Equation of state of Symmetric Nuclear matter and Neutron Matter in Brueckner-Hartree-Fock Approach with Three-Body Force

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Introduction

Non relativistic calculations based on purely two-body interactions fail to reproduce the correct saturation properties of symmetric nuclear matter [1]. Further two body potentials under binds ^3H and ^3He. This well known deficiency is commonly corrected by introducing three-body-forces (TBF). Unfortunately, it seems not possible to reproduce the experimental binding energies of light nuclei along with the correct saturation property of SNM accurately with one simple set of TBF. Presently, the most widely used model for TBF are the Urbana VII model [2,3] and the phenomenological density dependent three nucleon interaction (TNI) model of Lagris, Friedman, and Pandharipande [4,5].

In this paper we discuss our results concerning the calculation of binding energy of symmetric nuclear matter (SNM) in fig. 1 and pure neutron matter (PNM) in fig. 2 using Argonne V14 (AV14) two body nuclear force and the two models for three-body force (TBF) namely AV14 plus UVII and AV14 plus TNI. These models are briefly described below.

Three-Body Forces (TBF):

(a) UrbanaVII (UVII) model:

A realistic model for nuclear TBF has been introduced by Urbana Group. The Urbana model includes two terms :

$$V_{ijk} = V_{ijk}^{2\pi} + V_{ijk}^{R}$$

The two pion exchange term $V_{ijk}^{2\pi}$ is attractive and is a cyclic sum over the nucleon indices i, j, k of products of commutator and anticommutator terms:

$$V_{ijk}^{2\pi} = A\sum_{cyc}\left(\{X_{ij}, X_{jk}\}\{\tau_i.\tau_j, \tau_j.\tau_k\} + \frac{1}{4}[X_{ij}, X_{jk}][\tau_i.\tau_j, \tau_j.\tau_k]\right)$$

The repulsive part is taken as:

$$V_{ijk}^{R} = U\sum_{cyc} T(r_{ij})^2\, T(r_{jk})^2 \cdot$$

The constants A and U are treated as parameters. For the use in BHF calculations, this TBF is reduced to an effective, density dependent, two-body force by averaging over the third nucleon in the medium, taking account of the nucleon-nucleon correlations by means of the BHF defect function *g*.

$$v_3^{eff}(r_{ik}) = \rho \sum_{\sigma_j, \tau_j} \int d^3 r_j V_{ijk} \left[1 - g(r_{ij})\right]^2 \left[1 - g(r_{jk})\right]^2$$

For Further details see Ref. [2].

(b) Three Nucleon Interaction (TNI):

Lagris and Pandharipande [5] argued that a reasonable procedure for constructing a three body potential is to make an expansion of the form:

$$V_{ijk} = \sum_{l}\sum_{cyc} U_l u_l(r_{ij}) u_l(r_{ik}) P_l(\cos\theta_i)$$

The AV14 plus TNI model approximates the effect of three-body force by adding two density dependent terms: a three nucleon repulsive (TNR) and a three nucleon attractive (TNA) term. The TNR term is taken as the product of an exponential of the density with the intermediate range part of V_{ij}, such that

$$v_{14} + \mathrm{TNR} = \sum_{p=1}^{14} [v_\pi^p(r_{ij}) + v_I^p(r_{ij})\exp(-\gamma_1\rho) + v_S^p(r_{ij})]O_{ij}^p \ ,$$

TNA contribution to the nuclear matter has the form ;

$$\mathbf{TNA} = \gamma_2\rho^2\exp(-\gamma_3\rho)(3 - 2\beta^2)$$

where $\beta = (N - Z)/A$, and N and Z are numbers of neutrons and protons.

We calculate E (k_F, v_{14}+TNR) with the interaction using BHF method, and add the TNA contribution to obtain the nuclear matter energy.

Neutron Matter:

To calculate the EOS of pure neutron matter, the fermi momentum k_F is related to the density ρ of neutron matter

$$\rho = k_F{}^3 / 3\pi^2$$

The energy density ε (ρ) and pressure P (ρ) and velocity of sound in neutron matter (in units of c)are obtained using the following relation:

$$\varepsilon(\rho) = \rho\,(E(\rho) + M_N C^2),$$

$$P(\rho) = \rho^2 \frac{\partial E(\rho)}{\partial \rho}$$

$$s(\varepsilon) = \sqrt{\frac{\partial P(\varepsilon)}{\partial \varepsilon}}$$

Symmetry Energy:

The symmetry energy (fig. 3) can be expressed in terms of the difference of the energy per particle between PNM (β = 1) and SNM (β = 0).

$$E_{sym}(\rho) = \frac{E}{A}(\rho, \beta = 1) - \frac{E}{A}(\rho, \beta = 0)\quad ,$$

where the asymmetry parameter ;

$$\beta = \frac{N - Z}{A}\ .$$

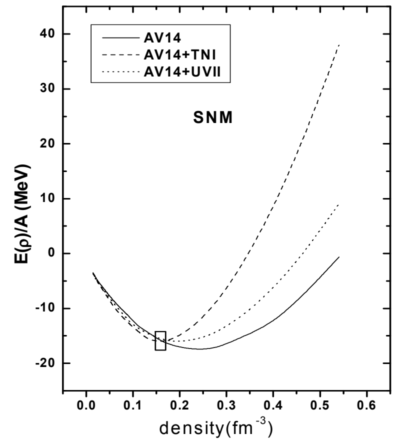

Fig. 1

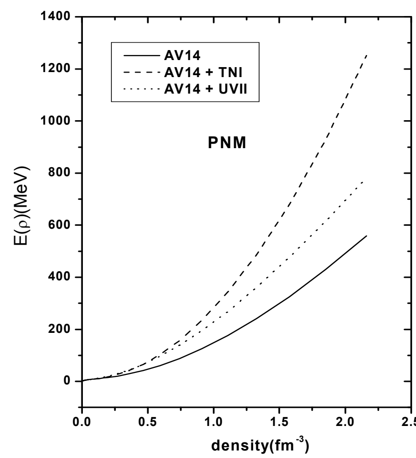

Fig. 2

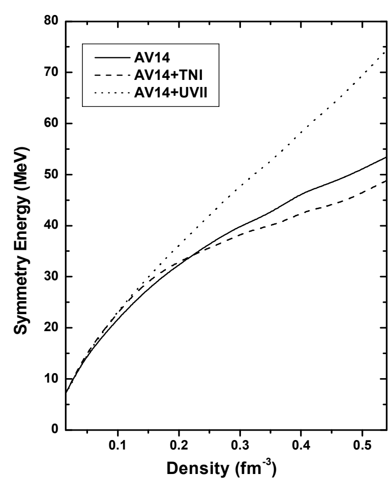

Fig. 3

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