Role of the tensor force in nuclear matter saturation

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In the fraamework of a relativistic Dirac-Brueckner analysis the pion contribution to the ground state energy of nuclear matter is studied using pseudovector coupling. Evidence is presented that the role of the tensor force in the saturation mechanism is substantially reduced compared to its dominant role in a usual nonrelativistic treatment. The reduction of the pion contribution in nuclear matter is due to many-body effects present in a relativistic treatment. In particular, we show that the damping of the one-pion-exchange potential is actually due to the decrease of M^*/M with increasing density. [S0556-2813(98)05310-2]

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The basic understanding of the saturation mechanism of nuclear matter has been the subject of numerous investigations. More than four decades ago it was pointed out that in the absence of the tensor component in the nuclear force the saturation properties of normal nuclear matter cannot be understood [1]. In particular, saturation then occurs at a density one order of magnitude or more higher than the empirical saturation density ρ_0 of normal nuclear matter, with $\rho_0 = 0.17\ \mathrm{fm}^{-3}$. The effect of the pion, being given essentially by the second-order one-pion-exchange potential (OPEP) contribution, is attractive and large at low density. Pauli blocking reduces the attraction as density increases. In a nonrelativistic description of the nuclear many-body system this mechanism leads to saturation of nuclear matter at a density well in correspondence with the empirical data.[1] The tensor force also plays a dominant role in the formation of the deuteron in a nonrelativistic framework. Thus for the deuteron

$$\langle D|V_{\mathrm{total}}|D\rangle \simeq 2\langle {}^3D_1|V_{\mathrm{tensor}}|{}^3S_1\rangle \sim -22\ \mathrm{MeV},$$

while the kinetic energy is ~ 20 MeV, adding up to a binding energy of ~ -2 MeV. In a nonrelativistic Bethe-Brueckner calculation of nuclear matter one finds typically [2]

$$\langle \mathrm{NM}|V_\pi|\mathrm{NM}\rangle_{\mathrm{nonrelativistic}} = V_\pi^{(0)}(\rho/\rho_0)^\beta \sim -34(\rho/\rho_0)^{0.45}\ \mathrm{MeV}. \qquad (1)$$

The exponent of the density ρ is markedly less than the nominally expected value of 1 because of Pauli blocking.

The values of $V_\pi^{(0)}$ and β in Eq. (1) are particular to the Bonn C potential used in the calculation. Another reasonable NN potential may give noticeably different values. What is important is the relationship between the two quantities $V_\pi^{(0)}$ and β and not their individual values. In a simplified view of nuclear matter saturation we may write $E/A \simeq T_N^{(0)}(\rho/\rho_0)^{2/3} + V_\pi^{(0)}(\rho/\rho_0)^\beta + V_{\mathrm{rest}}$, where $T_N^{(0)} = (3/5)k_F^2/2M \simeq 25$ MeV and the last term, which represents rest of the interaction energy, is taken to be nearly independent of density in the neighborhood of $\rho \sim \rho_0$. Then the condition for saturation requires

$$\beta \times V_\pi^{(0)} \sim -17\ \mathrm{MeV}. \qquad (2)$$

In the case of the Bonn C potential we have $\beta \times V_\pi^{(0)} \sim -15$ MeV, which is close to the right-hand side of Eq. (2). A very much smaller value for $\beta \times V_\pi^{(0)}$ would indicate that the OPEP is not playing an important role in the saturation mechanism.

In a relativistic theory one must first specify the choice of the form of the pion-nucleon coupling: pseudovector, $\mathcal{L}_{\mathrm{pv}} = (g_{\pi NN}/2M)\overline{\psi}(x)\gamma_5\gamma^\mu\vec{\tau}\psi(x)\cdot\partial_\mu\vec{\pi}(x)$, or pseudoscalar, $\mathcal{L}_{\mathrm{ps}} = g_{\pi NN}\overline{\psi}(x)i\gamma_5\vec{\tau}\vec{\pi}(x)\psi(x)$. So far most of the published relativistic calculations are based on the use of $\mathcal{L}_{\mathrm{pv}}$ for the simple reason that the problem of pair suppression is then taken care of without special effort. In this paper we assume that an effective hadronic Lagrangian using derivative coupling is the proper choice for describing the pion-nucleon interaction.

