REARRANGEMENT EFFECTS IN ASYMMETRIC NUCLEAR MATTER

By P. Haensel*,**

Institute of Physics, University of Liége

(Received July 20, 1976)

The rearrangement effects in asymmetric nuclear matter are investigated within the framework of the lowest order Brueckner theory with the Reid soft core nucleon-nucleon interaction. The accuracy of the single density approximation, which has been used previously in several investigations of the properties of asymmetric nuclear matter, is studied in the case of the symmetry energy and of the individual elements of the reaction matrix.

1. Introduction

In the theory of nuclear matter [1, 2] one considers usually the case of symmetric nuclear matter with equal neutron and proton number densities, $\varrho_n = \varrho_p = \frac{1}{2}\varrho$. The microscopic calculations of the structure of medium and heavy nuclei involve in fact asymmetric "nuclear matter" and the neutron excess parameter $\alpha = (N-Z)/A$ reaches the value $\alpha = 0.23$ in the case of ^{238}U. In the case of hypothetical superheavy nuclei the neutron excess is expected to be even larger. Moreover, investigations of the properties of the neutron star matter involve highly asymmetric nuclear matter with a large neutron excess [3].

Up to now, the general case of asymmetric nuclear matter has been studied in only a few complete nuclear matter calculations, performed within the framework of the lowest order Brueckner theory [4–7]. In the standard case of symmetric ($\alpha = 0$) nuclear matter one considers in fact a one component nucleon liquid, the exclusion principle and dispersion effects being the same for neutrons and protons. In the general case of asymmetric nuclear matter one must consider two components (neutrons and protons) of nuclear matter explicitly. Thus, the properties of asymmetric nuclear matter should be derived from the neutron-neutron, proton-proton and neutron-proton effective interactions, approximated usually by the corresponding reaction matrices of the lowest order

---

* Chercheur I.I.S.N.

** From November 1, 1975 to November 1, 1976, on leave of absence from the Institute of Theoretical Physics, Warsaw University, Hoża 69, 00-681 Warszawa, Poland.

Brueckner theory. The reaction matrix in asymmetric nuclear matter is different from that calculated in symmetric nuclear matter at the same total density ϱ; the former is, e.g., charge dependent [8], while the latter is charge independent The effects resulting from the intrinsic dependence of the reaction matrix on the composition of nuclear matter (in our case on α) are known as rearrangement effects [9].

The self-consistent calculation of the reaction matrix in the system with two different Fermi momenta (k_n and k_p, for neutrons and protons, respectively) is very complicated. Hence, in several papers the rearrangement effects were estimated using single density approximation (SDA), in which one approximates the exact reaction matrix $K_{\tau_z\tau'_z}(k_n, k_p)$ ($\tau_z, \tau'_z = n, p$) by the K-matrix calculated in symmetric nuclear matter with suitable defined Fermi momentum $\tilde{k}_F = \tilde{k}_n = \tilde{k}_p$ [9–14).

This approximation which in the case of the n−n and p−p pairs accounts exactly for the exclusion principle rearrangement effects, was introduced by Brueckner and Gammel in their paper on the properties of liquid ^{3}He [15]. It was subsequently generalized by Brueckner and Dąbrowski [9] to the case of asymmetric nuclear matter and by Dąbrowski and Haensel [11] to the case of polarized asymmetric nuclear matter (cf. [14]). In its original version the SDA was applied to the calculation of the magnetic susceptibility of neutron matter [16–18]. In a somewhat modified form the SDA was used by Ellis and Sprung in their study of the binding energy of neutron star matter [19]. The possibility of the application of the SDA in the calculations of the structure of heavy nuclei within the framework of the local density approximation has been mentioned by Siemens [5] and discussed by Sprung and Banerjee [10].

In the present paper the rearrangement effects in asymmetric nuclear matter are studied within the framework of the lowest order Brueckner theory [1, 2]. In some recent calculations [20] a discrepancy between the variational (Jastrow-theoretic) and the Brueckner theory results for nuclear matter has been found. The arguments leading to the possible explanation of these discrepancies has been recently presented in Refs [21, 22].

