The kink effect of the nuclear charge radii in some isotopic chains and the nucleon-nucleon tensor force within nonlinear relativistic models in the Hartree-Fock approximation.

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Abstract. Relativistic nonlinear models in the Hartree-Fock approach, with σ, ω, ρ and π mesons, are used to explore the influence of the nucleon-nucleon tensor force (*tf*) on the behaviour of the nuclear charge radii of the Pb isotopic chain. It is found that a part of its effect on the charge radii is channelled through its opposite effect to the spin-orbit interaction. The kink effect seems to be produced by the combination of the geometrical features of the $1i_{11/2}$ neutron orbital and its binding energy.

1 Introduction

The marked change in trend of the evolution of the charge radii of some isotopic families of nuclei versus the mass number A is known as kink effect (KE). This is a consequence of the shell structure of nuclei. The fact that the density-dependent Hartree-Fock model with standard Skyrme functionals [1] or Gogny forces [2] were not able to reproduce this effect for the Pb isotopic chain, for example, whereas the relativistic models in the simple mean-field approach did reasonably well [3, 4], has increased the interest in understanding the mechanism responsible for the KE [5-8]. However, it seems that the full theoretical understanding has not been reached yet.

The aim of this work is to consider a nuclear relativistic Lagrangian and use the Hartree-Fock approximation, without pairing correlations, to explore the influence of the NN tensor force (*tf*) on the behaviour of the nuclear charge radii of the Pb isotopic chain.

2 The model

The effective Lagrangian density L includes the nucleons and the σ, ω, ρ and π meson fields (φ, σ, ω_μ, ρ_μ and π, respectively), and the electromagnetic field A_μ [9]:

$$L = L_0(\varphi, \sigma, \omega_\mu, \rho_\mu, \pi, A_\mu) + L_{\text{int.}} - U_{\text{NL}}. \quad (1)$$

L_0 describes the free system and

$$L_{int.} = -g_\sigma\bar{\varphi}\sigma\varphi - g_\omega\bar{\varphi}\gamma^\mu\omega_\mu\varphi - g_\rho\bar{\varphi}\gamma^\mu\boldsymbol{\rho}_\mu\cdot\boldsymbol{\tau}\varphi - \frac{f_\pi}{m_\pi}\bar{\varphi}\gamma_5\gamma^\mu\partial_\mu\boldsymbol{\pi}\cdot\boldsymbol{\tau}\varphi - e\bar{\varphi}\gamma^\mu\frac{1+\tau_3}{2}A_\mu\varphi, \quad (2)$$

represents the interaction of nucleons with the boson fields. The nonlinear potential energy density

$$U_{NL} = \frac{1}{3}\bar{b}M(g_\sigma\sigma)^3 + \frac{1}{4}\bar{c}(g_\sigma\sigma)^4 \quad (3)$$

takes into account the σ-meson self-interactions. g_σ, g_ω, g_ρ and f_π are the σ, ω, ρ and π meson-nucleon coupling constants, respectively. $\boldsymbol{\tau}$ is the usual isovector operator, $\bar{b}$ and $\bar{c}$ are dimensionless parameters. $\frac{f_\pi^2}{2\pi} \cong 0.08$. The quantities m_σ, g_σ, g_ω, g_ρ, $\bar{b}$ and $\bar{c}$ are adjusted to nuclear ground state experimental data [9], see Table 1.

Table 1. Columns 3-8 give the fitted parameters of the model without (η=0) and with (η=1) tensor force contribution. m_σ is the σ meson mass, whereas g_σ, g_ω, g_ρ, $\bar{b}$ and $\bar{c}$ are the dimensionless parameters entering eqs. (2) and (3). The last 4 columns give the nuclear matter saturation values for the nuclear density (ρ_0), the binding energy per particle ($-E/A$), the symmetry energy coefficient (a_4) and the compressibility modulus (K).

Model	η	m_σ, MeV	g_σ	g_ω	g_ρ	$\bar{b}$ ×10³
HF0	0	441.7	5.015	9.510	0.67	−5.26
HF1	1	443.3	5.322	10.39	0.72	−4.36

Model	$\bar{c}$ ×10³	ρ_0, fm⁻³	E/A, MeV	a_4, MeV	K, MeV
HF0	−8.95	0.146	−16.3	36.8	294
HF1	−7.26	0.149	−16.3	35.5	285

3 Results

3.1 Effect of the tensor force

Fig. 1 shows the neutron single-particle energies of ^{208}Pb. It can be seen that the *tf* reduce the spin-orbit splittings. Fig. 2 shows the charge radius isotope shift $\Delta\langle r_c^2(\text{Pb})\rangle = \langle r_c^2(^A\text{Pb})\rangle - \langle r_c^2(^{208}\text{Pb})\rangle$. The *tf* reduces the difference between the radii of the two spin-orbit partners but it has little influence on $\Delta\langle r_c^2\rangle$ both for the i-conf. ($\ldots 1i_{11/2}^{N-126}$), where the KE is observable, and for the g-conf. ($\ldots 2g_{9/2}^{N-126}$), where it is not.

