SCOPE | SAUDI INTERNATIONAL CONFERENCE ON NUCLEAR POWER ENGINEERING

November 2-6, 2025   KFUPM, Dhahran, Saudi Arabia

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FINITE NUCLEI PROPERTIES FROM NUCLEAR MATTER EQUATION OF STATE

INTRODUCTION

The properties of nuclear matter and their connection to finite nuclei remain central challenges in nuclear physics, with important implications for both nuclear structure and astrophysics. Understanding the equation of state (EOS) of nuclear matter is essential for connecting microscopic nuclear interactions to the properties of both infinite and finite nuclear systems. In previous work, a nuclear matter EOS was developed using Brueckner–Hartree–Fock (BHF) theory with chiral nucleon-nucleon interactions at next-to-next-to-next-to-leading order (N3LO) and a phenomenological three-body force. This approach successfully reproduced empirical saturation properties and was applied to neutron-rich matter and neutron star structure.

Finite Nuclei are complex many body system. Any attempt to describe these objects within a single and fundamental theory becomes, from outset, too ambitious an undertaking. To overcome the many obstacles that are to be faced, approximation schemes that make the problem more tractable must be adopted. The conventional approach is based on non-relativistic formulation; relativistic effect were considered as begging negligible. Traditionally, the description of nuclear structure has been approached by solving a many-body Schrödinger equation which involve nucleons interacting through NN potentials

In this work, the nuclear matter EOS is applied to the study of bulk properties of finite nuclei through an energy density functional approach informed by microscopic input. Calculations of binding energies, charge and matter radii, and density distribution for selected closed-shell nuclei demonstrate good agreement with experimental data. This approach reveals the influence of three-body forces and tensor components on nuclear saturation and neutron-rich matter distributions.

The findings provide valuable insight into nuclear symmetry energy effects and pave the way for improved modeling of neutron-rich systems relevant to both terrestrial experiments and astrophysical environments.

THEORETICAL MODEL

The nucleon density distribution is represented by the two–parameter Fermi (2pF) function:

$$\rho_i = \frac{\rho_a}{1+e^{(r-b_i)/c_i}} \qquad (1)$$

where ρ_a is a normalization constant and i = (n, p). The constants b and c are the radius and the diffuseness parameter

$$E_C = \frac{e^2}{4\pi\epsilon_0}(4\pi^2)\int_0^\infty dr'\left[r'\rho_p(r')\int_0^{r'} dr\, r^2\rho_p(r)\right] \qquad (2)$$

The charge radius, which is the average radius determined from the charge distribution:

$$r_{ch}^2 = \frac{4\pi}{Z}\int_0^\infty \frac{2}{a\sqrt{\pi}} r^4 dr \int_0^\infty \frac{r'}{r}\rho_p(r')\sinh\left(\frac{2rr'}{a^2}\right) e^{-\left[\left(\frac{r'}{a}\right)^2+\left(\frac{r}{a}\right)^2\right]} dr' \qquad (3)$$

ABSTRACT

We provide an in-depth analysis of finite nuclei properties and nuclear matter saturation properties, highlighting the essential role of three-body forces (3BF) in connecting microscopic interactions with macroscopic nuclear phenomena. Energy density functional techniques are used in our extension to finite nuclei using the EOS from Brueckner-Hartree-Fock (BHF) theory with chiral N3LO potential, providing binding energies and charge radii that are in a good agreement with experimental data. The study presents enhanced density functionals and emphasizes the impact of the tensor force on EOS. These findings have important ramifications for nuclear structure and astrophysical applications since they demonstrate a strong correlation between finite-nuclei phenomenology and ab initio nuclear matter calculations.