The calculations of the present paper are performed at the density of nuclear matter $\varrho = 0.166\ \text{fm}^{-3}$ and for $\alpha \leqslant 0.4$. The reaction matrix is calculated self-consistently from the Reid soft core nucleon-nucleon interaction [23]. In Section 2 we briefly present the formalism used in the present paper. Section 3 contains general discussion of the rearrangement effects in asymmetric nuclear matter. In Section 4 we present the numerical results concerning the rearrangement effects in the symmetry energy and in the individual elements of reaction matrices. In particular, we discuss the role of the self-consistency of the single-particle spectra, and the accuracy of the SDA of Brueckner and Dąbrowski. The short Section 5 contains the conclusions of the present paper.

2. *Formalism*

We apply the lowest order Brueckner theory of nuclear matter [1, 2], with added complication of two different Fermi momenta,

$$k_n = k_F(1+\alpha)^{1/3} \tag{1}$$

for neutrons, and

$$k_p = k_F(1-\alpha)^{1/3} \tag{2}$$

for protons, where

$$\alpha = (\varrho_n - \varrho_p)/\varrho, \qquad \varrho = \frac{2k_F^3}{3\pi^2}.$$

The reaction matrices $K_{\tau_z\tau'_z}$ (τ_z, τ'_z = n, p) satisfy the integral equations

$$\langle \boldsymbol{m}\boldsymbol{M}|K_{\tau_z\tau'_z}|\boldsymbol{m}\boldsymbol{M}\rangle = \langle \boldsymbol{m}|v_{\tau_z\tau'_z}|\boldsymbol{m}\rangle$$

$$+ \int \frac{d^3k}{(2\pi)^3} \langle \boldsymbol{m}|v_{\tau_z\tau'_z}|\boldsymbol{k}\rangle \frac{Q_{\tau_z\tau'_z}(\frac{1}{2}\boldsymbol{M}+\boldsymbol{k}, \frac{1}{2}\boldsymbol{M}-\boldsymbol{k})}{e_{\tau_z}(\frac{1}{2}\boldsymbol{M}+\boldsymbol{m}) + e_{\tau'_z}(\frac{1}{2}\boldsymbol{M}-\boldsymbol{m}) - (\frac{1}{4}M^2+k^2)/\mathscr{M}} \langle \boldsymbol{k}\boldsymbol{M}|K_{\tau_z\tau'_z}|\boldsymbol{m}\boldsymbol{M}\rangle. \tag{3}$$

The notation of Ref. [7] will be used throughout this paper. By $\boldsymbol{m}$, $\boldsymbol{k}(\boldsymbol{M})$ we denote the relative (total) momenta of the nucleon pair, related to the individual momenta appearing in $\langle \boldsymbol{m}_1\boldsymbol{m}_2|K_{\tau_z\tau'_z}|\boldsymbol{m}_1\boldsymbol{m}_2\rangle$ by $\boldsymbol{m}_1 = \frac{1}{2}\boldsymbol{M}+\boldsymbol{m}$, $\boldsymbol{m}_2 = \frac{1}{2}\boldsymbol{M}-\boldsymbol{m}$.

All momenta will be measured in units of $\hbar$ and $\mathscr{M}$ is an average nucleon mass divided by $\hbar^2$. We consider spin saturated nuclear matter. Thus, we may suppress spin indices to simplify the notation: our $\mathscr{K}_{\tau_z\tau'_z}$ in the subsequent formulae are the spin traces of the corresponding matrices in the spin space divided by four (spin averages). The $Q_{\tau_z\tau'_z}$ in Eq. (3) are the exclusion principle operators,

$$Q_{\tau_z\tau'_z}(\boldsymbol{k}_1, \boldsymbol{k}_2) = \begin{cases} 1 & \text{if} \quad k_1 > k_{\tau_z} \quad \text{and} \quad k_2 > k_{\tau'_z} \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

The single-particle energies in the hole states ($m_1 < k_{\tau_z}, m_2 < k_{\tau'_z}$) are calculated self-consistently,

$$e_{\tau_z}(m_1) = \frac{m_1^2}{2\mathscr{M}} + V_{\tau_z}(m_1),$$

$$V_{\tau_z}(m_1) = \frac{3\varrho}{4k_F^3} \sum_{\tau'_z} \int_0^{k_{\tau'_z}} dm_2 m_2^2 \int_{-1}^{1} d\xi \mathscr{K}_{\tau_z\tau'_z}, \tag{5}$$

while in the intermediate states ($k_1 > k_{\tau_z}, k_2 > k_{\tau'_z}$) the pure kinetic energies are used [1, 2]. In Eq. (5) ξ is the cosine of the angle between $\boldsymbol{m}_1$ and $\boldsymbol{m}_2$. At fixed total density $\varrho = \varrho_n + \varrho_p$ the energy per nucleon in asymmetric nucleon matter will depend on the neutron excess parameter, α,

$$E(\alpha) = \tfrac{3}{10}\frac{k_F^2}{2\mathscr{M}}[(1+\alpha)^{5/3} + (1-\alpha)^{5/3}] + \tfrac{3}{4}k_F^{-3} \sum_{\tau_z} \int_0^{k_{\tau_z}} dm_1 m_1^2 V_{\tau_z}(m_1). \tag{6}$$

