Nuclear Matter Binding Energy Using Argonne V-14

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Introduction

In the present work we have used the local soft-core Argonne v14 [1] inter-nucleon potential and considered all two nucleon coupled and uncoupled states up to l = 10.

The nucleon-nucleus optical potential in nuclear matter is defined as the antisymmetrized matrix elements of the reaction matrix g [2]:

$$V_{NM}(k,E) = \sum_j n_{\langle}(j) \langle \vec{k}, \vec{j} | \; g(w = e(k) + e(j)) | \vec{k}, \vec{j} \rangle_A \quad (1)$$

where w = e(k) + e(j) is the starting energy, e(j) is the single particle energy of a bound nucleon of momentum j, and k is the momentum of the incident nucleon. The suffix A refers to antisymmetrization. The summation over j is over all the occupied states in the Fermi sea and the function $n_<(j)$ is defined as

$$n_<(j) = 1 \; ; \quad \text{if } j < k_F$$
$$= 0 \; ; \quad \text{if } j > k_F$$

The reaction matrix satisfies the following integral equation

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

Here v is the realistic inter-nucleon potential and Q is the Pauli operator which ensures that nucleons excited on the intermediate states with energies e (k_1) and e (k_2) have momenta above the Fermi sea.

The single particle energy e(k) is given by

$$e(k) = \frac{\hbar^2 k^2}{2m} + V(k) \quad (3)$$

The single particle potential V(k) is calculated from Brueckner g-matrix using equation (1), which is also required as an input (eq 3), for the energy denominator in eq (2). Thus an iteration process is required to obtain self-consistency. To achieve this we start from a guess:

$$V(k) = a + b k^2 + c k^4 + d k^6 \quad \text{for } 0 < k < k_m \quad (4a)$$

$$V(k) = a' - b' \exp(-c' k^2) \quad \text{for } k_m < k < \infty \quad (4b)$$

where a, b, c, d, a', b' and c' are constants. k is the momentum of the nucleon and k_m is some higher matching momentum up to which a polynomial fit (Eq.(4a)) to the calculated potential (Eq.(1)) is satisfactory. It is ensured that there is a smooth variation in V (k) using the equation (4a) and (4b). The values of the parameters a to d are determined by fitting Eq. (4a) to the calculated potential (Eq. (1)) in the range $0 < k < k_m$. The constants a' to c' are obtained by fitting Eq.(4b) to the calculated potential in the region $k_m < k < \infty$ .To obtain reliable values of the parameters, we have calculated the nuclear matter optical potential at 20 different incident momenta in the range k = 0.1 - 0.9 fm^{-1}. Self consistency is achieved in about 5 to 6 iterations.

Test of Self-Consistency

In fig. (1) we show our result of self-consistency obtained for the single particle potential as a function of incident momentum for fermi momenta k_F = 1.40 fm^{-1} . The solid line is a result of the single particle potential obtained from Polynomial approximation used as input for the calculation of g-matrix. We notice that in our calculation sixth order polynomial approximation (eq4a) is assumed up to a momentum cut off 4.70 fm^{-1}, beyond that exponential approximation (eq 4b) is used. Hence self- consistency is satisfactorily achieved using polynomial approximation.

Nuclear Matter Binding Energy

The energy of nucleon with momentum k in infinite nuclear matter is defined as the sum of kinetic energy and the potential energy, i.e

$$E(k) = \frac{\hbar^2 k^2}{2m} + V(k) \quad (5)$$

The energy per nucleon for infinite nuclear matter is given by

$$E/A = \frac{\int_0^{k_F} \left[\frac{\hbar^2 k^2}{2m} + \frac{1}{2} V(k) \right] k^2 dk}{\int_0^{k_F} k^2 dk} \quad (6)$$

After achieving the self-consistent single particle potential at a range of nuclear matter densities (k_f : 0.6 – 2.0 fm^{-1}) we can easily calculate the nuclear matter binding energy. The results are shown in Fig. (2). Empirically the nuclear matter saturates at a density $\rho_0 = 0.17 \pm 0.02\, fm^{-3}$ and energy per particle $\varepsilon_0 = -16 \pm 1 MeV$. Our results (see fig 2) show that Argonne V14 interaction gives rise to a nuclear matter which saturates at k_F = 1.6 fm^{-1} and E / A = -20.3MeV. Thus it predicts a large saturation density and an overbinding of the infinite nuclear matter. Our result reconfirms the coester band and thus there is an urgent need to include 3-body forces. The curves labeled AV14 is the results of our calculation. Curves labeled UV14 and AV18 in Fig. (2) refers to the result using Urbana V14 and Argonne V18 interaction. We have also shown in Fig. (2) the results of calculation using variational approach [3] with Argonne V14 interaction denoted by AV14 (PB).

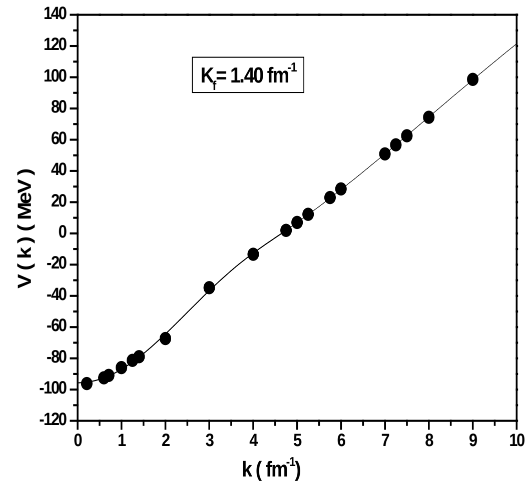

Fig. 1

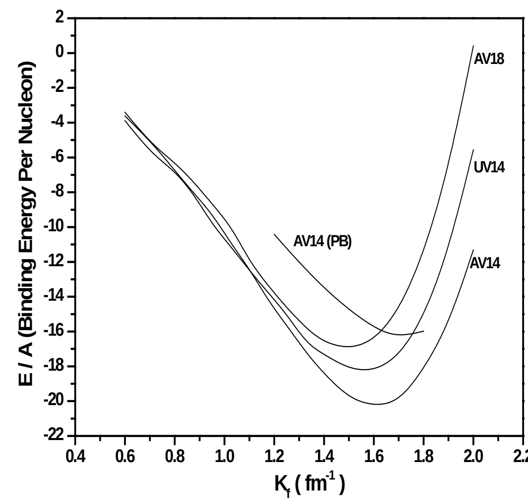

Fig. 2

References

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