RESULTS

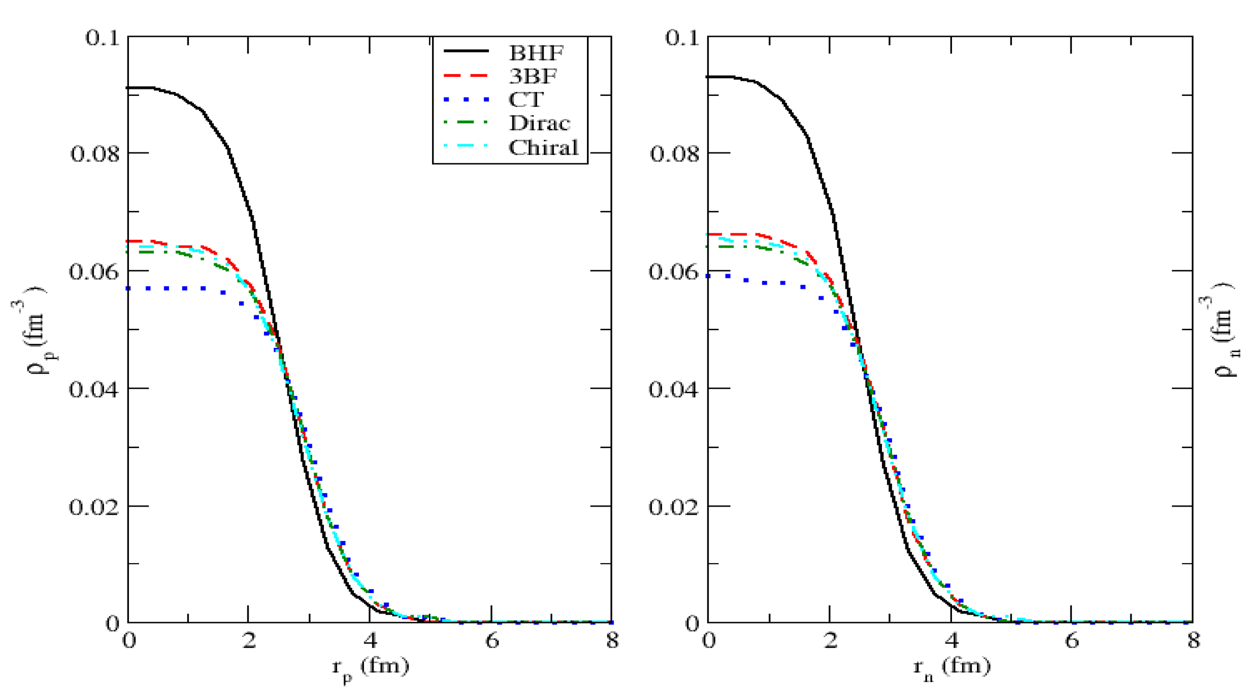

Figure 1: The density distribution of protons (left) and neutrons (right) for O^{16} using different EOS described in the text using the N3LO potential.

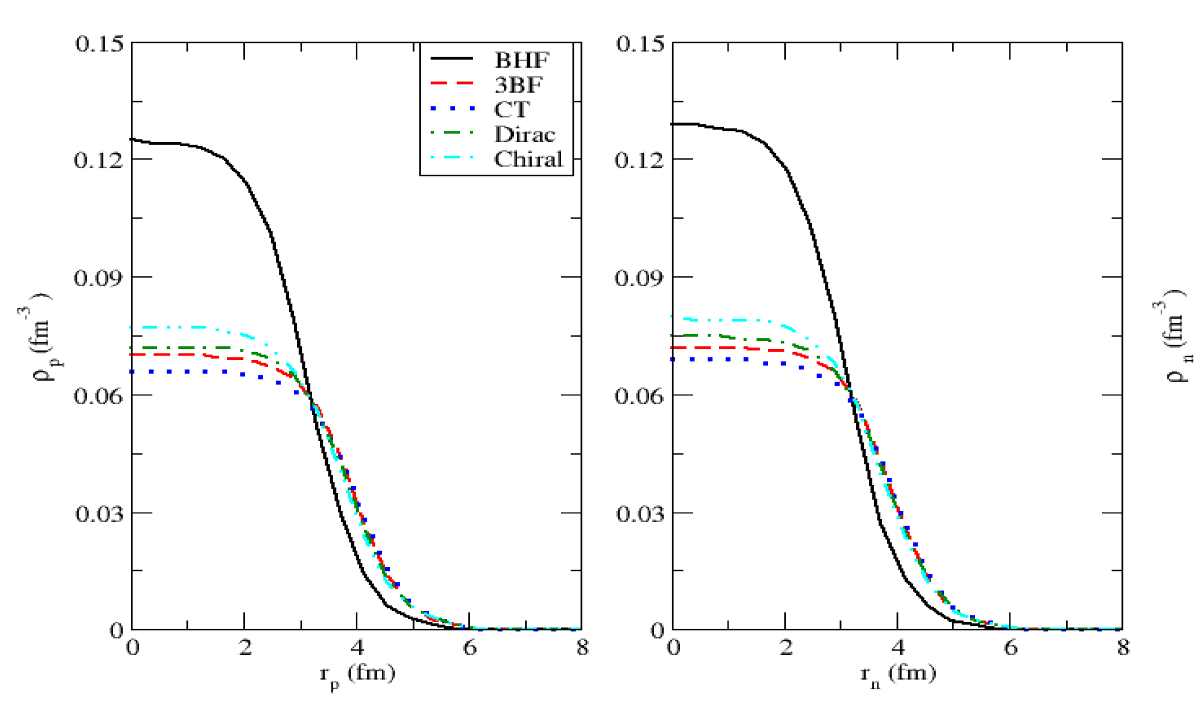

Figure 2: same as fig 1 but for Ca^{40}.

Nucleus	O^{16}		Ca^{40}	
Model	r_{ch}	BE	r_{ch}	BE
BHF	2.6653	-8.545	3.1218	-10.45
3BF	2.8551	-7.933	3.5534	-8.765
CT	2.935	-8.056	3.6215	-8.709
Dirac	2.8882	-7.481	3.55	-8.258
Chiral	2.8951	-7.234	3.518	-8.028
Ref.[5]	2.8897	-6.832	3.5736	-7.601
EXP.[8,9]	2.699	-7.976	3.478	-8.551

CONCLUSIONS

EOS is very sensitive to any change in the momentum-space cutoff, especially at high densities. By comparing the EOS of symmetric nuclear matter and that for pure neutron matter, it fond that the symmetric nuclear matter results display a stronger momentum-space cut-off depen.

The calculated values of binding energy (BE) and charge radii (r_{ch}) for the nuclei under consideration using different models using the N3LO potential after adding 3-body-force align reasonably well with the experimental data which clarify the important effect of 3-body-force.

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ACKNOWLEDGMENTS

Acknowledge any source(s) of funding, collaborative group, lab, or company.