The relativistic result for the contribution of V_π to the deuteron, as obtained in the work of Hummel and Tjon [3], is $\langle D|V_\pi|D\rangle = -22$ MeV. This leads one to expect an equally important role of the pion in the relativistic treatment. In sharp contrast, this seems not to be the case in a relativistic treatment of nuclear matter. The saturation mechanism is believed to rest upon the strong attractive, scalar (S) and repulsive, vector (V) fields of the order of a few hundred MeV that are typical for relativistic theories [4–6] of nuclear matter. These values are consistent with expectations based on the studies of scattering of ~ 1 GeV protons by nuclei [7–9]. At the same time, they are reproduced by a reasonable meson theoretical description of the nuclear force. The large scalar fields have far-reaching consequences in nuclear matter through the strongly medium-modified nucleon mass $M^* = M + S$. The saturation mechanism in a relativistic theory arises from the decrease of magnitude of the scalar charge of

[1]The role of the tensor force mediated by a ''tensor'' coupled ρ meson is also well known. It generates shorter-ranged repulsion which partially cancels the effect of the OPEP tensor force with increasing density and thus strengthens the saturation mechanism.

a nucleon, $g_\sigma(p)=g_{\sigma NN}\int d^3r\overline{u}(\vec{p})u(\vec{p})$, with increasing momentum, while the corresponding vector charge $g_{\omega NN}\int d^3ru^\dagger(\vec{p})u(\vec{p})$ remains constant.[2] Of course, it is the only possible mechanism for saturation in a mean field theory (MFT) like QHD [11,12].

The radically different explanations of the saturation mechanism in nonrelativistic and relativistic studies of nuclear matter constitute a puzzling issue. A valid nonrelativistic treatment must reproduce the main physics of a valid relativistic treatment in leading order in v/c. Although the issue is a long-standing one, no resolution of it has been given up to date. In this paper we address this question. A Dirac-Brueckner (DB) analysis [4,5] is at present the best tool we have for a relativistic study of nuclear matter. We examine here the role of the OPEP, using pseudovector coupling, in the DB analysis and show that it is substantially reduced due to relativity. Since the contribution of the OPEP to the deuteron binding energy remains large in a relativistic treatment, the damping in nuclear matter must be due to many-body effects. We find that it can be attributed to the decrease of M^*/M with increasing density.

Assuming that the nuclear matter is uniform in space and constant in time with a given density ρ, the baryon current is given by $B^\mu=\rho u^\mu$, with $u^\mu=(0,\vec{1})$ being the unit vector in the nuclear matter frame. Relativistic covariance implies that the self-energy contribution of the nucleon with momentum p can be characterized by

$$\Sigma=\Sigma^s-\Sigma^u\gamma\cdot u-\Sigma^v\gamma\cdot p. \tag{3}$$

The medium-modified mass of the nucleon is then given by

$$M^*=(M+\Sigma^s)/(1+\Sigma^v).$$

The ground state binding energy E/A is given in terms of the NN G matrix as

$$E/A=M^*\left(\frac{3\pi^2}{2k_F^3}\right)\Bigg[8\int_0^{k_F/M^*}\frac{d^3p}{(2\pi)^3}[E(\vec{p})-M^*] + \frac{1}{2}\sum_{(\lambda,i)}\int_0^{k_F/M^*}\frac{d^3p_1}{(2\pi)^3}\frac{1}{E(\vec{p}_1)}\int_0^{k_F/M^*}\frac{d^3p_2}{(2\pi)^3}\frac{1}{E(\vec{p}_2)}\langle\vec{p}_1,\lambda_1,i_1;\vec{p}_2,\lambda_2,i_2|G|\vec{p}_1,\lambda_1,i_1;\vec{p}_2,\lambda_2,i_2\rangle\Bigg], \tag{4}$$

