Roles of Chiral Symmetry and the Sigma Meson in Hadron and Nuclear Physics

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We first review the recent accumulating evidences of the existence of a scalar-isoscalar meson with the mass 500 to 800 MeV which may be identified with the sigma meson as the quantum fluctuation of the amplitude of the chiral order parameter \( \langle \bar{q}q \rangle \). We indicate that phase shift analyses which respect chiral symmetry (ChS), analyticity and crossing symmetry of the scattering amplitude show the sigma meson pole in the \( s \)-channel as well as the \( \rho \) meson pole in the \( t \)-channel in the \( \pi-\pi \) scattering in the \( I = J = 0 \) channel. We emphasize that the existence of the \( \sigma \) resonance does not contradict with the success of the chiral perturbation theory; phenomenological difficulties with the renormalizable linear sigma model do not necessarily deny the validity of the linear representation of ChS of QCD as given by the NJL-like models which not only admit the \( \sigma \) resonance but also reproduce the coupling constants \( L_i \) and \( H_i \) appearing the nonlinear chiral lagrangian. We give some examples of the hadronic phenomena which are naturally accounted for with the \( \sigma \) meson. We show that the the \( \sigma \) meson as the amplitude fluctuation of the chiral order parameter may be more clearly identified than in free space in hot and/or dense matter, even in finite nuclei where partial restoration of ChS may be realized.

§1. Introduction

The low-energy hadronic world is characterized by the dynamical breaking of chiral symmetry (ChS), \( U_A(1) \) anomaly, explicit \( SU_V(3) \) breaking, success of the constituent quark model, OZI rule and its violation in mesons and baryons, vector meson dominance, and so on, even apart from the confinement of the colored quarks and gluons. Although it is still a big challenge to explain the above mentioned problems directly from QCD, a semi-phenomenological but unified description of the above facts may be possible using a chiral effective model. As was first discussed by Nambu, the collective nature of the vacuum and some hadrons related to the dynamical breaking of ChS is essential for giving the unified description, especially in realizing the chiral quark picture. In Ref.2), the dominant role of chiral symmetry in low-energy hadron dynamics was emphasized. One may also recognize that ChS plays an essential role in making nuclei stable hence our very existence. Notice that nuclei are only stable bound systems in the hadron world. One may say that this stability is due to the chiral symmetry of QCD; see §6 of Ref. 9).

The basic observation on which the whole discussions in this report are based is that the dynamical breaking of ChS is a phase transition of the QCD vacuum with an

\* The \( \Delta I = 1/2 \) rule both in the meson and baryon decays may be a reflection of some collective nature of the dynamics originated from ChS; the \( \sigma \) meson and the diquarks may represent such collectiveness.
order parameter $\langle \bar{q}q \rangle \sim \sigma_0$, hence there may exist collective excitations corresponding to the quantum fluctuations of the order parameter: The quantum fluctuation of the phase of the order parameter is the pion, while the $\sigma$ meson as we call here is nothing but the quantum fluctuation of the amplitude of the chiral condensate. Therefore, exploring the existence of the $\sigma$ meson and its possible roles in the hadron world are of fundamental importance for understanding of the nonperturbative structure of the QCD vacuum.

§2. Low-energy QCD and the $\sigma$ meson

2.1. The $\sigma$ meson as the quantum fluctuation of chiral order parameter

Theoretically, the scalar quark condensate $\langle \bar{q}q \rangle = \sigma_0$ is determined as the value where the effective potential (free energy) $V(\sigma)$ takes the minimum. The $\sigma$ meson is the particle representing the quantum fluctuation $\tilde{\sigma} \sim \langle (\bar{q}q)^2 \rangle$ as stated above; $\sigma = \sigma_0 + \tilde{\sigma}$. In this sense, the $\sigma$ meson is analogous to the Higgs particle in the standard model, where the Higgs field is the order parameter, and the quantum fluctuation of the field around the minimum point of the Higgs potential or the effective potential is the Higgs particle in the present world.

2.2. Chiral perturbation theory and the $\sigma$ meson

Some effective theories including the ladder QCD predict the $\sigma$ meson mass $m_\sigma = 500 - 800$ MeV. Furthermore, Weinberg’s mended symmetry also leads to the existence of the $\sigma$ meson and the degeneracy of it with the $\rho$ meson.