Thus, the potential part of E depends on α in two ways: firstly, through the upper limits of the integrals in Eqs (5), (6), and secondly, through the intrinsic dependence of the reaction matrix on α, resulting from the α-dependence of the exclusion principle operators $Q_{\tau_z\tau'_z}$ and that of the starting energy $e_{\tau_z}(m_1)+e_{\tau'_z}(m_2)$, appearing in Eq. (3). This is the latter dependence on α which will imply the rearrangement effects in the symmetry energy of nuclear matter.

3. Rearrangement effects and the SDA

The rearrangement effects in asymmetric nuclear matter have two sources: the charge and α-dependence of the exclusion principle operator and the charge and α-depencence of the self-consistent starting energy $e_{\tau_z}(m_1)+e_{\tau'_z}(m_2)$ in Eq. (3). In the standard approximation in which the exclusion principle operator is replaced by its angle-averaged value (i.e., averaged over the directions of the total momentum of the nucleon pair) we have

$$Q_{\tau_z\tau_z} \approx \bar{Q}_{\tau_z\tau_z}(M, k) = \begin{cases} 0 & \text{if} \quad k < (k_{\tau_z}^2 - \tfrac{1}{4}M^2)^{1/2} \\ 1 & \text{if} \quad k > \tfrac{1}{2}M + k_{\tau_z} \\ (\tfrac{1}{4}M^2 + k^2 - k_{\tau_z}^2)/Mk & \text{otherwise} \end{cases} \tag{7}$$

in the case of the like nucleons pair, and

$$Q_{np} \approx \bar{Q}_{np}(M, k) = \begin{cases} 0 & \text{if} \quad k < [\tfrac{1}{2}(k_n^2 + k_p^2) - \tfrac{1}{4}M^2]^{1/2} \\ 1 & \text{if} \quad k > \tfrac{1}{2}M + k_n \\ \tfrac{1}{2}\left(1 + \dfrac{\tfrac{1}{4}M^2 + k^2 - k_n^2}{Mk}\right) & \text{for} \quad \tfrac{1}{2}M + k_p < k < \tfrac{1}{2}M + k_n \\ [\tfrac{1}{4}M^2 + k^2 - \tfrac{1}{2}(k_n^2 + k_p^2)]/Mk & \text{otherwise} \end{cases} \tag{8}$$

in the case of the n–p pair.

In the SDA [9], one approximates the exact, self-consistent reaction matrix $K_{\tau_z\tau'_z}(k_n, k_p)$ by that calculated in symmetric nuclear matter with a suitably defined value of $\tilde{k}_n = \tilde{k}_p = \tilde{k}_F$. In this way one avoids complicated self-consistent calculation with two different Fermi momenta. In the case of the like nucleons pair the SDA has the form

$$K_{\tau_z\tau_z}(k_n, k_p) \approx K_{\tau_z\tau_z}(k_{\tau_z}, k_{\tau_z}). \tag{9}$$

In this case approximate K-matrix is calculated from Eq. (3) with exact exclusion principle operator, but with a hole spectrum of symmetric nuclear matter of the density $\varrho = 2\varrho_{\tau_z}$. Let us mention that in the second order (in v) perturbation treatment of K, where the whole α-dependence of K is due only to the exclusion principle, relation (9) becomes exact (cf. [24]).

In the case of the unlike nucleons pair one approximates the self-consistent reaction matrix $K_{np}(k_n, k_p)$ by that calculated in symmetric nuclear matter with suitably defined "average" Fermi momentum ω,

$$K_{np}(k_n, k_p) \approx K_{np}(\omega, \omega). \tag{10}$$

In the original version of the SDA [9] the definition $\omega = [\frac{1}{2}(k_n^2+k_p^2)]^{1/2}$ has been used. In the case of the n−p pair even the exclusion principle effects are not treated exactly in the SDA, but the definition of ω as introduced in [9] may appear to be plausible in view of the form of $\overline{Q}_{np}$, Eq, (8). Let us mention, that the possibility of different definitions of ω, of the form $\omega = [(k_n^N+k_p^N)/2]^{1/N}$ with $N = 1, 3$, has been considered by Sprung and Banerjee [10].