where $E(\vec{p})=\sqrt{\vec{p}^2+M^{*2}}$. The G matrix satisfies the Dirac-Bethe-Brueckner-Goldstone equation. Within a relativistic *quasi-potential* approach it has, in the NN c.m. system, the form

$$\langle\vec{p}\,'|\overline{G}|\vec{p}\,\rangle=\langle\vec{p}\,'|\overline{V}|\vec{p}\,\rangle+\sum_{\rho,\lambda,i}\int\frac{d^3p''}{(2\pi)^3}\langle\vec{p}\,'|\overline{V}|\vec{p}\,''\rangle\overline{S}_2(p'')\langle\vec{p}\,''|\overline{G}|\vec{p}\,\rangle, \tag{5}$$

where we sum over the ρ spin, helicities, and isospin and integrate over the relative momenta $\vec{p}\,''$ of allowed intermediate states.

The quasipotential is a fairly complicated object. It involves summing over all irreducible graphs and containing in principle also resonances in the intermediate state. In practice, one approximates this by a sum of OBEP's to represent the nuclear force and fixes the parameters by fitting NN data. Through all of these the form of the OPEP remains exactly the same as that due to the original Lagrangian, since none of the higher order graphs will generate a term with a pole at $t=m_\pi^2$.

The quantity S_2 in Eq. (5) is the two-nucleon Green function, including the Pauli-blocking operator $\overline{Q}_{\rm Pauli}$. Using a Blankenbecler-Sugar-Logunov-Thavkhelidze prescription $\overline{S}_2$ has the form [13,14]

$$\overline{S}_2(l'')=\frac{\pi M^*}{(1+\Sigma^v)}\frac{[E_f\gamma_0-\vec{k}\vec{\gamma}+M^*][E_f\gamma_0+\vec{k}\vec{\gamma}+M^*]}{(E^*+E_f)^2(E_k^*-E_f-i\epsilon)}\overline{Q}_{\rm Pauli}, \tag{6}$$

with $E_f=W_0/(1+\Sigma^v)$ and $W_0^2=(p_1+p_2)^2$, W_0 being the total invariant energy of the final state. Furthermore, in Eq. (5), $\overline{V}$ are the quasipotential matrix elements in Dirac space,

$$\langle\vec{p}\,'|\overline{V}|\vec{p}\,\rangle=M^{*2}[\overline{u}(\vec{p}\,')^{(1)}_{\lambda_1',\rho_1'}\overline{u}(-\vec{p}\,')^{(2)}_{\lambda_2',\rho_2'}Vu(\vec{p})^{(1)}_{\lambda_1,\rho_1}u(-\vec{p})^{(2)}_{\lambda_2,\rho_2}], \tag{7}$$

where u's are the positive and negative energy ($\rho=\pm1/2$) spinors for mass M^* fermions, satisfying

$$(\rho E^*\gamma_0-\vec{\gamma}\cdot\vec{p}-M^*)u_{\lambda,\rho}(\vec{p})=0, \tag{8}$$

with $E^*=(\vec{p}^{\,2}+M^{*2})^{1/2}$.

[2]Actually the quark structure of the nucleon makes both charges density dependent [10] by small but interesting amounts.

Using an angle-averaged Pauli-blocking operator we may see that the two-nucleon Green function has the approximate form

$$\overline{S}_2=\frac{M^{*2}}{E^{*\,2}(\vec{P},\vec{p})-E^{*\,2}(\vec{P},\vec{k})}\approx\frac{1}{(\vec{p}/M^*)^2-(\vec{k}/M^*)^2}. \tag{9}$$