The Nambu-Jona-Lasinio(NJL)-like models are known to work well as an effective theory which well describe the chiral properties of of the low-energy hadronic world including resonance phenomena and the processes incorporating chiral anomaly. In these models, ChS is realized linearly and can incorporate the vector mesons as well. It is worth emphasizing that the NJL-like models not only predict the $\sigma$ meson with the mass mentioned above but also reproduce the phenomenological parameters $L_i$ and $H_i$ appearing in the nonlinear chiral lagrangian up to $O(p^4)$ only to which calculations are available; see also an excellent review.

It means that the fact that the renormalizable linear sigma model may not match the low-energy phenomenology, as emphasized by Gasser and Leutwyler, do not necessarily deny the linear realization of chiral symmetry as given in the NJL-like models.

2.3. Chiral symmetry, analyticity, crossing symmetry and the $\sigma$-meson pole in the $\pi-\pi$ scattering matrix

A tricky point on the $\sigma$ meson is that the elusive meson strongly couples to two pions to acquire a large width $\Gamma \sim m_\sigma$, which makes tough to deduce a phase shift reliably enough of the $\pi-\pi$ scattering in the $I = J = 0$ channel. Nevertheless recent

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* The Nambu-Goldstone (NG) bosons in the standard model are absorbed away to the longitudinal component of the gauge bosons, while the NG boson in QCD is the pion.

** It seems that the vector terms must be incorporated for a complete description of low-energy phenomena in the NJL model approach.
cautious phase shift analyses of the $\pi$-$\pi$ scattering in the scalar channel have come
to claim a $\sigma$ pole of the scattering matrix in the complex energy plane with the real
part Re $m_\sigma = 500-800$ MeV and the imaginary part Im $m_\sigma \simeq 500$ MeV \(^{16}\).

One should mention here that the same phase shift can be well reproduced
without the $\sigma$ pole but only with the $\rho$ meson pole in the $t$-channel using a model
lagrangian \(^{17}\). Then one may naturally wonder whether we can go or not with the
$\sigma$. A nice resolution of this dilemma has been provided by Igi and Hikasa
\(^{18}\); see also the contribution by Oller \(^{19}\).

Igi and Hikasa constructed the invariant amplitude for the $\pi$-$\pi$ scattering so
that it satisfies the chiral symmetry low energy theorem, analyticity, unitarity and
approximate crossing symmetry using the $N/D$ method \(^{20}\). In construction, they
assumed possible existence of resonances in $I = J = 0$ as well as $I = J = 1$ channels.
They calculated the two cases with and without the scalar resonance by putting on
and off the coupling $g_\sigma$ of the $\sigma$ with the pions. When including the $\sigma$, they assumed
that the scalar meson is degenerated with the $\rho$ meson as given in the mended
symmetry \(^{11}\), which also gives the same couplings $g_\sigma = g_\rho$ of the mesons with the
pions. Then their amplitude has essentially no free parameter; actually, the coupling
constant $g^2_\sigma$ is slightly varied between the KSRF coupling $m^2_\rho/2f^2_\pi$ and $m^2_\sigma/\pi f^2_\pi$
given by the Veneziano amplitude. What they found is that the $\rho$ only scenario can account
only about half of the observed phase shift, while the degenerate $\rho$-$\sigma$ scenario gives
a reasonable agreement with the data.

In the approach in Ref.17, it is unfortunately quite unclear how well chiral
symmetry, analyticity, nor crossing symmetry even in an approximate way are taken
into account.

§3. Hadron phenomenology and the $\sigma$ meson

If the $\sigma$ meson with a low mass is identified, many experimental facts which
otherwise are mysterious can be nicely accounted for in a simple way \(^{2,9}\).

3.1. $\Delta I = 1/2$ rule and the $\sigma$ meson

The correlation in the scalar channel as summarized by such a scalar meson may
account for the enhancement of the $\Delta I = 1/2$ processes in $K_0 \rightarrow \pi^+\pi^-$ or $\pi_0\pi_0$ \(^{7}\).
In fact, the final state interaction for the emitted two pions may include the $\sigma$ pole,
then the matrix element for of the scalar operator $Q_6 \sim \bar{q}_R q_L \bar{q}_L q_R$ is sown to be

$$\langle \pi^+\pi^- | Q_6 | K^0 \rangle = \langle \pi^0\pi^0 | Q_6 | K^0 \rangle = Y_0 \cdot \frac{F_K}{3F_\pi - 2F_K}.$$  \hspace{1cm} (3.1)

