Equation of state of Symmetric Nuclear matter in Brueckner theory with Three-Nucleon Interaction

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Introduction

In the present work we describe our results concerning the calculation of equation of state (EOS) of symmetric zero temperature nuclear matter in first order Brueckner-Hartree-Fock (BHF) theory. BHF theory is being increasingly used to study the properties of symmetric nuclear matter (SNM), neutron matter (NM) and nucleon optical potential at low and intermediate energies. To calculate the properties of SNM and NM the only input required in BHF is the realistic inter-nucleon potential which is obtained by fitting the two nucleon scattering and bound state data. Thus there are no free parameters in BHF calculation. An appropriate EOS must predict the correct saturation point for symmetric nuclear matter (SNM); give symmetry energy compatible with phenomenology and values of compressibility in agreement with empirical estimates. Further the velocity of sound in both SNM and neutron matter must not exceed the speed of light. However none of the two-body potentials are able to reproduce the correct saturation property of nuclear matter. This deficiency can be removed by using three-body forces.

In view of the above we have performed BHF calculation of the saturation properties of SNM using Argonne AV-14 [1] inter-nucleon potential. We have used a phenomenological density dependent three nucleon interaction (TNI) model of Lagris and Pandharipande [2] in addition to the two-body force. In our effective interaction code to calculate EOS of SNM. As shown by lagaris and Pandharipande in Ref. [2], realistic two-nucleon interaction seem to overbind nuclear matter very significantly at $k_F > 1.5\ \mathrm{fm}^{-1}$, whereas at low $k_F < 1.3\ \mathrm{fm}^{-1}$ nuclear matter is underbound. This strongly suggests the need for more attraction at low densities and higher repulsion at high densities. Lagris and pandharipande take a phenomenological point of view and add contribution of TNI to the V14 model to get the correct E (k_F) around k_F=1.33 fm^{-1}.

Three Nucleon Interaction (TNI)

In the following we briefly describe the TNI model as proposed by Lagris and pandharipande. In Ref. [2] the three body potential is expressed as:

$$V_{ijk} = \sum_{l} \sum_{\mathrm{cyc}} U_l u_l(r_{ij}) u_l(r_{ik}) P_l(\cos\theta_i) \tag{1}$$

where U_l are strength parameters, $u_l(r)$ are functions of interparticle distance, θ_i is the angle between vectors r_{ij} and r_{ik} and Σ_{cycl} represents cyclic permutation of the indices i,j,k. At very high densities only the l = 0 component of V_{ijk} will contribute. It must be repulsive and so we refer to it as TNR. The $l \neq 0$ components will give negative contributions to $E(k_f)$ through correlations, but these will saturates as density increases, and we refer to them collectively as TNA.

The TNR term is taken as the product of an exponential of the density with the intermediate range part of v_{ij}, such that

$$v_{14} + \mathrm{TNR} = \sum_{p=1}^{14} [v_{\pi}^{p}(r_{ij}) + v_{I}^{p}(r_{ij}) \exp(-\gamma_1 \rho) + v_{S}^{p}(r_{ij})] O_{ij}^{p} , \tag{2}$$

A reasonable parameterization of the TNA contribution is then given by:

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

where β = (N – Z) /A, N and Z are neutron and proton numbers.

We calculate E (k_F, v_{14} + TNR) with the interaction (Eq. 2) using BHF method, and add the TNA contribution (Eq. 3) to obtain the nuclear matter energy.

Results and Discussion

Our results for nuclear matter binding energy per nucleon for SNM using three-nucleon interaction (TNI) model along with two nucleon interaction AV-14 in BHF are shown in Fig. 1. Solid and dashed line show results using AV-14 plus TNI (with three-body force) and Argonne AV-14 alone respectively. We note that the nuclear matter saturates at $k_F = 1.5$ fm^{-1} with 17.52 MeV binding energy per nucleon for Argonne AV-14 and at $k_F = 1.33$ fm^{-1} with 16.004 MeV binding energy per nucleon for AV-14 plus TNI. Empirically [3] the nuclear matter saturates at a density $\rho_0 = 0.17 \pm 0.1$ fm^{-3} ($k_F = 1.35 \pm 0.05$ fm^{-1}) and energy per particle is $\varepsilon_0 = -16 \pm 1$ MeV. Empirical saturation values are shown as the rectangular box in Fig 1. We have presented our results for EOS in BHF using three-nucleon interaction (TNI) model along with two nucleon interaction AV-14. We show that we are able to obtain appropriate saturation density and energy per nucleon for SNM when TNI is included our BHF calculations.

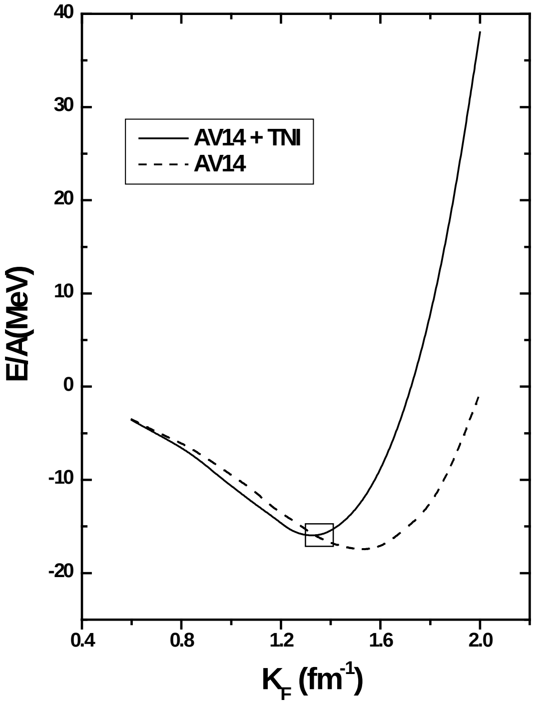

Fig. 1

References

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