Equation of state of Symmetric Nuclear matter and Neutron Matter from Argonne inter-nucleon potentials in BHF

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Introduction

The equation of state (EOS) of nuclear matter at high densities is one of the relevant issue in the theory of neutron star structure. In the present work, we calculate the EOS and other properties of pure neutron matter up to about five times the saturation density (ρ =0.17fm^{-3}), more appropriate for neutron star studies.

Pure neutron matter is defined as an idealized infinite, homogenous system of neutrons. At the given density the properties of such a system, treated as a gas of interacting fermions at T = 0°K, are determined by the neutron-neutron interaction.

In the present paper we describe BHF calculation of the saturation properties of SNM and PNM using Argonne AV-18 [1] and Argonne AV-14 [2] inter-nucleon potential.

General Theory

The nuclear matter optical potential is defined as the antisymmetrized matrix elements of the reaction matrix g:

$$U_{NM}(k) = \sum_j \left\langle \vec{k}, \vec{j} \right| \; g(w = e(k) + e(j)) \left| \vec{k}, \vec{j} \right\rangle_A \quad (1)$$

The reaction matrix satisfies the following Bethe-Goldstone [3] integral equation;

$$g(w = e(j) + e(k)) = v - v \frac{Q}{e(k_1) + e(k_2) - w} g \quad (2)$$

Where the single particle spectrum e(k) is:

$$e(k) = \frac{\hbar^2 k^2}{2m} + \mathrm{Re}\,U_{NM}(k) \quad (3)$$

The energy per nucleon for infinite nuclear matter is given by;

$$E/A = \frac{3}{5}\frac{k_F^2}{2m} + \frac{\int_0^{k_F} \frac{1}{2}\mathrm{Re}\,U_{NM}(k) k^2 dk}{\frac{1}{3}k_F^3} \quad (4)$$

Properties of 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 $\varepsilon(\rho)$ and pressure $P(\rho)$ are obtained from $E(\rho)$, where $E(\rho)$ is the energy per nucleon , ρ is the number density;

$$\varepsilon(\rho) = \rho\,(E(\rho) + MC^2), \quad (5)$$

$$P(\rho) = \rho^2 \frac{\partial E(\rho)}{\partial \rho} \quad (6)$$

The cold equation of state for P (ε) is obtained by eliminating ρ from (5) and (6), and sound velocity (in units of c) is given by;

$$s(\varepsilon) = \sqrt{\frac{\partial P(\varepsilon)}{\partial \varepsilon}} \quad (7)$$

Results and Discussion

Our results for nuclear matter binding energy per nucleon for symmetric nuclear matter (SNM) and neutron matter (NM) in BHF are shown in Figs. 1 and 2. Solid and dashed line show results using Argonne AV-18 and AV-14 respectively.In Fig. 1, we see that the nuclear matter saturates at a density 0.228 nucleon/fm^3

with 17.52 MeV binding energy per nucleon for Argonne AV-14 and at 0.228 Nucleon/fm^3 with 17.01 MeV binding energy per nucleon for Argonne AV-18. Empirical saturation values are shown as the rectangular box in Fig 1. Fig. 2 show our result for EOS of Pure neutron matter. The energy density ε (ρ), pressure P(ρ),and sound velocity are shown in figure3. From Fig. 3 we see that the causality condition (eq. 8) is also fulfilled.

$$C_s / c = \left(\frac{dp}{d\varepsilon}\right)^{1/2} \leq 1 \quad (8)$$

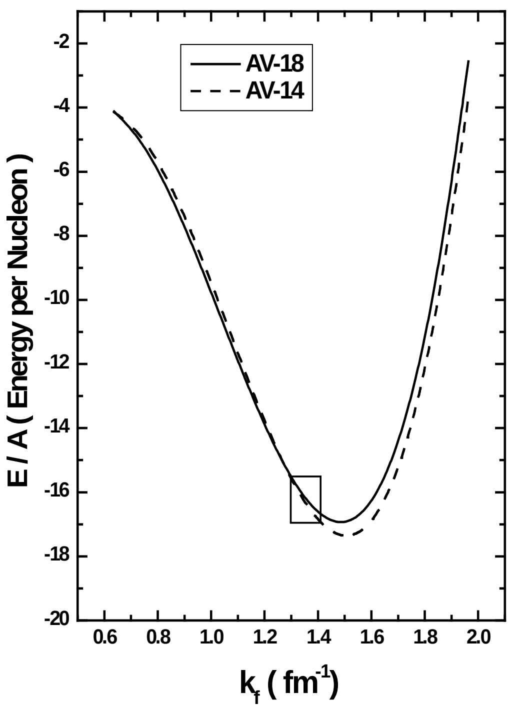

Fig. 1

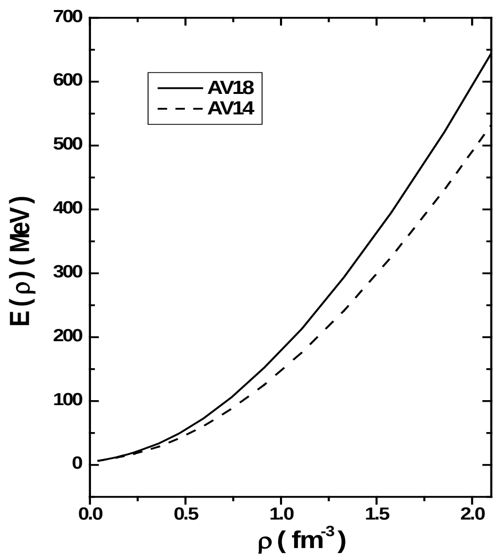

Fig. 2

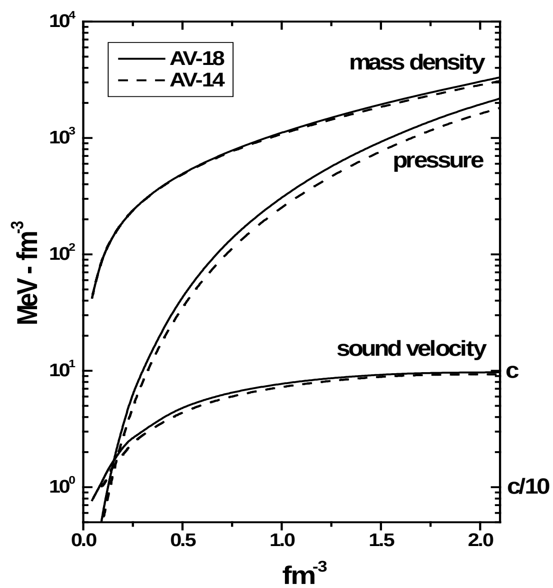

Fig. 3

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