where the $Y_0$ is the standard matrix element given by the vacuum saturation approx-
imation and the last factor involving the pion and the kaon decay constants gives
the enhancement factor due to the $\sigma$ pole. The relevance of the $\sigma$ pole is best seen
by rewriting it in terms the meson masses \(^{\text{\[3.3\]}}

$$\frac{F_K}{3F_\pi - 2F_K} = \frac{m_\sigma^2 - m_\pi^2}{m_\rho^2 - m_K^2} \cdot \frac{F^2_K}{F^2_\pi}.$$  \hspace{1cm} (3.3)
which shows that the approximate degeneracy of the kaon and the σ can give a large enhancement as required to account the experimental data.

3.2. The nuclear force and the σ meson

The phase shift analyses of the nucleon-nucleon scattering in the $^1S_0$ channel show the existence of the state-independent attraction in the intermediate range, $1 \sim 2$ fm. This attraction is indispensable for the binding of a nucleus. In the meson-theoretical models for the nuclear force, i.e., One-Boson-Exchange Potential (OBEP), a scalar and isoscalar meson exchange with the mass range $400 \sim 700$ MeV is responsible for the state-independent attraction. The boson responsible for the state-independent attraction has been denoted as “σ” with a quotation, because it is a substitute of the two-pion exchange potential in this channel; the two-pion exchange includes the ladder, the cross and the rescattering diagrams with the Δ(1232) being incorporated in the intermediate states.

However, the problem is again how ChS is taken into account to construct the N-¯N to π-π amplitude in the t-channel. An analysis which respects ChS showed that the direct σ-N coupling is necessary to insure ChS in the N-¯N to π-π amplitude. Furthermore, the amplitude of the rescattering of the pions mentioned above should be constructed consistently with the π-π phase shift in the $I = J = 0$ channel, for which we have seen that ChS, analyticity and the crossing symmetry are important.

3.3. The π-N sigma term and the σ meson

The collective excitation in the scalar channel as described as the σ meson is essential in reproducing the empirical value of the π-N sigma term.

The basic quantities here are the quark contents of baryons $\langle B|\bar{q}_i q_i|B\rangle \equiv \langle \bar{q}_i q_i \rangle_B$ $(i = u, d, s, ...).$ Actually, it is more adequate to call them the scalar charge of the hadron. Feyman-Hellman theorem tells us that

$$\langle \bar{q}_i q_i \rangle_B = \frac{\partial M_B}{\partial m_i},$$

which shows that once the baryon mass $M_B$ is known as a function of the current quark masses $m_i$, the quark content of the baryon is calculable. The problem is of

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* One should, however, notice that it is urgent to explore whether the σ can systematically describe the processes involving the kaon like the mass difference of $K_L$ and $K_S$. We remark that the incorporation of the vector mesons may be a missing link for the systematic description of the weak processes involving the kaon, as in the description of the π-π scattering in a consistent way with chiral symmetry, analyticity and crossing symmetry.

** A discussion to take into account ChS in the nuclear force was first given by Brown.

*** In a phenomenological point of view, the nuclear forces with and without the direct σ-N coupling are indistinguishable. Nevertheless when one tries to describe the baryon-baryon interactions including hyperon-N and hyperon-hyperon interaction systematically, one may encounter cases where the baryon-baryon forces constructed in a chirally symmetric way with the direct σ baryon coupling give a better phenomenology than the ones constructed without the direct σ-baryon coupling.
course to give the functional dependence of $M_B$ on $m_i$. For this purpose, the chiral quark model is useful, where $M_B$ is given with “constituent quark masses” $M_i$ which is identified with the mass generated by the dynamical breaking of chiral symmetry (plus current quark mass), hence ChS and the constituent quark model is nicely reconciled in the chiral quark model.