4. Numerical results and discussion

The calculations have been performed at the density of nuclear matter $\varrho = 0.166\ \mathrm{fm}^{-3}$ (corresponding to the average Fermi momentum $\varrho = 1.35\ \mathrm{fm}^{-1}$) and for $\alpha = 0$, 0.2, 0.3 and 0.4. The Reid soft core potential [23] has been used as input nucleon-nucleon interaction. The reaction matrix has been calculated using angle-averaged exclusion principle operators, Eqs (7), (8) and effective mass approximations for the hole spectra. In the case of $\alpha \neq 0$ the self-consistent reaction matrix K_{np} has been calculated with the energy denominator of Eq. (3) averaged over the directions of the total momentum of the n−p pair [7] (cf., [6]). In contrast to all previous calculations [4–6] we have not used the average total momentum approximation [2]. A detailed description of our calculational procedure may be found in Ref.[7].

The energy per nucleon in asymmetric nuclear matter was calculated in four cases, which are described below:

A. Complete self-consistent calculation at each α;

B. The exclusion principle is treated correctly but single-particle spectra for symmetric ($\alpha = 0$) nuclear matter are used;

C. The calculation is performed using the reaction matrix of symmetric nuclear matter;

D. The calculation is performed using the reaction matrices calculated in the SDA.

The corresponding values of the symmetry energy, ε_s, has been obtained from the calculated values of $E(\alpha)$ using the least-squares fit of the usual form

$$E(\alpha)-E(0) = \varepsilon_s\alpha^2(1+\lambda\alpha^2). \tag{11}$$

The least-squares fits, Eq. (11), lead to the values of the symmetry energy, ε_s, and of the dimensionless parameter, λ, which are given in Table I. Our values of ε_s^* and λ, column A of Table I, should be compared with those obtained by Sjöberg [6] for the same density of nuclear matter. The least-squares fit to Sjöberg's values of $E(\alpha)-E(0)$ for $\alpha \leqslant 0.6$ yields $\varepsilon_s = 23.6$ MeV and $\lambda = 0.08$, which agree quite well with our results (see Ref. [7] for the discussion of the related problems).

The rearrangement contributions to the symmetry energy seem to be small (cf., [4, 6, 9]). The SDA leads to an overestimate of these contributions.

One may note quite a good agreement between the SDA value of ε_s and that calculated with exact treatment of the exclusion principle but with single particle spectra from symmetric nuclear matter, column B.

TABLE I

Calculated values of the symmetry energy, ε_s (in MeV) and of the dimensionless parameter λ

	A	B	C	D
ε_s	23.1	24.3	22.7	24.5
λ	0.13	0.30	0.35	0.25

Column A: exact self-consistent calculation. Column B: exact treatment of exclusion principle but hole spectrum from symmetric nuclear matter. Column C: calculated using the K matrix of symmetric nuclear matter. Column D: calculated in the SDA with $\omega = [(k_n^2+k_p^2)/2]^{1/2}$.

The direct calculation of ε_s from Eq. (11) gives

$$\varepsilon_s = \tfrac{1}{2}\left[\partial^2 E(\alpha)/\partial\alpha^2\right]_{\alpha=0}, \tag{12}$$

and the rearrangement contribution to ε_s, S_R, may be shown to be of the form [9]

$$S_R = -\tfrac{1}{3} V_{0R}(k_F) + S_{R1}, \tag{13}$$

where $V_{0R}(k_F)$ is the rearrangement potential at the top of the Fermi sea in symmetric nuclear matter. The first term in Eq. (13), $S_{R0} = -\frac{1}{3} V_{0R}(k_F)$, is negative and may be calculated from the density dependence of the reaction matrix in symmetric nuclear matter [11]. At $k_F = 1.35\,\mathrm{fm}^{-1}$ we obtain $S_{R0} \approx -3.2$ MeV. The second term in Eq. (13) contains the derivatives of the reaction matrix in asymmetric nuclear matter with respect to α and has been usually calculated using the SDA [9–13]. Our results (Table I, columns C and D) yield, together with our estimate of S_{R0}, the SDA value $S_{R1}^{SDA} \approx 5$ MeV, while exact calculation yield $S_{R1} \approx 3.6$ MeV. Thus, the SDA, Eqs (9), (10), overestimates S_{R1} (and S_R) by 1.4 MeV.

