TENSOR EFFECTS IN SHELL EVOLUTION AT $Z, N = 8$, 20 AND 28

Miguel Moreno-Torres Tirado

Departamento de Física Atómica, Molecular y Nuclear

Universidad de Granada

M. Anguiano. Univ. de Granada, Spain
V. de Donno. Univ. del Salento, INFN, Italy
M. Grasso, N. Van Giai. IPN Orsay, France
H. Liang, Peking University. P.R. of China.

Contenido

Contenido

Contenido

Contenido

Contenido

Contenido

Contents

Outline

- Study of **tensor force** effects in shell evolution.
- Comparison of most recent parametrizations of interactions with tensor

Tensor **OFF** - Tensor **ON** - **Experiment**

- HF approach. No pairing or correlations.
- Where should it be tested? Gaps at Z, $N = \mathbf{8, 20}$ and **28**.
- Conclusions: Considerations for new fits including tensor.

Contents

The Tensor Force

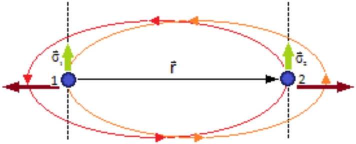
The whole tensor force is determined by a function of the distance (including $\vec{\tau}_1 \cdot \vec{\tau}_2$ part) and the tensor operator S_{12}.

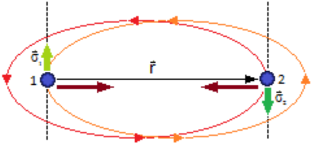
$$V_T(1,2) = [V_{T_0}(r) + V_{T_\tau}(r)\vec{\tau}_1 \cdot \vec{\tau}_2]S_{12}$$

- Local non-central contribution to the N-N force.
- Accounts for the observed values of the magnetic dipole moment and electric quadrupole moment of the deuteron.
- Neglected up to very recently in the mean-field framework.
- Modeled differently in the different interactions.
- Shell evolution and modifications of some magic numbers far from stability may be related to tensor effects.

The Tensor Force

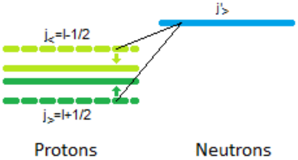
$$S_{12} = \left(\frac{(\vec{\sigma}_1 \cdot \vec{r}_{12})(\vec{\sigma}_2 \cdot \vec{r}_{12})}{(\vec{r}_{12})^2} - \vec{\sigma}_1 \cdot \vec{\sigma}_2 \right)$$

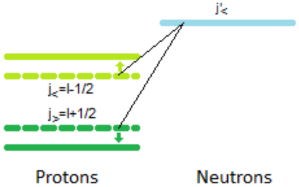




The Tensor Force

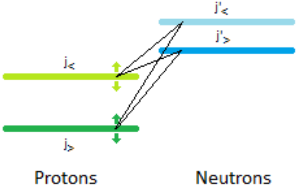
$$S_{12} = \left(\frac{(\vec{\sigma}_1 \cdot \vec{r}_{12})(\vec{\sigma}_2 \cdot \vec{r}_{12})}{(\vec{r}_{12})^2} - \vec{\sigma}_1 \cdot \vec{\sigma}_2 \right)$$

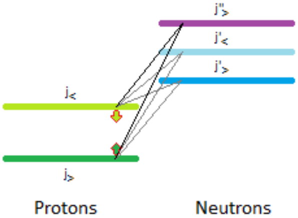




The Tensor Force

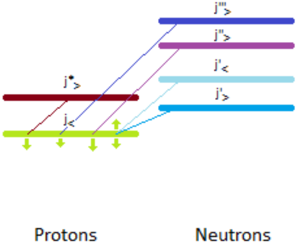
$$S_{12} = \left(\frac{(\vec{\sigma}_1 \cdot \vec{r}_{12})(\vec{\sigma}_2 \cdot \vec{r}_{12})}{(\vec{r}_{12})^2} - \vec{\sigma}_1 \cdot \vec{\sigma}_2 \right)$$

