Search for isospin effects on nuclear level density

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Why is it important to study the level density?

Level density is a basic ingredient for x-section calculations.

Astrophysical processes

“Astrophysical Reaction Rates from Statistical Model Calculations”, ADNDT 75 (2000) 1-351

SHE’s production

\[ \sigma_{ER} = \sigma_{capture} \cdot P_{CN} \cdot P_{surv} \]

Capture of two nuclei in the attractive potential pocket.

Probability of forming a compact compound nucleus (CN).

Survival probability against fission.

Fluctuation-dissipation dynamics: Fokker-Plank or Langevin equations

Evaporative process: Statistical Model
Study of isospin effects on level density through fusion-evaporation reactions

\[ P(U_0, J_0, \varepsilon, l, U, J) \propto \rho(U, J) \cdot T_l(\varepsilon) \]

\[
\rho(U) = \frac{1}{12\sqrt{2}} \frac{1}{\sigma a^{1/4}} \frac{\exp[2\sqrt{a(U-\delta)}]}{(U-\delta)^{5/4}}.
\]

\[
\rho(U, J) = \frac{(2J+1)}{2\sigma^2} \exp\left[-\frac{(J+\frac{1}{2})^2}{2\sigma^2}\right] \rho(U).
\]

Angular momentum, Pairing & Shell effects ...

Isospin (?)

Isospin can affect two quantities:

- Level density parameter \( a \)
- Symmetry Energy
Effects on level density parameter $a$

Are the level densities for $r$- and $rp$-process nuclei different from nearby nuclei in the valley of stability?

S. I. Al-Quraishi, S. M. Grimes, T. N. Massey, and D. A. Resler

$$\rho(U) = \frac{\sqrt{\pi} \exp(2\sqrt{aU})}{12 a^{1/4} U^{-5/4}}.$$  

Best fit: 241 nuclei  
$E_x$ up to 7 MeV  
$20 < A < 110$ ENSDF

Form A: $a = \alpha A$
Form B: $a = \alpha A / \exp[\beta(N-Z)^2]$.
Form C: $a = \alpha A / \exp[\gamma(Z-Z_0)^2]$.

Strong support from recent L.D. calculations

Z-Zo dependence: better reproduction of data

Strong implications in nuclear astrophysics
Search for clues of isospin effects in 180 MeV $^{32}$S + $^{107}$Ag reaction

126 Si- CsI Telescopes (E-DE & PSD)

8πLP apparatus at LNL (Legnaro – Italy)
$^{32}\text{S} + ^{107}\text{Ag} \rightarrow E_{\text{LAB}} = 180 \text{ MeV}: \text{data against SM simulations}$

Code Lilita_N97; Optical model transmission coefficient; level density from Al-Quraishi et al.

**Multiplicity distribution of alpha particles**

No evidence of Z-Zo effects – No possible to discriminate between st. and N-Z

**$\alpha$ energy spectrum**

Al Quraishi parameters are not appropriate for this Ex (?)
Need of a systematic study with RIB at different $E_x$, N-Z, Z-Zo

SPES – SPIRAL2 can offer this opportunity:

- Observables: multiplicities, energy spectra, ER-lp angular correlations, ER yield.

- Reactions on $^4$He: low angular momentum effects, possibility to produce CN starting from low Ex ($\sim 20$ MeV).

- Possible reactions:
  $^{76}$Cu, $^{79}$Zn, $^{84}$Ge, $^{94}$Rb, $^{120}$Ag, $^{124}$Cd, $^{128}$In, $^{134}$Sn, $^{144}$Cs
  + $^4$He

$E_{lab} \sim 3 \text{ – } 10 \text{ MeV/A}; \ E_x \sim 20 \text{ – } 50 \text{ MeV}; \ \sigma_{\text{FUS}} \sim 0.2 \text{ – } 1 \text{ barn}$
SM predictions for n-rich nuclei

**84Ge + 4He**

- Increasing $E_x$
  - $E_x = 20$ MeV
  - $E_x = 60$ MeV

**134Sn + 4He**

- $E_x = 20$ MeV
ER yields at $E_x = 80$ MeV

$^{84}$Ge + $^4$He

$^{134}$Sn + $^4$He

N-Z  Z-Zo
Why is it important to study the symmetry energy?

\[ E_{\text{sym}} = b_{\text{sym}}(T)(N-Z)^2/A \]

- As a part of the nuclear Equation Of State it may influence the mechanism of Supernova explosion
- General theoretical agreement on its temperature dependence (LRT+QRPA vs. large scale SMMC)
- Effects enhanced by the intrinsic isospin dependence of \( E_{\text{sym}} \)

Fusion-evaporation reactions: \( E_{\text{sym}} \) affects the particle B.E.
Framework: Dynamical Shell Model

Hartree-Fock
Coupling single particle states to surface vibrations

Nucleon effective mass

\[ m^* = \frac{m_k m_\omega}{m} \]

\[ m_\omega(T) \quad 0 < T < 3 \text{ MeV} \quad -^{98}\text{Mo}, \quad ^{64}\text{Zn}, \quad ^{64}\text{Ni} \]

-LRT – QRPA

Decrease of the effective mass \( \frac{\partial}{\partial T} \)
Increase of \( E_{\text{sym}} \)

\[ E_{\text{sym}}(T) = b_{\text{sym}}(T) \times \frac{(N-Z)^2}{A} \]

\[ a \propto m^* \]

Good reproduction of data
Level density parameter $a(T)$

\[ a = \frac{A}{k} \]

\[ a(T) = a(T = 0) \frac{m_\omega(T)}{m_\omega(T = 0)} \]

Inclusion of $E_{sym}$ and $a(T)$ in Lilita_N97
SM predictions for exotic nuclei (RIB + $^4$He)

Icp channels are open assuming Esym+a(T) effects
Energy spectra

$^{120}\text{Ag} + ^4\text{He}$

neutrons

protons

alpha particles

Very low cross section
n spectral shapes

Importance to select $xn$ channels

The Yield of ER plays an important role
ER yields

120Ag E_sym + a(T)

Counts

N

Z

45 46 47 48 49 50 69 70 71 72 73 74

100000 10000 1000 100 10 1

120Ag Standard

Counts

N

Z

45 46 47 48 49 50 69 70 71 72 73 74

100000 10000 1000 100 10 1

Target

4-5

60cm
Experimental set-up

- $8\pi$LP ER-lcp angular correlation
  - lcp energy spectra (?)
  - ER angular distribution

- Exogam (Agata, Vamos) + Diamant + NEDA
  - ER yields, n spectra, lcp spectra (?)

- LNL separator
  - ER angular distribution and cross section
Conclusions

- Level density of exotic nuclei can be strongly affected by the isospin degree of freedom, through the level density parameter $a$ and the symmetry energy.

- Statistical model calculations show that evaporative light particles and evaporation residues are a good probe to study the level density of the exotic nuclei, as those produced by SPES and SPIRAL2.

- Future developments of the model combining the effects on the level density parameter $a$ and on the symmetry energy. Use of more realistic level densities.