The calculation performed using the prescription $\omega = (k_n+k_p)/2$ would yield smaller value of S_{R1}. This follows from the inequality $(k_n+k_p)/2 < [(k_n^2+k_p^2)/2]^{1/2}$; the reaction matrix $\mathscr{K}_{np}$ is more attractive when calculated with arithmetic mean of k_n and k_p, leading to slightly stronger binding of asymmetric nuclear matter. On the contrary, the choice $\omega = [(k_n^3+k_p^3)/2]^{1/3} = k_F$ would increase the value of S_{R1}, leading to the stronger overestimating of the rearrangement contribution to ε_s (cf., Ref. [10]). Let us note, that even at $\alpha = 0.4$ the differences between the values of $\omega = [(k_n^N+k_p^N)/2]^{1/N}$ calculated for $N = 1, 2$ and 3 are quite small. At $k_F = 1.35\,\mathrm{fm}^{-1}$ we obtain $\omega = 1.324\,\mathrm{fm}^{-1}$, $1.337\,\mathrm{fm}^{-1}$ and $1.350\,\mathrm{fm}^{-1}$ for $N = 1$, 2 and 3, respectively, while $k_n = 1.510\,\mathrm{fm}^{-1}$, and $k_p = 1.139\,\mathrm{fm}^{-1}$. This relative sensibility to the choice of ω in Eq. (10) for $\mathscr{K}_{np}$ is due to the presence of the $^3S_1 - {}^3D_1$ channel in the n–p interaction.

Let us discuss now the rearrangement effects in the individual elements of the reaction matrix. In Table II we give the values of $\mathscr{K}_{\tau_z\tau'_z}$ for chosen values of momentum variables m and M. The results for $\mathscr{K}_{nn}$ and $\mathscr{K}_{pp}$ may be easily understood using qualitative con-

TABLE II

The values of $\mathscr{K}_{\tau_z\tau_z'}$ (in MeV fm^3) at $k_F = 1.35$ fm^{-1} and for $m = 0.7\ k_F$, $M = 0.3\ k_F$

	$\alpha = 0$	$\alpha = 0.4$		
		A	B	D
$\mathscr{K}_{nn}$	−207.1	−206.6	−203.5	−195.9
$\mathscr{K}_{pp}$	−207.1	−210.4	−213.3	−226.7
$\mathscr{K}_{np}$	−339.1	−337.6	−333.0	−343.7

For the explanation see the caption to Table I.

siderations. In our calculations we approximate the single-particle potentials by the effective mass expressions,

$$V_{\tau_z}(m_1) = -\Delta_{\tau_z} + \frac{m_1^2}{2\mathscr{M}}\left(\frac{1}{m^*_{\tau_z}} - 1\right). \tag{14}$$

In asymmetric nuclear matter with $\alpha > 0$ we have $\Delta_n < \Delta^0 < \Delta_p$, where Δ^0 is the depth of the hole spectrum in symmetric nuclear matter. On the other hand, $k_n > k_p$ and thus the exclusion principle tends to make $\mathscr{K}_{pp}$ more attractive then $\mathscr{K}_{nn}$ (cf., p. 133 of Ref. [1]). The results presented in Table II show, that the large part of this exclusion principle effect is suppressed by the dispersion effects, stemming from the large difference between Δ_n and Δ_p: at $\alpha = 0.4$ we have $\Delta_p - \Delta_n \approx 26$ MeV. The self-consistency tends to make $\mathscr{K}_{nn}$ more attractive than $\mathscr{K}_{pp}$. When applying at such a high α the SDA, we grossly violate the self-consistency. In fact, using the prescription of the SDA we obtain $\Delta_p^{SDA} - \Delta_n^{SDA} = -37$ MeV. Thus, in the SDA the dispersion effects act in the same direction as those stemming from the exclusion principle: they make $\mathscr{K}_{pp}$ more attractive, making at the same time $\mathscr{K}_{nn}$ less attractive (as compared with symmetric nuclear matter).

The qualitative discussion of the $\mathscr{K}_{np}$ case is more difficult. One may note, that self-consistency corrections to the starting energy are here of the order $\sim \alpha^2$ (and not $\sim\alpha$, as in the case of the like nucleons pair). However, in the case of the n−p pair the presence of the $^3S_1 - {}^3D_1$ channel makes the reaction matrix more sensitive to the exclusion principle and dispersion corrections. Consequently, the SDA results for $\mathscr{K}_{np}$ are quite sensitive to the definition of ω, appearing in Eq. (10).