The last line of Eq. (9) shows the emergence of a new scale in the problem, viz., M^*. The contributions of intermediate states of relative momentum $\vec{p}$ to second- and higher-order terms in an expansion of the right hand side of Eq. (5) will be suppressed as p/M^* increases. The effect is best seen by introducing dimensionless momenta $l_i=p_i/M^*$. Then the expression for E/A becomes

$$\begin{aligned}E/A=M^*\left(\frac{3\pi^2}{2k_F^3}\right)\Bigg[8\int_0^{k_F/M^*}\frac{d^3l}{(2\pi)^3}[\overline{E}(\vec{l})-1]\\
+\frac{1}{2}\sum_{(\lambda,i)}\int_0^{k_F/M^*}\frac{d^3l_1}{(2\pi)^3}\frac{1}{\overline{E}(\vec{l}_1)}\int_0^{k_F/M^*}\frac{d^3l_2}{(2\pi)^3}\frac{1}{\overline{E}(\vec{l}_2)}\langle\vec{l}_1,\lambda_1,i_1;\vec{l}_2,\lambda_2,i_2|\overline{G}|\vec{l}_1,\lambda_1,i_1;\vec{l}_2,\lambda_2,i_2\rangle\Bigg],\end{aligned} \tag{10}$$

where $\overline{E}(\vec{l})=\sqrt{\vec{l}^2+1}$.

Interdependence of the nucleon self-energy and the G matrix, for a fixed given nuclear matter density, requires self-consistency in solving the DB equations. As stated earlier, the NN quasipotential is taken to be given by the relativistic one-boson-exchange (OBE) model with π, ρ, ω, σ, δ, and η mesons. We also remind the reader that we use derivative coupling for the pion. We do the same for η. We have, ignoring the isospin factors, for the scalar, vector, and pseudoscalar meson exchanges in nuclear matter

$$\langle\vec{p}\,'|V_\sigma|\vec{p}\rangle=-g_\sigma^2\frac{[\overline{u}(\vec{p}\,')u(\vec{p})]^{(1)}[\overline{u}(-\vec{p}\,')u(-\vec{p})]^{(2)}}{(\vec{p}\,'-\vec{p})^2+m_\sigma^2}=-\frac{1}{M^{*2}}g_\sigma^2\frac{[\overline{u}(\vec{l}\,')u(\vec{l})]^{(1)}[\overline{u}(-\vec{l}\,')u(-\vec{l})]^{(2)}}{(\vec{l}\,'-\vec{l})^2+(m_\sigma/M^*)^2}, \tag{11}$$

$$\begin{aligned}\langle\vec{p}\,'|V_{\omega,\rho}|\vec{p}\rangle&=g_V^2\left[\overline{u}(\vec{p}\,')\left\{\gamma_\mu+i\frac{f_V}{2M}\sigma_{\mu\nu}(p'-p)^\nu\right\}u(\vec{p})\right]^{(1)}\frac{1}{(\vec{p}\,'-\vec{p})^2+m_V^2}\left[\overline{u}(-\vec{p}\,')\left\{\gamma^\mu-i\frac{f_V}{2M}\sigma^{\mu\nu}(p'-p)_\nu\right\}u(-\vec{p})\right]^{(2)}\\
&=\frac{1}{M^{*2}}g_V^2\left[\overline{u}(\vec{l}\,')\left\{\gamma_\mu+i\frac{f_V}{2}\frac{M^*}{M}\sigma_{\mu\nu}(l'-l)^\nu\right\}u(\vec{l})\right]^{(1)}\frac{1}{(\vec{l}\,'-\vec{l})^2+(m_V/M^*)^2}\\
&\quad\times\left[\overline{u}(-\vec{l}\,')\left\{\gamma^\mu-i\frac{f_V}{M}\frac{M^*}{M}\sigma^{\mu\nu}(l'-l)_\nu\right\}u(-\vec{l})\right]^{(2)},\end{aligned} \tag{12}$$

$$\begin{aligned}\langle\vec{p}\,'|V_P|\vec{p}\rangle&=-\left(\frac{g_P}{2M}\right)^2[\overline{u}(\vec{p}\,')\gamma_5(\not{p}'-\not{p})u(\vec{p})]^{(1)}\frac{1}{(\vec{p}\,'-\vec{p})^2+m_P^2}[\overline{u}(-\vec{p}\,')\gamma_5(\not{l}'-\not{l})u(-\vec{p})]^{(2)}\\
&=-\left(\frac{M^*}{M}\right)^2\frac{1}{M^{*2}}\left(\frac{g_P}{2}\right)^2[\overline{u}(\vec{l}\,')\gamma_5(\not{l}'-\not{l})u(\vec{p})]^{(1)}\frac{1}{(\vec{l}\,'-\vec{l})^2+(m_P/M^*)^2}[\overline{u}(-\vec{l}\,')\gamma_5(\not{l}'-\not{l})u(-\vec{l})]^{(2)}.\end{aligned} \tag{13}$$

We will assume that the possible density dependence of meson-nucleon couplings and meson masses [10] can be neglected in the present context.

