Mean-field calculations with the Gogny force including the tensor force

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Motivation

- To understand exotic phenomena appearing in unstable nuclei
- To investigate, in particular, **Tensor-force** effect on single-particle energies (SPE)
- Its effect on them is different from that of the LS force
Brief description of the Tensor Force

Tensor force

• originates from the $\pi$- (and $\rho$-) meson exchange
• plays an important role in nuclear properties, such as binding energies
• can influence on SPE in the different way compared to the LS force

\begin{align*}
V_T &= V_T(r) S_{12} \\
S_{12} &= 3(\sigma_1 \cdot \hat{r})(\sigma_2 \cdot \hat{r}) - (\sigma_1 \cdot \sigma_2) \\
    &= 3 \left( [\sigma_1 \otimes \sigma_2]^{(2)} \cdot [r \otimes r]^{(2)} \right)
\end{align*}
Monopole Contribution of the Tensor Force

\[(2j_> + 1)V_{j'_j>} + (2j_< + 1)V_{j'_j<} = 0\]

- Repulsive \( j_>j'_> \) or \( j<_j'_< \)
- Attractive \( j_>j'_< \) or \( j<_j'_> \)
Skyrme (SIII) + Tensor (zero range)

\[ V_T = \frac{1}{2} T \left\{ \left[ (\sigma_1 \cdot \hat{k}) (\sigma_2 \cdot \hat{k}) - \frac{1}{3} (\sigma_1 \cdot \sigma_2) \hat{k}^2 \right] \delta(r) + \delta(r) \left[ (\sigma_1 \cdot \hat{k}) (\sigma_2 \cdot \hat{k}) - \frac{1}{3} (\sigma_1 \cdot \sigma_2) \hat{k}^2 \right] \right\} + U \left\{ (\sigma_1 \cdot \hat{k}) \delta(r) (\sigma_2 \cdot \hat{k}) - \frac{1}{3} (\sigma_1 \cdot \sigma_2) \left( \hat{k} \cdot \delta(r) \hat{k} \right) \right\} \]
Gogny-type Interaction


Tensor

\[ V_T = (\tau_1 \cdot \tau_2) V_T(r) S_{12} \]
\[ V_T(r) = V_T^0 \exp(-r^2/\mu^2) \]
Radial dependences of various interactions

$V_{TE}:$ Triplet-Even

$\mu_T = 1.2[\text{fm}]$
$V_T^0 = 50[\text{MeV}]$
One-body potential

Proton

Neutron

\[ V_{LS} = V_{LS}(r) \mathbf{L}_{12} \cdot (s_1 + s_2) \]

\[ \simeq iW_0 (\sigma_1 + \sigma_2) \cdot \mathbf{k} \times \delta(r) \mathbf{k} \]

\[ U_p \propto \frac{d}{dr} (\rho_n + 2\rho_p) \]

\[ U_n \propto \frac{d}{dr} (2\rho_n + \rho_p) \]
$^{68}$Ni and $^{78}$Ni (Neutron)

![Graph showing neutron SPE by D1S (Z=28) and GT2 (Z=28) with labels for $1f_{5/2}$ and $1f_{7/2}$ states.]
$^{68}$Ni and $^{78}$Ni (Proton)

(e) Proton SPE by D1S (Z=28)
(f) Proton SPE by GT2 (Z=28)

Energy [MeV]

Neutron number

$1g_{9/2}$
$1f_{5/2}$
$1f_{7/2}$
$2p_{1/2}$
$2p_{3/2}$
$1f_{7/2}$
$1g_{9/2}$
Variation of the gap between $1f_{5/2}$ and $1f_{7/2}$
(N= 40-50)

\[ \Delta E \]

N=50

N=40

\(1f_{5/2}\)

\(1f_{7/2}\)

(a) GT2
proton
neutron

(b) D1S
proton
neutron

(c) SLy4
proton
neutron

\[ \Delta F \]

-4
-2
0

Cent
LS
Tensor

Cent
LS
Tensor

Cent
LS

Cent
LS

0 1 2 3 4

5
Density and spin-orbit potential

(a) Proton $1f_{5/2}$

(b) Neutron $1f_{5/2}$

(c) Proton $1f_{7/2}$

(d) Neutron $1f_{7/2}$

(e) $g_p = d(\rho_n + 2\rho_p)/dr$

(f) $g_n = d(2\rho_n + \rho_p)/dr$

$N=40$ $N=50$
Proton $1h_{11/2}$ and $1g_{7/2}$ of $^{51}$Sb isotopes

Central Proton

N = 64 - 82  N = 94 - 104

Tensor

LS

\[ \Delta E \]

1h_{11/2}

1g_{7/2}
Summary

- Tensor force can influence on single-particle energies in the different way compared to the LS force
- For example,
  - Gap between $1f_{7/2}$ and $1f_{5/2}$ of Ni isotopes
  - Gap between $1h_{11/2}$ and $1g_{7/2}$ of Sb isotopes