The SDA seems to give better results for the symmetry energy of nuclear matter than for the individual elements of the reaction matrix in asymmetric nuclear matter. The summations and integrations in Eqs (5), (6) imply, quite fortunately, the cancellation of the large part of the incorrect dispersion effects of the SDA.

5. *Conclusions*

The lowest order Brueckner theory calculations show, in agreement with previous estimates, that the rearrangement contribution to the symmetry energy is small. The SDA, used in the previous studies of the properties of asymmetric nuclear matter, overestimates

the rearrangement contribution to the symmetry energy[1]. The rearrangement effects, resulting from the exclusion principle, are partly cancelled by those resulting from the self-consistency of the hole spectra. The calculation of the reaction matrix in asymmetric nuclear matter shows, that the SDA may give a rather poor representation of the effective nucleon-nucleon interaction in asymmetric nuclear matter with a large neutron excess (e.g., $\alpha = 0.4$). The incorrect treatment of the dispersion effects by the SDA leads to quite a large overestimate of the rearrangement effects in the n−n and p−p reaction matrices in such a highly asymmetric nuclear matter.

The author expresses his gratitude to Professor C. Mahaux from the Institute of Physics of the University of Liége for critical reading of the manuscript.

REFERENCES

[1] H. A. Bethe, *Ann. Rev. Nucl. Sci.* **21**, 93 (1971).
[2] D. W. L. Sprung, *Adv. Nucl. Phys.* **5**, 225 (1972).
[3] G. Baym, C. Pethick, *Ann. Rev. Nucl. Sci.* **25**, 27 (1975).
[4] K. A. Brueckner, S. A. Coon, J. Dąbrowski, *Phys. Rev.* **168**, 1184 (1968).
[5] P. J. Siemens, *Nucl. Phys.* **A141**, 225 (1970).
[6] O. Sjöberg, *Nucl. Phys.* **A222**, 161 (1974).
[7] M. Haensel, P. Haensel, *Z. Phys.* **A** (in print).
[8] P. Haensel, *J. Phys. G* (*Nucl. Phys.*) **2**, L 117 (1976).
[9] K. A. Brueckner, J. Dąbrowski, *Phys. Rev.* **134**, B722 (1964).
[10] D. W. L. Sprung, P. K. Banerjee, *Nucl. Phys.* **A168**, 273 (1971).
[11] J. Dąbrowski, P. Haensel, *Phys. Rev.* **C7**, 916 (1973).
[12] J. Dąbrowski, P. Haensel, *Phys. Lett.* **42B**, 163 (1972).
[13] J. Dąbrowski, P. Haensel, *Can. J. Phys.* **52**, 1768 (1974).
[14] J. Dąbrowski, *Acta Phys. Pol.* **B7**, 657 (1976).
[15] K. A. Brueckner, J. L. Gammel, *Phys. Rev.* **109**, 1040 (1958).
[16] E. Østgaard, *Nucl. Phys.* **A154**, 202 (1970).
[17] P. Haensel, *Phys. Rev.* **C11**, 1822 (1975).
[18] P. Haensel, *Acta Phys. Pol.* **B6**, 755 (1975).
[19] D. Ellis, D. W. L. Sprung, *Can. J. Phys.* **50**, 2277 (1972).
[20] V. R. Pandharipande, R. B. Viringa, B. D. Day, *Phys. Lett.* **57B**, 205 (1975); J. C. Owen, R. F. Bishop, J. M. Irvine, *Phys. Lett.* **61B**, 147 (1976).
[21] E. Krotscheck, K. Takaishi, preprint
[22] E. Krotscheck, preprint.
[23] K. V. Reid, *Ann. Phys.* **50**, 411 (1968).
[24] J. Dąbrowski, M. Y. M. Hassan, *Acta Phys. Pol.* **29**, 309 (1966).

[1] Let us mention that the comparison of results of Ref. [4] with the SDA estimates of Ref. [9] leads to a similar conclusion. However, in Ref. [11] the difference $\varepsilon_5^{\mathrm{SDA}} - \varepsilon_5 \approx 2$ MeV has been interpreted as a consequence of not sufficiently accurate treatment of the density dependence of the reaction matrix in symmetric nuclear matter.