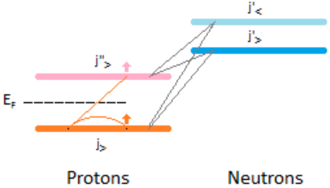




The Tensor Force

$$S_{12} = \left(\frac{(\vec{\sigma}_1 \cdot \vec{r}_{12})(\vec{\sigma}_2 \cdot \vec{r}_{12})}{(\vec{r}_{12})^2} - \vec{\sigma}_1 \cdot \vec{\sigma}_2 \right)$$





Contents

- We make a comparative study for:
  1. Tensor in Skyrme: zero-range tensor originally introduced by Skyrme. Fit by Colò on Sly5 [1].
  2. Tensor in Gogny: finite-range tensor and GT2 parameters introduced by Otsuka[2].
  3. Tensor in RHF: PKA1 parametrization[3], pion and ρ-tensor couplings.

[1] G. Colò, H. Sagawa, S.Fracasso and P. Bortignon, Phys. Lett. **B**, 646 (2007) 227

[2] T. Otsuka, T. Matsuo, D. Abe, Phys. Rev. **C** 97 (2006) 162501

[3] W. H. Long, H. Sagawa, N. Van Giai and J.Meng, Phys. Rev. **C** 76 (2007) 034314

Tensor in Skyrme

$$\begin{aligned} v_{\mathrm{T}} &= \frac{T}{2}\left[\left((\vec{\sigma}_1\cdot\overleftarrow{k})(\vec{\sigma}_1\cdot\overleftarrow{k}) - \frac{1}{3}(\vec{\sigma}_1\cdot\vec{\sigma}_2)\overleftarrow{k}^2\right)\delta(\vec{r}_1-\vec{r}_2)\right] \\ &+ \frac{T}{2}\left[\delta(\vec{r}_1-\vec{r}_2)\left((\vec{\sigma}_1\cdot\vec{k})(\vec{\sigma}_2\cdot\vec{k}) - \frac{1}{3}(\vec{\sigma}_1\cdot\vec{\sigma}_2)\vec{k}^2\right)\right] \\ &+ U\left[(\vec{\sigma}_1\cdot\overleftarrow{k})\delta(\vec{r}_1-\vec{r}_2)(\vec{\sigma}_2\cdot\vec{k}) - \frac{1}{3}(\vec{\sigma}_1\cdot\vec{\sigma}_2)\otimes(\overleftarrow{k}\cdot\delta(\vec{r}_1-\vec{r}_2)\vec{k})\right] \end{aligned}$$

$\vec{k} = (\vec{\nabla}_1 - \vec{\nabla}_1)/2i$ acts on the right and $\overleftarrow{k} = (\overleftarrow{\nabla}_1 - \overleftarrow{\nabla}_1)/2i$ on the left.

T and U are the parameters that define the strength of the tensor

- This tensor is zero range as the rest of the force channels.
- Tensor modifies the energy density:

$$\Delta E = \frac{1}{2}\alpha(J_n^2 + J_p^2) + \beta J_n J_p$$

and the spin-orbit potential:

$$W_{SO}^q = \frac{W_0}{2}\left(2\frac{d\rho_q}{dr} + \frac{d\rho_{q'}}{dr}\right) + (\alpha J_q + \beta J_{q'})$$

where J_q are the spin-orbit densities ($q(q')$=n(p)/p(n)):

$$J_q = \frac{1}{4\pi r^3}\sum_i (2j_i + 1)\left[j_i(j_i+1) - l_i(l_i+1) - \frac{3}{4}\right] R_i^2(r)$$

Parameters α and β are expressed as:

$$\alpha = \alpha_{\mathrm{C}} + \alpha_{\mathrm{T}} \qquad \beta = \beta_{\mathrm{C}} + \beta_{\mathrm{T}}$$

so that α_{T} and β_{T} are related to the tensor part:

$$\alpha_{\mathrm{T}} = \frac{5}{12} U \qquad \beta_{\mathrm{T}} = \frac{5}{24}(T + U)$$

and α_{C} and β_{C} to the central part:

$$\alpha_{\mathrm{C}} = \frac{1}{8}(t_1 - t_2 - t_1 x_1 - t_2 x_2); \beta_{\mathrm{C}} = -\frac{1}{8}(t_1 x_1 + t_2 x_2)$$

We use Colò *et al.* fit: $(\alpha_{\mathrm{T}}, \beta_{\mathrm{T}}) = (-170, 100)$ MeV fm^5.