One will immediately find that the scalar charge of a baryon is given in terms of the scalar charge of the constituent quark,

$$Q_{ji} = \frac{\partial M_j}{\partial m_i} = \langle \bar{q}_i q_j \rangle_{q_j}, \quad i, j = u, d, s, \ldots \quad (3.5)$$

Notice that

$$\frac{d\langle \bar{q}_i q_j \rangle}{dM_i} = \Pi_i^S(q^2 = 0), \quad (3.6)$$

where $\Pi_i^S(q^2)$ is the zero-th order polarization in the scalar channel due to the $i$-quark ($i=u, d, s$). If one uses the NJL model with a determinantal interaction, one has

$$Q = \left[ 1 + V_{\sigma} \cdot \Pi_i^S(0) \right]^{-1}, \quad (3.7)$$

where $V_{\sigma}$ is the vertex of the interaction Lagrangian in the scalar channel in the flavor basis; $L_{\sigma} = \sum_{i,j=u,d,s} \langle \bar{q}_i V_{ij} q_j \rangle$. The scalar charge matrix is nicely rewritten in terms of the the propagator $D_{\sigma}(q^2)$ of the scalar mesons

$$Q = -D_{\sigma}(0) \cdot V_{\sigma}^{-1}, \quad (3.8)$$

where

$$D_{\sigma}(q^2) = -[1 + V_{\sigma} \cdot \Pi_i^S(q^2)]^{-1} \cdot V_{\sigma}. \quad (3.9)$$

Notice that when the interaction is absent $Q = 1$.

Effective charges are usually enhanced (suppressed) due to collective excitations generated by the attractive (repulsive) forces. In the present case, we have of course an enhancement. The enhancement is caused by the polarization of the vacuum in the $I = J = 0$ channel; one may use the word “quantum fluctuation” for the physical origin of the enhancement. The quantum fluctuation is nicely summarized by the scalar meson, i.e., the $\sigma$ meson.

The resulting scalar charges of the proton were calculated to be

$$\langle \bar{u}u \rangle_P = 4.97(2), \quad \langle \bar{d}d \rangle_P = 4.00(1), \quad \langle \bar{s}d \rangle_P = 5.3(0), \quad (3.10)$$

where the numbers with a parenthesis are the scalar charges given by the naive quark model. One can see the collective effect corresponding to the $\sigma$ meson enhances the quark contents greatly. It is also to be noted that the strangeness in proton are related with the flavor-mixing property of the scalar mesons. Accordingly, we have

$$\Sigma_{\pi N} = 49\text{MeV}, \quad (3.11)$$

which is in good agreement with the “experimental value”.

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3.4. Remarks

We remark also the convergence radius of the chiral perturbation theory is linked with the mass of the scalar meson.

The above facts indicate that the scalar-scalar correlation is important in the hadron dynamics. This is in a sense natural because the dynamics which is responsible for the correlations in the scalar channel is nothing but the one which drives the chiral symmetry breaking.

§4. Partial chiral restoration and the $\sigma$ meson in hadronic matter

Although the recent phase shift analyses of the $\pi$-$\pi$ scattering and the identification of the pole in the $I = J = 0$ channel which might be identified with our $\sigma$ meson are great achievement, one must say that it is still obscure whether the pole really corresponds to the quantum fluctuation of the chiral order parameter, i.e., our $\sigma$. As was first shown by us, the $\sigma$ meson decreases the mass (softening) in association with the chiral restoration in the hot and/or dense medium, and the width of the meson is also expected to decrease because the pion hardly changes the mass as long as the system is in the Nambu-Goldstone phase. Thus one can expect a chance to see the $\sigma$ meson as a sharp resonance at high temperature and/or density.

Some years ago, the present author proposed several nuclear experiments including one using electro-magnetic probes to produce the $\sigma$ meson in nuclei, thereby have a clearer evidence of the existence of the $\sigma$ meson and also explore the possible restoration of chiral symmetry in the nuclear medium. To make a veto for the two pions from the rho meson, the produced pions should be neutral ones which may be detected through four $\gamma$’s.

When a hadron is put in a nucleus, the hadron may dissociate into complicated excitation to loose its identity in the medium. Then the most informative quantity is the response function or spectral function of the system. A response function in the energy-momentum space is essentially the spectral function in the meson channel. If the coupling of the hadron with the environment is relatively small, then there may remain a peak with a small width in the spectral function, corresponding to the hadron. Such a peak is to be identified with an elementary excitation or a quasi-particle, known in Landau’s Fermi liquid theory for fermions. It is quite nontrivial whether a many-body system can admit an elementary excitation or quasi-particle with a specific quantum number. Landau gave an argument that there will be a chance to describe a system as an assembly of almost free quasi-particles owing to the Pauli principle when the temperature is low. Then how will the decrease of $m_\sigma$ in the nuclear medium reflect in the spectral function in the $\sigma$ channel?

