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Workshop on Pairing Degrees of Freedom in Nuclei and the Nuclear Medium

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Motivation

N=Z nuclei, unique systems to study \( np \) correlations

As you move out of N=Z \( nn \) and \( pp \) pairs are favored

Role of isoscalar (\( T=0 \)) and isovector (\( T=1 \)) pairing

Large spatial overlap of \( n \) and \( p \)

Pairing vibrations (normal system)

Pairing rotations (superfluid system)

Does isoscalar pairing give rise to collective modes?

What is (are) the “smoking-gun(s)”?

Binding energy differences

Ground states of odd-odd self-conjugate nuclei

Rotational properties: moments of inertia, alignments

Two-particle transfer cross-sections
NOTE ON THE TWO-NUCLEON STRIPPING REACTION

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Received 9 February 1962

Abstract: The magnitude of the two-nucleon stripping reactions is calculated using the pairing interaction model. The calculation also is applied to final states of collective type. For some types of reaction a collective enhancement of the reaction cross section is predicted.
PAIR CORRELATIONS AND
DOUBLE TRANSFER REACTIONS

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ISOVECTOR PAIRING VIBRATIONS

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Two nucleon transfer reactions

Generalized densities $a+a^+$, $aa$ represent the pair field and in close analogy to the collective excitations corresponding to the ordinary density, they can give rise to collective modes.

Two particle transfer reactions like $(t,p)$ or $(p,t)$, where 2 neutrons are deposited or picked up at the same point in space provide an specific tool to probe the amplitude of this collective motion. The transition operator $\langle f|a^+a^+|i\rangle$ will be proportional to the pair density of the nucleus.

$$\Delta = G \langle \sum a^+_v a^+_\bar{v} \rangle$$
Collective pairing vibrations near closed shells

Collective excitations have a phonon-like spectrum

\[ \Omega G / D < 1 \]

\[ \hbar \omega \sim D \left(1 - x\right)^{1/2} \]

\[ x = \frac{G}{G_{\text{crit}}} \]
Study binding energies around closed shells ($^{56}\text{Ni}$)

$T=0$ Energy comparable with single particle separation - low collectivity.

$T=1$ Energy consistent with collective excitations.
Measure the $np$ transfer cross section to $T=1$ and $T=0$ states

Both absolute $\sigma(T=0)$ and $\sigma(T=1)$ and relative $\sigma(T=0) / \sigma(T=1)$ tell us about the character and strength of the correlations.
n-p Pair Transfer Probability

$G^{T=1} = 0.33 \text{ MeV}$

Single Particle Energies $^{57}\text{Ni}$ Levels

- $T=1$ Pair Transfer
- $T=0$ Pair Transfer

Initial State $<^{56}\text{Ni} Q=1 |$

Final State $<^{58}\text{Cu} Q=1 |$

Final State $<^{58}\text{Cu} Q=2 |$

R. Chasman
$^{40}\text{Ca}(^{3}\text{He},p)^{42}\text{Sc} \ 200\text{MeV}$

$\theta_{\text{lab}}$ (degrees)

$L=0$ transfer
Study of the $^{56}\text{Ni}(d,p)^{57}\text{Ni}$ Reaction and the Astrophysical $^{56}\text{Ni}(p,\gamma)^{57}\text{Cu}$ Reaction Rate

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\[ \sim 10^5 \text{ /sec} \]
From ATLAS

Degrader 10mg/cm²

\[ ^{56}\text{Ni} \xrightarrow{\text{Reaction}} ^{58}\text{Cu} \]

\[ ^{3}\text{He} \]

Si detector 500µ
16x16 ~1sr

Gas cell ~100µg/cm²

20 counts/day
Proof of principle

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$^{40}\text{Ca}(^3\text{He},p)$ @ 220 MeV

Raw

FMA Gated

[Graph showing energy spectra and labels for various isotopes such as $^{39}\text{Si}$, $^{39}\text{Ar}$, $^{39}\text{S}$, $^{40}\text{Ca}$, with peaks labeled as $0^+$, $1^+$, and $0^+(3^+)$.]
What is our reference?

Single-particle estimate $\sim (\text{spin})x(^3\text{He})x(\text{LS} \rightarrow jj)$
Systematic of \(^3\text{He},p\) and \((t,p)\) reactions in stable N=Z nuclei

![Graph showing systematic of \(^3\text{He},p\) and \((t,p)\) reactions in stable N=Z nuclei.](image)
Ratios using both (t,p) and (3He,p). The blue line is the sp estimate assuming that the j2 configuration varies from an s1/2 to a j>>1
Summary and Conclusions

- **Ground State Binding Energies (pair gaps)**
- **Energies of T=0 T=1 in N=Z nuclei**
- **Excitation spectra near shell gaps (pair vibrations)**

Evidence for full isovector T=1 pairing (nn,np,pp) - charge independence.

BE differences can be described by an appropriate combination of the symmetry energy and the isovector pairing energy.

No evidence for a T=0 deuteron-like pairing condensate in N=Z nuclei. The T=0 states in an odd-odd N=Z nucleus can be characterized as a seniority 2 state (as in any other odd-odd nucleus).

**Inverse kinematics - Successful test with stable beams**

**Next step - Measure “collectivity” with transfer reactions (^3He,p)**

Approved ATLAS runs with ^44Ti and ^56Ni beams

“Role of pairing phonons near ^40Ca and ^56Ni”
And looking ahead