As can be seen from Eqs. (11)–(13) the corresponding matrix elements of the tensor force have two extra powers of momentum in the numerator compared to other potential matrix elements. After scaling, these result in extra factors of $(M^*/M)^2$. Thus the contributions of the π, η, and the Pauli coupling of the vector mesons to second- and higher-order terms of Eq. (5) are suppressed by powers of M^*/M.[3] So with increasing density and, therefore, with decreasing M^* these matrix elements have suppression factors not present in other matrix elements generated by exchanges of even parity mesons like σ and the time components of ω. We should

[3]These couplings have only minor contributions in the first order, coming entirely from the Fock term.

expect that the tensor forces will play a less important role in a relativistic theory.

Given the solutions of the G matrix the binding energy can be obtained using Eq. (4). The contributions of the various meson-exchange potentials to the binding energy can be calculated using the Hellmann-Feynman theorem

$$\langle \mathrm{NM}|V_\alpha|\mathrm{NM}\rangle = g_{\alpha NN}^2 \frac{\partial}{\partial g_{\alpha NN}^2}(E/A). \tag{14}$$

In a DB calculation with the interactions of Ref. [5] we find, for the scalar field,

$$S_{\mathrm{DB}} = -306(\rho/\rho_0)^{0.81} \ \ \mathrm{MeV} \tag{15}$$

and, for the vector field,

$$V_{\mathrm{DB}} = 233(\rho/\rho_0)^{0.97} \ \ \mathrm{MeV}. \tag{16}$$

This reduction in the rate of increase of the strength of S compared to the increase of V with increasing density is the saturation mechanism in the DB analysis.

In a MFT the vector field and the scalar field arise from the exchange of the ω and the σ meson [11,12]. The relevant equations for the fields are

$$V_{\mathrm{MFT}} = \rho \frac{g_{\omega NN}^2}{m_\omega^2}, \tag{17}$$

$$S_{\mathrm{MFT}} = \rho \overline{q}_s \frac{-g_{\sigma NN}^2}{m_\sigma^2}, \tag{18}$$

where the average scalar charge $\overline{q_s}$ is given by

$$\overline{q_s} = \frac{3}{4\pi k_K^3}\int_0^{k_F} d^3p \frac{M^*}{E^*(\vec{p})} \tag{19}$$

and

$$M^* = M + S, \tag{20}$$

$$E^*(\vec{p}) = \sqrt{M^{*2} + \vec{p}^2}. \tag{21}$$

The energy functional is

$$E/A = \frac{3}{5}\frac{k_F^2}{2M^*} + \frac{1}{2}V + \frac{1}{2}\overline{q}_s S. \tag{22}$$

Equations (17)–(22) are solved self-consistently to obtain the results for MFT treatment of nuclear matter. Using the interaction of Ref. [5] we obtain

$$S_{\mathrm{MFT}} = -358(\rho/\rho_0)^{0.92} \ \ \mathrm{MeV}, \tag{23}$$

$$V_{\mathrm{MFT}} = 295\,(\rho/\rho_0) \ \ \mathrm{MeV}. \tag{24}$$

The reduced rate of increase of S_{MFT} with increasing ρ is entirely due to the decrease of scalar charge of the nucleon.

