Tsushima, Kazuo; Lu, D. H.; Thomas, Anthony William; Saito, K.; Landau, R. H.
Charmed mesic nuclei: Bound D and D¯ states with ^{208}Pb Physical Review C, 1998; 59(5):2824-2828

Charmed mesic nuclei: Bound D and $\bar{D}$ states with ^{208}Pb

K. Tsushima,[1] D. H. Lu,[1] A. W. Thomas,[1] K. Saito,[2] and R. H. Landau[3]

[1]*Department of Physics and Mathematical Physics, and Special Research Center for the Subatomic Structure of Matter,
University of Adelaide, Adelaide, 5005 Australia*
[2]*Physics Division, Tohoku College of Pharmacy, Sendai 981-8558, Japan*
[3]*Department of Physics, Oregon State University, Corvallis, Oregon 97331*

We show that the D^- meson will form narrow bound states with ^{208}Pb. Mean-field potentials for the D^0, $\bar{D}^0$, and D^- in ^{208}Pb are calculated self-consistently using the quark-meson coupling model in the local density approximation. The meson-^{208}Pb bound-state energies are then calculated by solving the Klein-Gordon equation with these potentials. The experimental confirmation and comparison with the $\bar{D}^0$ and D^0 will provide distinctive information on the nature of the interaction between the charmed meson and matter. [S0556-2813(99)02205-0]

In relativistic models of nuclear structure like quantum hadrodynamics (QHD) [1] or quark-meson coupling (QMC) model [2–10], the isoscalar-scalar meson σ is responsible for a large reduction in the mass of the nucleon ($m_N \to m_N^*$). Although there is no firm evidence of a σ meson with mass in the range 500 – 600 MeV (cf. the Particle Data Group discussion of the $f_0(400-1200)$ and σ [11]), there is considerable empirical justification for using the σ as a phenomenological representation of correlated two-pion exchange between nucleons [12]. In QMC the justification for coupling the σ to the confined light quarks (hereafter referred to as q) is that dynamical chiral symmetry breaking requires that the confined quarks couple to pions. Quarks in different hadrons can interact by exchanging two pions and this is represented phenomenologically by σ exchange. Using this model it is possible to investigate the reduction of the masses not only of baryons, but also of mesons containing light quarks [5–7]. (See Refs. [13–19] for other approaches not all of which result in a mass reduction for the mesons.)

The result for the ω meson within relativistic mean-field models is especially interesting. Because it consists of almost pure q-$\bar{q}$ pairs (ideal mixing), in an isoscalar nucleus the q and $\bar{q}$ "feel" equal and opposite vector potentials. This means that the effect of the mean σ field is unmasked which leads to expectations of quite deeply bound ω-nucleus states [7,14,20,21,23]. These states are currently the subject of intense experimental investigation, with the most promising involving recoilless production in the $(d,{}^3\mathrm{He})$ reaction at GSI [20,21].

In this paper we consider a possibility that is in some ways even more exciting, in that it promises more specific information on the relativistic mean fields in nuclei and the nature of dynamical chiral symmetry breaking. We focus on systems containing an anticharm quark and a light quark ($\bar{c}q$), which have no strong decay channels if bound. If we assume that dynamical chiral symmetry breaking is the same for the light quark in the charmed meson as in purely light-quark systems, we expect the same σ-q coupling constant. (On the one hand, this assumption seems quite reasonable,

given the success in reproducing the pion coupling constants for various charmed baryons using a model based on a common light quark pion coupling [22], while on the other hand, the present predictions could also be viewed as an independent test of this picture.) In the absence of any strong interaction, the D^- will form atomic states, bound by the Coulomb potential. We use the QMC model to estimate the effect of the strong interaction. The resulting binding for, say, the $1s$ level in ^{208}Pb is between 10 and 30 MeV and should provide a very clear experimental signature.

Systems of the form $\bar{q}c$ are also extremely interesting because the coupling of the mean vector field to the light antiquark will be attractive. Indeed, we expect a D meson ($c\bar{q}$) to experience an attraction in excess of 100 MeV in an average size atomic nucleus. Unfortunately, the D meson in matter will also couple strongly to open channels such as $DN \to B_c(\pi's)$, with B_c a charmed baryon. Our present knowledge does not permit an accurate calculation of the corresponding widths, which may be 10–100 MeV. At the lower end of this range, such states should be able to be seen as very deeply bound mesic-nuclei, while at the upper end they may not be detectable. We regard the widths as an experimental issue at present and show the $_{D^0}^{208}$Pb bound-state energies without the effect of absorption.