It has been shown by using linear sigma models that an enhancement in the spectral function in the $\sigma$ channel occurs just above the two-pion threshold along with the decrease of $m_\sigma$. Recently, it has been shown that the spectral enhancement near the $2m_\pi$ threshold takes place in association with partial restoration of ChS at finite baryon density.

Referring to for the detailed account, we here describe the general features
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of the spectral enhancement near the two-pion threshold. Consider the propagator of the $\sigma$-meson at rest in the medium: $
D_{\sigma}^{-1}(\omega) = \omega^2 - m^2_{\sigma} - \Sigma_{\sigma}(\omega; \rho)$, where $m_{\sigma}$ is the mass of $\sigma$ in the tree-level, and $\Sigma_{\sigma}(\omega; \rho)$ is the loop corrections in the vacuum as well as in the medium. The corresponding spectral function is given by

$$
\rho_{\sigma}(\omega) = -\pi^{-1}{\text{Im}} D_{\sigma}(\omega),
$$

(4.1)

One can show that $\text{Im}\Sigma_{\sigma} \propto \theta(\omega - 2m_{\pi}) \sqrt{1 - \frac{4m^2_{\rho}}{\omega^2}}$ near the two-pion threshold in the one-loop order. On the other hand, partial restoration of ChS implies that $m^*_{\sigma}$ defined by $\text{Re} D_{\sigma}^{-1}(\omega = m^*_{\sigma}) = 0$ approaches to $m_{\pi}$. Therefore, there exists a density $\rho_c$ at which $\text{Re} D_{\sigma}^{-1}(\omega = 2m_{\pi})$ vanishes even before the complete restoration of ChS where $\sigma$-$\pi$ degeneracy is realized. At this point, the spectral function is solely given in terms of the imaginary part of the self-energy;

$$
\rho_{\sigma}(\omega \simeq 2m_{\pi}) = -\frac{1}{\pi \text{Im}\Sigma_{\sigma}} \frac{\theta(\omega - 2m_{\pi})}{\sqrt{1 - \frac{4m^2_{\rho}}{\omega^2}}},
$$

(4.2)

which clearly shows the near-threshold enhancement of the spectral function. This is a general phenomenon correlated with the partial restoration of ChS.

This result is interesting in relation with the experiment by CHAOS collaboration[36]; see[35,37] and the report presented by Hatsuda[38] for more details and recent development.

§5. Summary

The $\sigma$ meson is the quantum fluctuation of the amplitude of the order parameter of the chiral transition in QCD. The existence of the $\sigma$ meson does not contradict with the success of the chiral perturbation theory for the low-energy phenomena. If analyticity, crossing symmetry are respected as well as chiral symmetry (ChS) and unitarity, the phase shift analyses of the $\pi$-$\pi$ scattering in $I = J = 0$ channel is in favor of the existence of a scalar-isoscalar meson as well as the $\rho$ meson in t-channel. The scalar meson might be identified with the $\sigma$ meson as the quantum fluctuation of the chiral order parameter, though some work is still needed to make the identification conclusive.

If the $\sigma$ meson exists, the collective mode in the $I = J = 0$ channel as summarized by the $\sigma$ can account for various phenomena in hadron physics which otherwise remain mysterious.

The study of the spectral function in the $\sigma$ channel obtained for the systems with finite $T$ and/or the density $\rho_B$ is interesting to elucidate the existence of the $\sigma$ meson more clearly and also the possible partial restoration of ChS. The CHAOS[36] group may have seen an evidence of partial restoration of ChS in the nuclear medium.