In a DB study, the ladders include exchanges of other mesons and they contribute to both S and V. As a result there are significant differences in both the magnitude and density

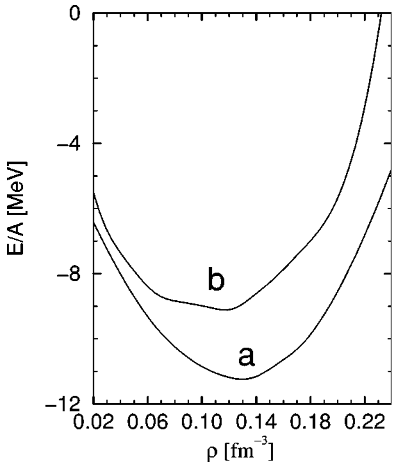

FIG. 1. Plots of the Dirac-Brueckner predictions of E/A (curve a) and $E/A - \langle \mathrm{NM}|v_\pi|\mathrm{NM}\rangle - 17$ MeV (curve b).

dependence of S and V in the two treatments. Thus when ladders are summed the saturation mechanism need not be exclusively due to σ exchange.

We find for the pion contribution to E/A

$$\langle \mathrm{NM}|V_\pi|\mathrm{NM}\rangle_{\mathrm{relativistic}} = V_\pi^{(0)}(\rho/\rho_0)^\beta \sim -20\,(\rho/\rho_0)^{0.16} \ \ \mathrm{MeV}. \tag{25}$$

We note that in this particular relativistic calculation the product $\beta \times V_\pi^{(0)} = -3.2$ MeV, far short of the estimated value of -17 MeV required for saturation and quoted in Eq. (2). Another interaction model and different treatment may lead to different values of β and $V_\pi^{(0)}$. But the product is likely to remain small.

Thus we find that the pion contribution and its role in the saturation mechanism are considerably suppressed compared to the corresponding results, given by Eq. (1), for the nonrelativistic case. Subsequent discussions will make clear that the suppression of the OPEP is generic and not particular to the present calculation. The fact that the OPEP has only a minor role in the saturation mechanism is illustrated further by Fig. 1 where we plot our calculated results of E/A (curve a) and $E/A - \langle \mathrm{NM}|v_\pi|\mathrm{NM}\rangle - 17$ MeV (curve b). The two curves have practically the same density dependence, verifying that the OPEP contributes little to the saturation mechanism. The subtraction of 17 MeV in curve b makes the scale more compact.

The above results can be understood qualitatively by examining the second-order contributions to the G matrix. Keeping only the positive energy M^* state contributions in the intermediate states we have, in terms of the dimensionless momenta,

$$\langle \vec{l}\,'|\overline{G}|\vec{l}\,\rangle = \langle \vec{l}\,'|\overline{V}|\vec{l}\,\rangle + \sum_{\lambda,i}\int \frac{d^3l''}{(2\pi)^3}\langle \vec{l}\,'|V|\vec{l}\,''\rangle \times \frac{\overline{Q}_{\mathrm{Pauli}}}{\overline{W}_0 - \vec{L}\,'^2/4 - \vec{l}\,''^2}\langle \vec{l}\,''|\overline{V}|\vec{l}\,\rangle, \tag{26}$$

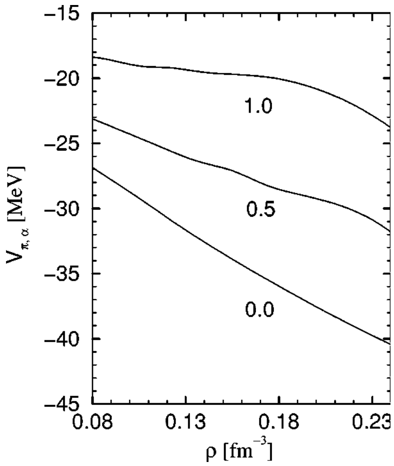

FIG. 2. Plots of $\langle \mathrm{NM}|V_\pi|\mathrm{NM}\rangle$ with the parameters of Ref. [5]. In the G-matrix calculations S is replaced by αS. The plots are for $\alpha=0$, 0.5, and 1.0. The last one is the result of a DB self-consistent calculation. The other two are not self-consistent.