A detailed description of the Lagrangian density and the mean-field equations of motion needed to describe a finite nucleus is given in Refs. [3,4]. At position $\vec{r}$ in a nucleus (the coordinate origin is taken at the center of the nucleus), the Dirac equations for the quarks and antiquarks in the D and $\bar{D}$ meson bags are given by [6,7]:

$$\left[i\gamma \cdot \partial_x - [m_q - V_\sigma^q(\vec{r})] \mp \gamma^0\left(V_\omega^q(\vec{r}) + \frac{1}{2}V_\rho^q(\vec{r})\right)\right]\begin{pmatrix}\psi_u(x)\\\psi_{\bar{u}}(x)\end{pmatrix}$$
$$= 0, \tag{1}$$

$$\left[i\gamma \cdot \partial_x - [m_q - V_\sigma^q(\vec{r})] \mp \gamma^0\left(V_\omega^q(\vec{r}) - \frac{1}{2}V_\rho^q(\vec{r})\right)\right]\begin{pmatrix}\psi_d(x)\\\psi_{\bar{d}}(x)\end{pmatrix}$$
$$= 0, \tag{2}$$

TABLE I. The physical masses fitted in free space, the bag parameters z, and the bag radii in free space R. The quantities with an asterisk * are those quantities calculated at normal nuclear matter density, $\rho_0 = 0.15$ fm^{-3}. They are obtained with the bag constant, $B = (170.0$ MeV$)^4$, current quark masses, $m_u = m_d = 5$ MeV and $m_c = 1300$ MeV. (Note that the free space widths for D and $\bar{D}$ mesons are negligible [11].)

	Mass (MeV)	z	R (fm)	m^* (MeV)	R^* (fm)
N	939.0 (input)	3.295	0.800 (input)	754.5	0.786
$D,\bar{D}$	1866.9 (input)	1.389	0.731	1804.9	0.730

$$[i\gamma\cdot\partial_x - m_c]\psi_c(x) \quad [\text{or} \quad \psi_{\bar{c}}(x)] = 0. \qquad (3)$$

The mean-field potentials for a bag centered at position $\vec{r}$ in the nucleus are defined by $V_\sigma^q(\vec{r}) = g_\sigma^q \sigma(\vec{r}), V_\omega^q(\vec{r}) = g_\omega^q \omega(\vec{r})$ and $V_\rho^q(\vec{r}) = g_\rho^q b(\vec{r})$, with g_σ^q, g_ω^q, and g_ρ^q the corresponding quark and meson-field coupling constants. (Note that we have neglected a possible, very slight variation of the scalar and vector mean fields inside the meson bag due to its finite size [3].) The mean meson fields are calculated self-consistently by solving Eqs. (23)–(30) of Ref. [4], namely, by solving a set of coupled nonlinear differential equations for static, spherically symmetric nuclei, resulting from the variation of the effective Lagrangian density involving the quark degrees of freedom and the scalar, vector, and Coulomb fields in the mean-field approximation.

The normalized, static solution for the ground-state quarks or antiquarks in the meson bags may be written as

$$\psi_f(x) = N_f e^{-i\epsilon_f t/R_j^*} \psi_f(\vec{x}), \quad (j = D,\bar{D}), \qquad (4)$$

where $f = u,\bar{u},d,\bar{d},c,\bar{c}$ refers to quark flavors, and N_f and $\psi_f(\vec{x})$ are the normalization factor and corresponding spin and spatial part of the wave function. The bag radius in medium R_j^*, which depends on the hadron species to which the quarks and antiquarks belong, will be determined through the stability condition for the (in-medium) mass of the meson against the variation of the bag radius [3,4,6,7] [see also Eq. (9)]. The eigenenergies ϵ_f in Eq. (4) in units of $1/R_j^*$ are given by

$$\begin{pmatrix} \epsilon_u(\vec{r}) \\ \epsilon_{\bar{u}}(\vec{r}) \end{pmatrix} = \Omega_q^*(\vec{r}) \pm R_j^*\left(V_\omega^q(\vec{r}) + \frac{1}{2} V_\rho^q(\vec{r}) \right), \qquad (5)$$

$$\begin{pmatrix} \epsilon_d(\vec{r}) \\ \epsilon_{\bar{d}}(\vec{r}) \end{pmatrix} = \Omega_q^*(\vec{r}) \pm R_j^*\left(V_\omega^q(\vec{r}) - \frac{1}{2} V_\rho^q(\vec{r}) \right), \qquad (6)$$