- Parameters α and β must reproduce experimental spin-orbit splittings.
- The choice of α_{T} and β_{T} will determine how the tensor modifies these splittings in the case of same and different isospin.
- α_{T} and β_{T} are either estimated from the tensor part of the nucleon-nucleon interaction or considered as free parameters to fit. In this case they are free parameters.

Tensor in Gogny

Gogny GT2 parametrization includes a finite-range isospin tensor term:

$$v_{\mathrm{T}} = F_{\mathrm{T}}\, \vec{\tau}_1 \cdot \vec{\tau}_2\, 3 \left(\frac{(\vec{\sigma}_1 \cdot \vec{r}_{12})(\vec{\sigma}_2 \cdot \vec{r}_{12})}{(\vec{r}_{12})^2} - \vec{\sigma}_1 \cdot \vec{\sigma}_2 \right) f_{\mathrm{G}}(r)$$

where $F_{\mathrm{T}} = 50.79506$ MeV and $f_{\mathrm{G}}(r)$ is a gaussian function, with a range of 1.2 fm.

- The parameter F_{T} has been fixed assuming that the volume integral reproduces that of the AV8'[4]
- GT2 was fitted at HF level by Otsuka *et al.*
- The parameter F_{T} has an analogous role to Skyrme β_{T} in the regions we study: It changes the intensity and direction of the effect of the tensor on the gap evolution.

[4] B.S. Pudliner, J. Carlson, R.B. Wiringa, Phys. Rev. **C** 56 (1997) 1720.

Tensor in RHF

Tensor correlations are deduced from π-nucleon and ρ-nucleon tensor interactions.

$$\begin{aligned}\mathcal{L}_{\pi+\rho} \quad = \quad & +\frac{1}{2}\partial_\mu\vec{\pi}\cdot\partial^\mu\vec{\pi} - \frac{1}{2}m_\pi^2\vec{\pi}\cdot\vec{\pi} - \frac{f_\pi}{m_\pi}\bar{\psi}\gamma_5\gamma^\mu\partial_\mu\vec{\pi}\cdot\vec{\tau}\psi \\ & -\frac{1}{4}\vec{R}^{\mu\nu}\cdot\vec{R}_{\mu\nu} + \frac{1}{2}m_\rho^2\vec{\rho}^\mu\cdot\vec{\rho}_\mu - g_\rho\bar{\psi}\gamma^\mu\vec{\rho}_\mu\cdot\vec{\tau}\psi \\ & +\frac{f_\rho}{2M}\bar{\psi}\sigma_{\mu\nu}\partial^\nu\vec{\rho}^\mu\cdot\vec{\tau}\psi,\end{aligned}$$

where $\vec{R}^{\mu\nu} = \partial^\mu\vec{\rho}^\nu - \partial^\nu\vec{\rho}^\mu$.

- We use two different parametrizations:
  - PKA1[5]. Considering tensor with exponentially density dependent couplings f_ρ,g_ρ and f_π.
  - DDME2[6], which does not include π and ρ-tensor interactions.
- Tensor can not be isolated in PKA1.

[5] W. H. Long, H. Sagawa, N. Van Giai and J.Meng, Phys. Rev. **C** 76 (2007) 034314

[6] G.A. Lalazissis, T. Nikšić, D. Vretemar. and P. Ring, Phys. Rev. **C** 71 (2005) 024312.

Contents

Gap Energy

We focus on gap energies around magic numbers:

$$E_{\text{gap}}(Z_{\text{magic}}, N) = \epsilon_a - \epsilon_b.$$

ϵ_a and ϵ_b are single-particle energies for the orbits above and below the fermi level. They are calculated:

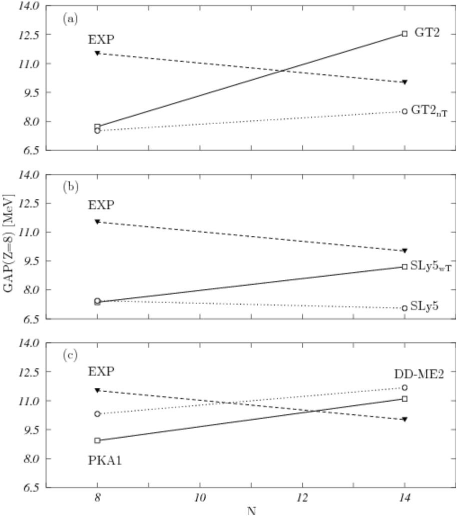
$$\begin{aligned}
\epsilon_b(Z_{\text{magic}}, N) &= -(E(Z_{\text{magic}}, N) - E(Z_{\text{magic}} - 1, N)) \\
&= -S_p(Z_{\text{magic}}, N) \\
\epsilon_a(Z_{\text{magic}}, N) &= -(E(Z_{\text{magic}} + 1, N) - E(Z_{\text{magic}}, N)) \\
&= -S_p(Z_{\text{magic}} + 1, N),
\end{aligned}$$

*Analogous procedure for $E_{\text{gap}}(Z, N_{\text{magic}})$.

Contents

PROCEDURE OF OUR ANALISIS

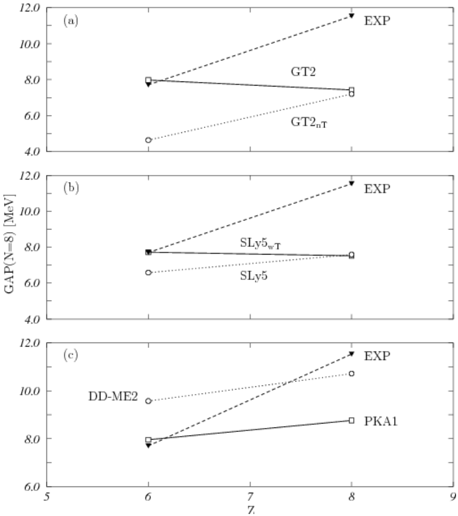
- We consider nuclei with fixed $Z(N) = 8, 20, 28$ and $N(Z)$ changing through values of different subshell closures.
- Calculate the proton(neutron) gap for these nuclei using:
  - HF with tensor activated: Gogny, Skyrme, RHF (PKA1).
  - HF with tensor not activated: Gogny, Skyrme, RHF (DDME2).
  - Experimental data.
- We compare the effect of activating the tensor between the three interactions.
- We check if introducing tensor improves the adjustment to the experimental GAP and SLOPE of the gap.



GAP Z=8

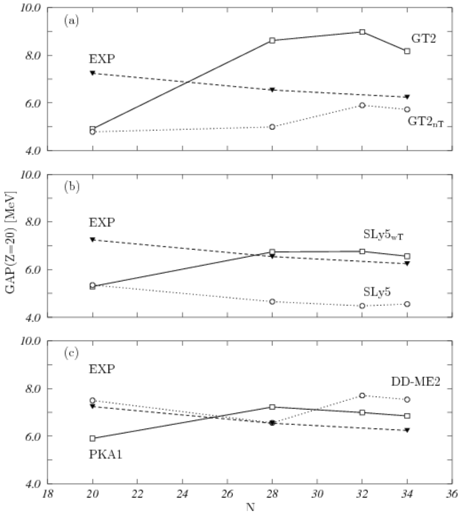
△ *The gap is between π $1p_{1/2}$, with spin down, and π $1d_{5/2}$, with spin up.*

△ *At $N = 14$ ν $1d_{5/2}$ is active and produces a tensor force attractive for π $1p_{1/2}$ and repulsive for π $1d_{5/2}$, broadening the gap.*



GAP N=8

△ *The gap is between ν $1p_{1/2}$, with spin down, and ν $1d_{5/2}$, with spin up.*
△ *At $Z = 6$ π $1p_{3/2}$ produces a tensor force repulsive for ν $1d_{5/2}$ and attractive for ν $1p_{1/2}$, broadening the gap.*