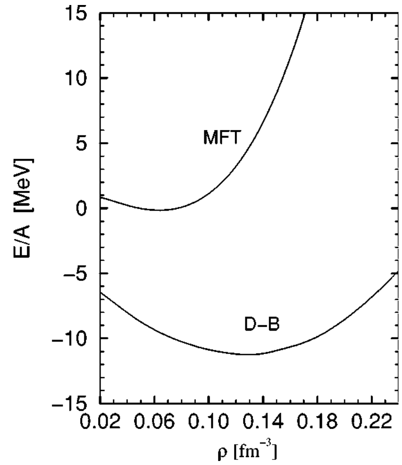

FIG. 3. Plots of E/A with the quasipotential of Ref. [5] from a Dirac-Brueckner and a MFT calculation using Eqs. (17)–(22).

where $\overline{W}_0 = W_0/M^*$ and $\vec{L}=(\vec{p}_1+\vec{p}_2)/M^*$. The tensor force contributes mainly to the second term of Eq. (26). It has the form

$$\langle \vec{l}\,'|\overline{V}_\pi|\vec{l}\rangle = -\left(\frac{g_{\pi NN}}{2}\right)^4\left(\frac{M^*}{M}\right)^4[\overline{u}(\vec{l})\gamma_5(\not{l}'-\not{l})u(\vec{l})]^{(1)} \times\frac{1}{(\vec{l}\,'-\vec{l})^2+\overline{m}_\pi^2}[\overline{u}(-\vec{l}\,')\gamma_5(\not{l}'-\not{l})u(-\vec{l})]^{(2)}, \tag{27}$$

where u's are the positive energy spinors. Similar to the nonrelativistic case the second-order pion contribution is density dependent because of the Pauli blocking. However, as mentioned earlier and now exhibited in Eq. (27), the effective coupling of the pion to the nucleon in the relativistic case is suppressed by a factor of M^*/M when the expressions are written in terms of dimensionless variables.

The M^*/M suppresssion is corroborated in more detail by the following calculation. Let us modify the S obtained from the self-consistent DB calculation by multiplying it by the factor $\alpha\leqslant 1$, thus generating a modified $M^*=M+\alpha S$. By using the modified scalar self-energy in the nucleon propagators we recalculate first the G matrices and then E/A and finally $\langle \mathrm{NM}|V_\pi|\mathrm{NM}\rangle$ using Eq. (14). Only the $\alpha=1$ analysis is self-consistent; others are not. But such a calculation is particularly suitable to exhibit the role of M^*/M on the OPEP contribution. Figure 2 exhibits clearly the damping due to decreasing M^*/M. We stress that the mechanism of damping is generic to any relativistic treatment using a derivative-coupled pion and not particular to either interaction of Ref. [5] or the use of the prescription of Ref. [13].

We want to be careful that the present work not be interpreted as providing support for MFT. As shown in Fig. 3, for the same interaction the strengths of the scalar and vector fields found in the MFT treatment are distinctly different from the predictions of DB calculations. Undoubtedly, if one releases oneself from the constraint of fitting NN data and freely chooses the NN interaction one can obtain proper binding and saturation of nuclear matter with a MFT calculation.

All published relativistic studies to date of nuclear matter have been based on using the pseudovector pion-nucleon interaction. We must point out that our results are also based on this. Unfortunately there is no study of nuclear matter using a pseudoscalar coupling. We prefer not to speculate about the possible outcome of such a calculation.

In conclusion, the results presented in this paper are the first explicit calculations showing that in a relativistic treatment the tensor force contributions are reduced in size in nuclear matter. Because of this, in complete contrast to the nonrelativistic situation, they cease to play an essential role in the saturation mechanism. The reduction of the tensor force contributions is principally due to the relativistic M^*/M effect. But even the reduced role of the OPEP is not negligible in the actual saturation properties of nuclear matter. As noted, it contributes -20 MeV to E/A. The dominant mechanism of the saturation of nuclear matter is basically very different in the two approaches. In the nonrelativistic approach it is mainly the density-dependent reduction due to Pauli blocking of the second- and higher-order contributions of tensor forces, while in the relativistic approach it is mainly the reduction of the rate of growth with increasing ρ of the attraction from the scalar field relative to the growth of repulsion from the vector field.

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