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References
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[1] U. Vogl and W. Weise, Prog. Part. Nucl. Phys. 27 (1991), 195.
[2] T. Hatsuda and T. Kunihiro, Phys. Rev. 247 (1994) 221.
[3] J. Bijnens, Phys. Rep. 265 (1996), 369.
[4] A. Manohar and H. Georgi, Nucl. Phys. B234 (1984) 189.
[5] T. Hatsuda and T. Kunihiro, Prog. Theor. Phys. 74 (1985) 765.
[6] Y. Nambu and G. Jona-Lasinio, Phys. Rev. 122 (1961) 345, 124 (1961) 246.
[7] E. P. Shabalin, Sov. J. Nucl. Phys. 48 (1988) 172, T. Morozumi, C. S. Lim and A. I. Sanda, Phys. Rev. Lett. 65 (1990) 172, T. Morozumi, C. S. Lim and A. I. Sanda, Phys. Rev. Lett. 65 (1990) 404; see also A. I. Sanda, these proceedings; M. Takizawa, these proceedings.
[8] M. Neubert and B. Stech, Phys. Lett. B231 (1989), 477; Phys. Rev. D44 (1991), 775.
[9] T. Kunihiro, Prog. Theor. Phys. Supplement 120 (1995), 75.
[10] V. Elias and M. D. Scadron, Phys. Rev. Lett. 53 (1984) 1129.
[11] S. Weinberg, Phys. Rev. D65 (1990) 1177.
[12] S. Klevansky, Rev. Mod. Phys. 64 (1992), 649.
[13] J. Gasser and H. Leutwyler, Ann. Phys. 158 (1984), 142.
[14] E. Ruiz Arriola, Phys. Lett. B253 (1991), 430.
[15] M. Takizawa, K. Tsushima, Y. Kohyama and K. Kubodera, Nucl. Phys. A507 (1990) 617.
[16] R. Kaminski et al, Phys. Rev. D50, 3145 (1994); S. Ishida et al., Prog. Theor. Phys. 95, 745, 98, 1005 (1997); N. A. Tärnqvist and M. Roos, Phys. Rev. Lett. 76, 1575 (1996); M. Harada, F. Sannino and J. Schechter, Phys. Rev. D54, 1991 (1996); J. A. Oller, E. Oset and J. R. Peláez, Phys. Rev. Lett. 80, 3452 (1998); K. Igi and K. Hikasa, Phys. Rev. D59, 034005 (1999); and these proceedings. See also G. Mennessier, Z. Phys. C16 (1983) 241; E. Van Beveren et al., Z. Phys. C30 (1986) 515; S. Minami, Prog. Theor. Phys. B59 (1990), 1005.
[17] C. Schutz, K. Holind, J. Speth, P.C. Pearce and J. W. Durso, Phys. Rev. C51 (1995), 1374; K. Holinde, Prog. Part. Nucl. Phys. 36 (1996), 311 and the references cited therein.
[18] K. Igi and K. Hikasa, Phys. Rev. D59, 034005 (1999); K. Igi, these proceedings.
[19] J.A. Oller, these proceedings, hep-ph/0007349; also the comprehensive review, J. A. Oller, E. Oset and A. Ramos, Prog. Part. Nucl. Phys. 45 (2000): hep-ph/0002193.
[20] G. F. Chew and S. Mandelstam, Phys. Rev. D14 (1976) 3432.
[21] P. Carruthers and R. W. Haymaker, Phys. Rev. Lett. 27 (1971) 455.
[22] T. Hatsuda, Phys. Rev. Lett. 65 (1990) 543.
[23] T. Hatsuda and T. Kunihiro, Phys. Rev. Lett. 55 (1985), 158; Prog. Theor. Phys. 74 (1985), 765; Phys. Lett. B185, 304 (1987).
[24] T. Kunihiro, invited talk presented at Japan-China joint symposium, “ Recent Topics on Nuclear Physics”, Tokyo Institute of Technology, 30 Nov - 3 Dec, 1992, (nucl-th/0006035).
[25] L. D. Landau, E. Exptl. Theoret. Phys. 35 (1958), 97.
[26] S. Chiku and T. Hatsuda, Phys. Rev. D58, 076001 (1998); M. K. Volkov, E. A. Kuraev, D. Blaschke, G. Roepke and S. M. Schmidt, Phys. Lett. B424, 235 (1998).
[27] T. Hatsuda, T. Kunihiro and H. Shimizu, Phys. Rev. Lett. 82, 2840 (1999).
[28] E. Ruiz Arriola, Phys. Rev. C58 (1998), 076001; M. K. Volkov, E. A. Kuraev, D. Blaschke, G. Roepke and S. M. Schmidt, Phys. Lett. B424, 235 (1998).
[29] T. Hatsuda and T. Kunihiro, Nucl. Phys. A677, (2000), 213.
[30] R. Rapp et al, Phys. Rev. C 59 (1999), R1237; Z. Aouissat, G. Chanfray, P. Schuck and J. Wambach, Phys. Rev. C61 (2000), 12202; M. J. Vicente-Vacas and E. Oset, Phys. Rev. C60 (1999), 064621.
[38] T. Hatsuda, these proceedings.