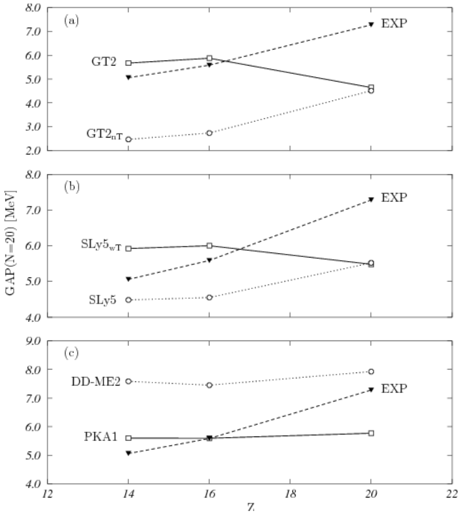


GAP Z=20

△ The gap is between π $1d_{3/2}$, with spin down, and π $1f_{7/2}$, with spin up.

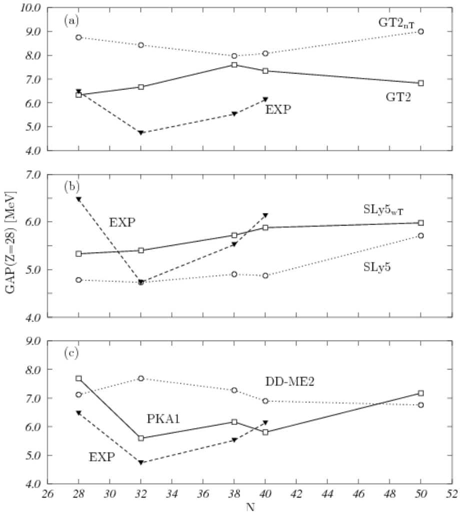
△ At $N = 28$ ν $1f_{7/2}$ produces a tensor force attractive for π $1d_{3/2}$ and repulsive for π $1f_{7/2}$, broadening the gap

△ At $N = 32$ ν $2p_{3/2}$ effect broadens again the gap and At $N = 34$ ν $2p_{1/2}$ effect makes it narrower



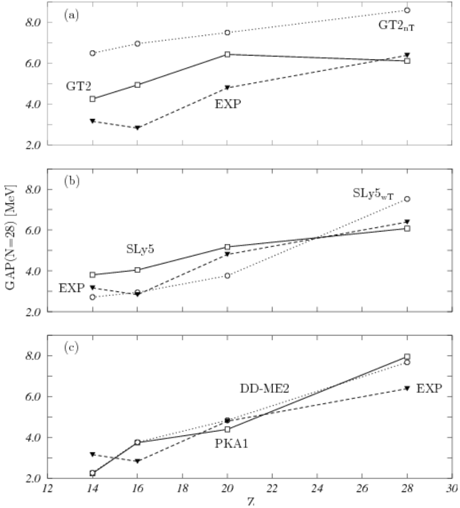
GAP N=20

△ *The gap is between ν $1d_{3/2}$, with spin down, and ν $1f_{7/2}$, with spin up.*
△ *At $Z = 14$ and $Z = 16$ π $1d_{5/2}$ produces a tensor force repulsive for ν $1f_{7/2}$ and attractive for ν $1d_{3/2}$, broadening the gap.*
△ *π $2s_{1/2}$ effect is neutral.*



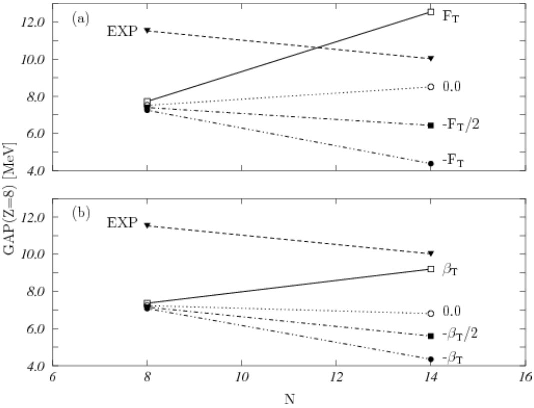
GAP Z=28

△ π $1f_{7/2}$ *tensor effect is also active (not spin-saturated).*
△ *The gap is between* π $1f_{7/2}$ *and* π $2p_{3/2}$*, both with spins up.*
△ *Filling of* ν $2p_{3/2}$ *and* $1g_{9/2}$ *should raise the gap while* ν $1f_{5/2}$ *and* $2p_{1/2}$ *should lower it, but not change its value*



