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New parameterization of the effective field theory motivated relativistic mean field model

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Abstract

A new parameter set is generated for finite and infinite nuclear system within the effective field theory motivated relativistic mean field (ERMF) formalism. The isovector part of the ERMF model employed in the present study includes the coupling of nucleons to the δ and ρ mesons and the cross-coupling of ρ mesons to the σ and ω mesons. The results for the finite and infinite nuclear systems obtained using our parameter set are in harmony with the available experimental data. We find the maximum mass of the neutron star to be $2.03M_{\odot}$ and yet a relatively smaller radius at the canonical mass, 12.69 km, as required by the available data.

Keywords: Nuclear structure models; Binding energies and masses; Symmetry energy; Nuclear matter aspects of neutron star

1. Introduction

The nuclear physics inputs are essential in understanding the properties of dense objects like neutron stars. The relativistic mean field models based on the effective field theory (ERMF) motivated Lagrangian density have been instrumental in describing the neutron star properties,

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since, the ERMF models enables one to readily include the contributions from various degrees of freedoms such as hyperons, kaons and Bose condensates. The model parameters are obtained by adjusting them to reproduce the experimental data on the bulk properties for a selected set of finite nuclei. However, these parameterizations give remarkable results for bulk properties such as binding energy, quadrupole moment, root mean square radius not only for beta stable nuclei, but also for nuclei away from the stability line [1,2]. However, the same model, sometimes does not appropriately reproduce the behavior of the symmetric nuclear matter and pure neutron matter at supra-normal densities as well as those for the pure neutron matter at the sub-saturation densities.

The ERMF model usually includes the contributions from the self and cross-couplings of isoscalar–scalar σ, isoscalar–vector ω and isovector–vector ρ mesons. The inclusion of various self and cross-couplings makes the model flexible to accommodate various phenomena associated with the finite nuclei and neutron stars adequately without compromising the quality of the fit to those data considered a priory. For example, the self-coupling of σ mesons remarkably reduces the nuclear matter incompressibility to the desired values [3]. The cross-coupling of ρ mesons with σ or ω allows one to vary the neutron-skin thickness in a heavy nucleus like ^{208}Pb over a wide range [4,5]. These cross-couplings are also essential to produce desired behavior for the equation of state of pure neutron matter. Though, the effects are marginal, but, the quantitative agreement with the available empirical informations call for them [5,6].

One may also consider the contributions due to the couplings of the meson field gradients to the nucleons as well as the tensor coupling of the mesons to the nucleons within the ERMF model [2]. These additional couplings are required from the naturalness view point, but very often they are neglected. Only the parameterizations of the ERMF model in which the contributions from gradient and tensor couplings of mesons to the nucleons considered are the TM1*, G1 and G2 [2,7]. However, these parameterizations display some disconcerting features. For instance, the nuclear matter incompressibility and/or the neutron-skin thickness associated with the TM1*, G1 and G2 parameter sets are little too large in view of their current estimates based on the measured values for the isoscalar giant monopole and the isovector giant dipole resonances in the ^{208}Pb nucleus [8,9]. The equation of state (EoS) for the pure neutron matter at sub-saturation densities show noticeable deviations with those calculated using realistic approaches.

In the present paper, our motivation is to construct a new parameter set taking into account the multiple cross-couplings as well as the addition of δ-meson which are generally ignored. Our new parameterization is confronted with the EoS for the symmetric and pure neutron matters available from diverse sources which indicate that the proposed parameter set can be employed to model the finite nuclei as well as the neutron stars.

The paper is organized as follows. Sec. 2 is devoted to a brief outline of the extended relativistic mean-field model. After getting our newly generated parameter set, we have calculated the bulk properties of finite nuclei, nuclear matter and neutron star in Sec. 3. Finally, the concluding remarks are given in Sec. 4.

2. The model

Here, we start with the energy density functional for the ERMF model which includes the contributions from δ-meson to the lowest order and the cross-coupling between ω and ρ mesons which were not considered earlier by TM1*, G1 and G2 parameterizations. The energy density functional can be written as [2,7,10],