[\theta = 3^\circ \div 13^\circ \]
\[\theta = 7^\circ \div 19^\circ \]
\[\theta = 13^\circ \div 25^\circ \]
### Main features

<table>
<thead>
<tr>
<th></th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum magnetic rigidity</td>
<td>1.8 T m</td>
</tr>
<tr>
<td>Solid angle</td>
<td>50 msr</td>
</tr>
<tr>
<td>Momentum acceptance</td>
<td>± 13%</td>
</tr>
<tr>
<td>Momentum dispersion for $k = -0.104$ (cm/%)</td>
<td>3.68</td>
</tr>
<tr>
<td>First order momentum resolution ( R_p = \frac{D}{M \Delta x} )</td>
<td>5400</td>
</tr>
</tbody>
</table>

### Measured resolution

- Energy $\Delta E/E \sim 1/1000$
- Angle $\Delta \theta \sim 0.3^\circ$
- Mass $\Delta m/m \sim 1/160$

**MAGNEX**

**Algebraic trajectory-reconstruction**

**Scattering Chamber**

**Quadrupole**

**Dipole**

**Focal Plane Detector**
Particle Identification Technique

$^{18}\text{O} + ^{13}\text{C}$ reaction at 84 MeV and scattering angle of $\theta_{\text{lab}} = 7^\circ - 19^\circ$

$B \rho \propto \frac{p}{q}$
Comparison of different reaction channels for $^{18}\text{O} +^{13}\text{C}$ at 84 MeV

$7^\circ < \theta_{\text{lab}} < 13^\circ$

Enhancement of the two-neutron stripping channel

Relevant contribution of the direct transfer of the neutron pair

Efficiency for the production of different charge states estimated using the program INTENSITY
J.A.Winger et al., NIM B70(1992) 380-392
Reconstructed angle%energy

\[ \tilde{X}_i = (x_i, \theta_i, y_i, \phi_i, l_i, \delta_i) \]

One gets

\[ \begin{cases} 
\theta_{lab} & \text{Scattering angle} \\
E_{ecc} & \text{Excitation energy} 
\end{cases} \]

\(^{16}\text{O angle % energy spectrum}\)
Enhancement of the known \( L = 0 \) transition (state at 3.103 MeV) and of the 11 MeV bump

\[ ^{13}\text{C}(^{18}\text{O},^{16}\text{O})^{15}\text{C} \]

\[ 4.5 < \theta_{\text{lab}} < 7 \]

\[ ^{13}\text{C}(^{18}\text{O},^{16}\text{O})^{15}\text{C} \]

\[ 9 < \theta_{\text{lab}} < 12 \]

Comparison of the angular distributions

State at $E_x = 11$ MeV

$^{13}$C$_{gs}$ (1/2$^-$) $^{(18}$O $^{16}$O)$^{15}$C$_{3.103}$ (1/2$^-$) \hspace{1cm} L = 0

$^{13}$C$_{gs}$ (1/2$^-$) $^{(18}$O $^{16}$O)$^{15}$C$_{gs}$ (1/2$^+$) \hspace{1cm} L = 1

$^{13}$C$_{gs}$ (1/2$^-$) $^{(18}$O $^{16}$O)$^{15}$C$_{6.84}$ (7/2$^-$/9/2$^-$) \hspace{1cm} L = 4

$^{13}$C($^{18}$O,$^{16}$O)$^{15}$C at 84 MeV, $\theta_{sc} = 7^\circ \pm 18^\circ$

- 3.1 MeV $L = 0$
- 6.84 MeV $L = 4$
- 12.9 MeV
Transfer experiments on different targets

\[ ^9\text{Be}, \ ^{11}\text{B}, \ ^{12,13}\text{C}, \ ^{28}\text{Si}, \ ^{58,64}\text{Ni}, \ ^{128}\text{Sn}, \ ^{208}\text{Pb} \]

- Absolute horizontal position calibration of the FPD
- Relative calibration of the pads for the horizontal position measurement
- Absolute vertical calibration (drift time)
- Relative calibration of the silicon detectors energy
- Identification of \(^{16}\text{O}^{8+}\) ions at the FPD
- Representation in the focal plane parameters \((X_{\text{foc}}, \theta_{\text{foc}}, Y_{\text{foc}}, \phi_{\text{foc}})\)
- Construction of the spectrometer transport matrix
Preliminary spectrum of $^{11}\text{Be}$

$^9\text{Be}(^{18}\text{O},^{16}\text{O})^{11}\text{Be}$
$^{12}\text{C}(^{18}\text{O},^{16}\text{O})^{14}\text{C}$

$\Theta_{\text{lab}} = 8^\circ$

$^{18}\text{O}$ beam 84 MeV

$^9\text{Be}$ target 114 $\mu$g/cm$^2$ + collodion 6 $\mu$g/cm$^2$

Counts

$^{11}\text{Be}$ excitation energy (MeV)

$^9\text{Be}$ target

$^{12}\text{C}$ target
Preliminary spectrum of $^{13}\text{B}$

$^{18}\text{O}$ beam 84 MeV

$^{11}\text{B}$ target 33 $\mu$g/cm$^2$ + Formvar 4 $\mu$g/cm$^2$

$^{12}\text{C}$ target 50 $\mu$g/cm$^2$

Contribution due to carbon impurities subtracted
$^{64}\text{Ni}(^{18}\text{O},^{16}\text{O})^{66}\text{Ni}$

PRELIMINARY

$^{64}\text{Ni}(^{18}\text{O},^{16}\text{O})^{66}\text{Ni}$

$E_{\text{beam}} = 84 \text{ MeV}$

$\Theta_{\text{lab}} \approx 18^\circ$

Max $E^* 28 \text{ MeV}$

$12^\circ < \Theta_{\text{lab}} < 24^\circ$
MAGNEX + EDEN

MAGNEX to measure high resolution energy spectra for well identified reaction products

EDEN to study the decaying neutrons emitted by the observed resonances with good efficiency and energy resolution

Unique facility to study the resonant states of neutron rich nuclei (low separation energy)
Memorandum Of Understanding

Proposal at the LNS PAC for the commissioning

\[ \text{\12C}^{(\text{18O}, \text{17O})} \text{\13C} \]

\[ \text{\16O}^{(\text{18O}, \text{17O})} \text{\17O} \]

\[ \text{\13C}^{(\text{18O}, \text{16O})} \text{\15C} \]

To setup electronics and study efficiency and resolution

2 neutron coincidences
Conclusions and outlooks

A broad resonance observed in $^{15}\text{C}$ spectrum populated via $(^{18}\text{O},^{16}\text{O})$ at 84 MeV

Compatible with GPV?

Analysis of the angular distributions in progress

Break-Up calculations will be done to study the continuum background (TDSE)

Different targets ($^{9}\text{Be}$, $^{11}\text{B}$, $^{28}\text{Si}$, $^{58}\text{Ni}$, $^{66}\text{Ni}$, $^{120}\text{Sn}$, $^{208}\text{Pb}$) explored via $(^{18}\text{O},^{16}\text{O})$, data analysis in progress
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