GAP N=28

△ *ν $1f_{7/2}$ tensor effect is also active (not spin-saturated).*
△ *The gap is between ν $1f_{7/2}$ and ν $2p_{3/2}$, both with spins up.*
△ *Filling of π $1f_{7/2}$ should raise the gap, π $2s_{1/2}$ be neutral and $1d_{3/2}$ should lower it, but not change its value*



REPARAMETRIZING

If parameters β_T and F_T are considered free the slope produced by tensor force can be adjusted by changing their value and/or sign

Contents

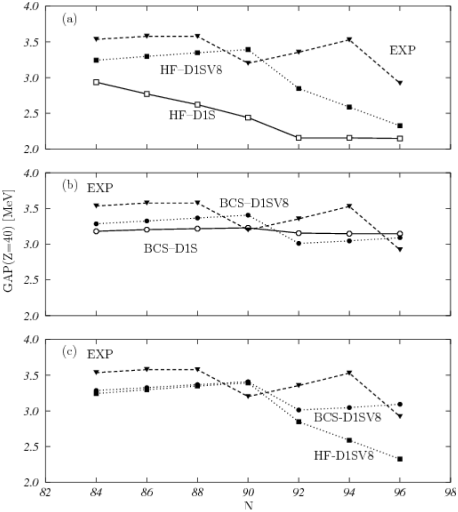
Conclusions:

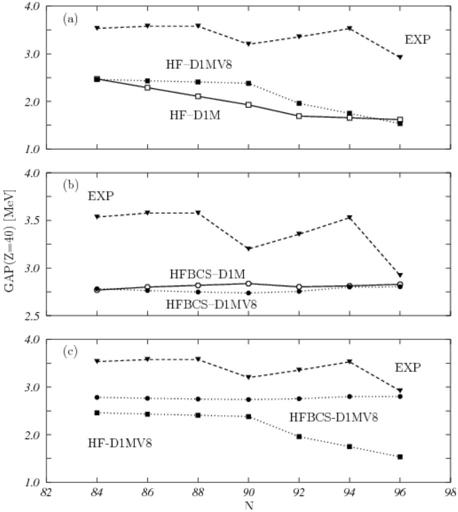
- Tensor effects can be clearly identified at $Z, N = 8, 20$.
- Tensor effects are entangled at $Z, N = 28$. No spin-saturation.
- $Z, N = 8, 20$ are optimum regions to perform new fits considering tensor.
- $Z, N = 28$ is not good for fitting. OK for testing.
- The effect of the tensor is similar between the three interactions, except at the regions $Z, N = 28$.
- None of the parametrizations tested give a good adjustment to the experimental gaps.

Perspectives

- Extend this study to Z, $N = 40$, which are also spin-saturated.
- Study regions Z, $N = 8$, 20 and 40 using HF+BCS and new Gogny interactions with tensor D1SV8, D1MV8 that we are developing.
- Perform new fits reproducing gaps more accurately.

These results were extracted from the article:
M. Moreno-Torres, M. Grasso, H. Liang, V. De Donno, M. Anguiano, and N. Van Giai, Phys. Rev. C 81, 064327 (2010)


4.0
3.5
3.0
2.5
2.0
(a)
EXP
HF–D1SV8
HF–D1S
(b)
EXP
BCS–D1SV8
BCS–D1S
GAP(Z=40) [MeV]
(c)
EXP
BCS-D1SV8
HF-D1SV8
82
84
86
88
90
92
94
96
98
N


(a)
EXP
HF–D1MV8
HF–D1M
(b)
EXP
HFBCS–D1M
HFBCS–D1MV8
(c)
EXP
HFBCS-D1MV8
HF-D1MV8
GAP(Z=40) [MeV]
N
4.0
3.0
2.0
1.0
3.5
2.5
82
84
86
88
90
92
94
96
98

- Wigner correction[7] is susceptible to be applicable for cases with $N \approx Z$:

$$E_W = V_W exp\left(-\lambda\left(\frac{N-Z}{A}\right)^2\right)$$

with $V_W =$ -2.327 MeV and $\lambda = 400$

[7] Goriely et al., Phys. Rev. **C** 71 (2005) 024312.