$$\epsilon_c(\vec{r}) = \epsilon_{\bar{c}}(\vec{r}) = \Omega_c(\vec{r}), \qquad (7)$$

where $\Omega_q^*(\vec{r}) = \sqrt{x_q^2 + (R_j^* m_q^*)^2}$, with $m_q^* = m_q - g_\sigma^q \sigma(\vec{r})$ and $\Omega_c(\vec{r}) = \sqrt{x_c^2 + (R_j^* m_c)^2}$. The bag eigenfrequencies, x_q and x_c, are determined by the usual, linear boundary condition [3,4]. [Note that the lowest eigenenergy value for the Dirac equation (Hamiltonian) for the quark, which is positive, should be identified with a constituent quark mass.]

The D and $\bar{D}$ meson masses in the nucleus at position $\vec{r}$, are calculated by

$$m_j^*(\vec{r}) = \frac{\Omega_q^*(\vec{r}) + \Omega_c(\vec{r}) - z_j}{R_j^*} + \frac{4}{3}\pi R_j^{*3} B, \qquad (8)$$

$$\left.\frac{\partial m_j^*(\vec{r})}{\partial R_j}\right|_{R_j = R_j^*} = 0, \quad (j = D,\bar{D}). \qquad (9)$$

In Eq. (8), the z_j parametrize the sum of the center-of-mass and gluon fluctuation effects, and are assumed to be independent of density. The parameters are determined in free space to reproduce their physical masses.

In this study we chose the values $m_q \equiv m_u = m_d = 5$ MeV and $m_c = 1300$ MeV for the current quark masses, and $R_N = 0.8$ fm for the bag radius of the nucleon in free space. Other input parameters and some of the quantities calculated are listed in Table I. The parameters at the hadronic level associated with the core nucleus can be found in Refs. [3,4]. We stress that while the model has a number of parameters, only three of them, g_σ^q, g_ω^q, and g_ρ^q, are adjusted to fit nuclear data—namely the saturation energy and density of symmetric nuclear matter and the bulk symmetry energy. None of the results for nuclear properties depend strongly on the choice of the other parameters—for example, the relatively weak dependence of the final results for the properties of finite nuclei, on the chosen values of the current quark mass and bag radius, is shown explicitly in Refs. [3,4]. Exactly the same coupling constants, g_σ^q, g_ω^q, and g_ρ^q, are used for the light quarks in the mesons as in the nucleon. However, in studies of the kaon system, we found that it was phenomenologically necessary to increase the strength of the
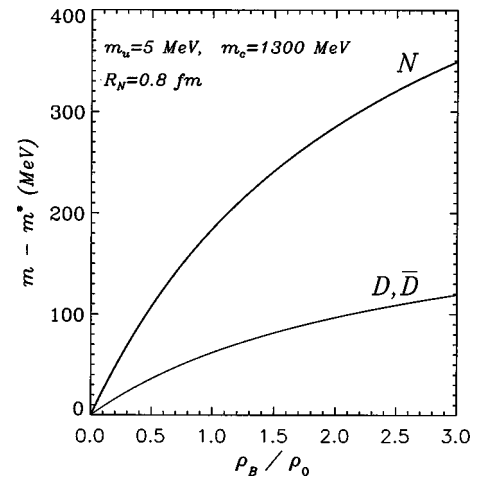

FIG. 1. Shift of the mass of the nucleon and the D or $\bar{D}$ meson. (Normal nuclear matter density, ρ_0, is 0.15 fm^{-3}.)
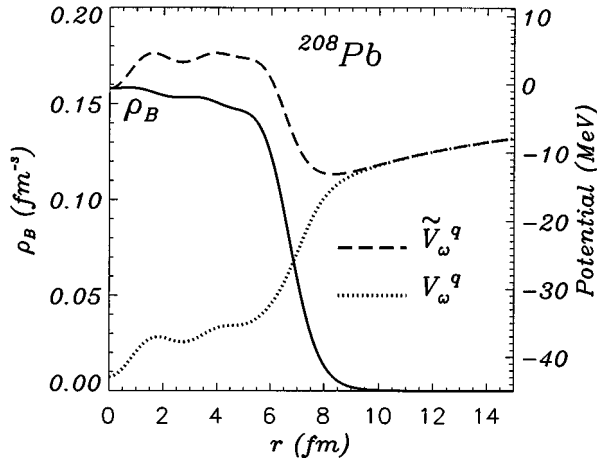
FIG. 2. Sum of the scalar, vector and Coulomb potentials for the D^- meson in ^{208}Pb for two cases, $[m^*_{D^-}(r)-m_{D^-}]+\tilde{V}^q_\omega(r)$ $+\frac{1}{2}V^q_\rho(r)-A(r)$ (the dashed line) and $[m^*_{D^-}(r)-m_{D^-}]+V^q_\omega(r)$ $+\frac{1}{2}V^q_\rho(r)-A(r)$ (the dotted line), where $\tilde{V}^q_\omega(r)=1.4^2 V^q_\omega(r)$.