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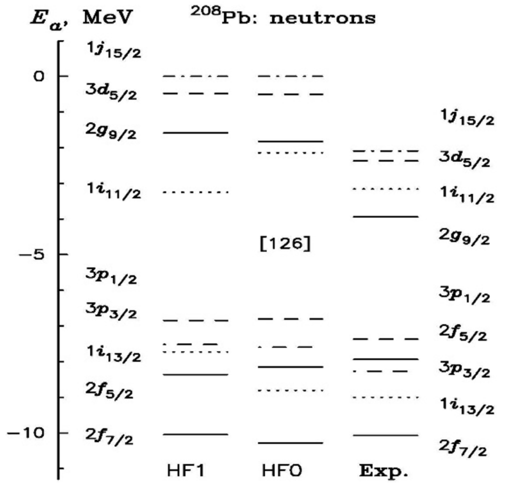

Figure 1: Neutron sp energies of ^{208}Pb for models HF0 (η=0) and HF1 (η=1), and Experiment data

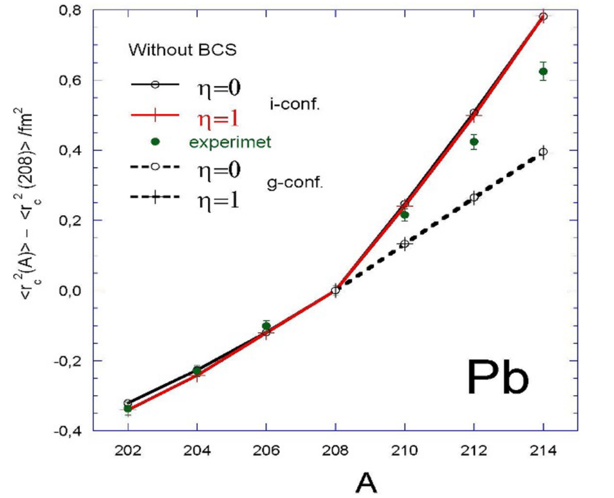

Figure 2: Charge radius isotope shift $\Delta\langle r_c^2\rangle$ for the Pb isotopic chain with respect to that of the ^{208}Pb for models HF0 (η=0) and HF1 (η =1) and for the neutron *i*- and *g*-confs.

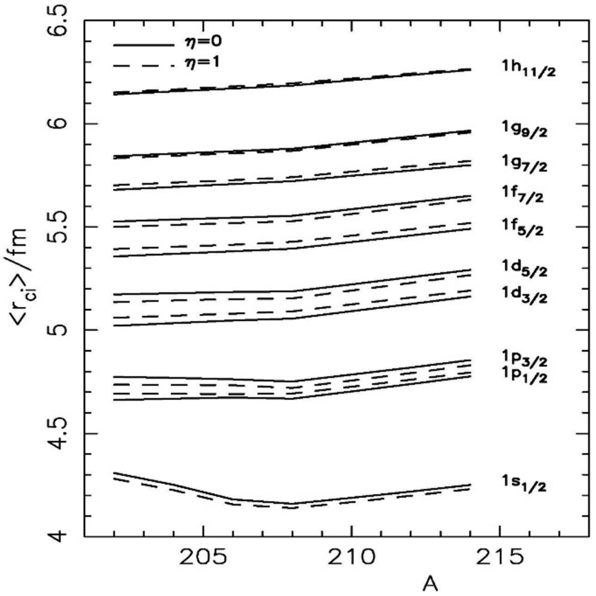

Figure 3: The sp r.m.s. charge radii of the proton nodeless orbitals of the Pb isotopic chain for the HF0 (η=0) and HF1 (η=1) models and *i*-conf.

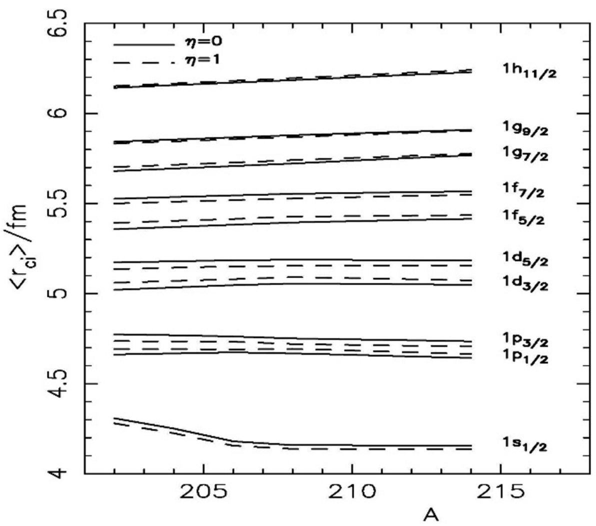

Figure 4: The same as Fig. 3, but for the *g*-conf.

Figs. 3 and 4 show the charge radii of the proton nodeless orbitals of the Pb isotopic chain. The effect of the *tf* on $\langle r_{ci}\rangle$ for the two orbitals of a spin-orbit doublet is opposite to each other and decreases as *l* increases. The effect of the *tf* is observable and it seems (only) qualitatively equivalent to that of reducing the spin-orbit interaction.

4 Conclusions

The effect of the tensor force (*tf*) on the nuclear charge radii of the nodeless proton orbitals of the Pb isotopic chain is opposite to that of the spin-orbit interaction and it decreases as *l* increases. For orbitals with nodes, the effect is more involved and less important. The global effect of the *tf* on the nuclei charge radii is very small.

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