vector coupling to the nonstrange quarks in the K^+ (by a factor of 1.4^2) in order to reproduce the empirically extracted K^+-nucleus interaction [6]. It is not yet clear whether this is a specific property of the K^+, which is a pseudo-Goldstone boson, or a general feature of the interaction of a light quark, perhaps associated with the Pauli exclusion principle. In any case, we show results for the $\bar{D}$ binding energies with both choices for this potential, in order to test the theoretical uncertainty. The ω mean-field potential with the larger coupling will be labeled $\tilde{V}^q_\omega$ ($=1.4^2 V^q_\omega$).

Through Eqs. (1)–(9) we self-consistently calculate effective masses, $m^*_j(\vec{r})$ ($j=D,\bar{D}$), and mean-field potentials, $V^q_{\sigma,\omega,\rho}(\vec{r})$, at position $\vec{r}$ in the nucleus. The scalar and vector potentials felt by the hadron, which will depend only on the distance from the center of the nucleus, $r=|\vec{r}|$, are given by

$$V^j_s(r)=m^*_j(r)-m_j, \qquad (10)$$

$$V^{D^-}_v(r)=V^q_\omega(r)-\frac{1}{2}V^q_\rho(r)-A(r), \qquad (11)$$

$$V^{\bar{D}^0}_v(r)=V^q_\omega(r)+\frac{1}{2}V^q_\rho(r), \qquad (12)$$

$$V^{D^0}_v(r)=-\left(V^q_\omega(r)+\frac{1}{2}V^q_\rho(r)\right), \qquad (13)$$

where $A(r)$ is the Coulomb interaction between the meson and the nucleus. Note that the ρ meson mean-field potential $V^q_\rho(r)$ is negative in a nucleus with a neutron excess, such as, e.g., ^{208}Pb. For the larger ω meson coupling, suggested by K^+A scattering, $V^q_\omega(r)$ is replaced by $\tilde{V}^q_\omega(r)$.

Before showing the calculated potentials for the D^- in ^{208}Pb which is particularly interesting in view of the strong Coulomb field, we first show in Fig. 1 the mass shift of the $D(\bar{D})$ meson, calculated in symmetric nuclear matter (no contributions from the ρ and Coulomb fields). As is expected, the relation $(m_{D,\bar{D}}-m^*_{D,\bar{D}})\simeq\frac{1}{3}(m_N-m^*_N)$ is well realized [5].

Next, in Fig. 2 we show the sum of the potentials for the D^- in ^{208}Pb for the two choices of $V^{D^-}_s(r)+V^{D^-}_v(r)$ [the dashed line corresponds to $\tilde{V}^q_\omega(r)$ and the dotted line to $V^q_\omega(r)$]. Because the D^- meson is heavy and may be described well in the (nonrelativistic) Schrödinger equation, one expects the existence of the $^{208}_{D^-}$Pb bound states just from inspection of the naive sum of the potentials, in a way which does not distinguish the Lorentz vector or scalar character.

Now we are in a position to calculate the bound-state energies for the D and $\bar{D}$ in nuclei, using the potentials calculated in QMC. There are several variants of the dynamical equation for a bound meson-nucleus system. Consistent with the mean-field picture of QMC, we actually solve the Klein-Gordon equation:

$$\{\nabla^2+[E_j-V^j_v(r)]^2-m^{*2}_j(r)\}\phi_j(\vec{r})=0, \qquad (14)$$

where E_j is the total energy of the meson (the binding energy is E_j-m_j). To deal with the long-range Coulomb potential, we first expand the quadratic term (the zeroth component of Lorentz vector) as, $[E_j-V^j_v(r)]^2=E^2_j+A^2(r)+V^2_{\omega\rho}(r)$ $+2A(r)V_{\omega\rho}(r)-2E_j[A(r)+V_{\omega\rho}(r)]$, where $V_{\omega\rho}(r)$ is the combined potential due to ω and ρ mesons [$V_{\omega\rho}(r)$ $=V^q_\omega(r)-\frac{1}{2}V^q_\rho(r)$ for D^-]. Then Eq. (14) can be rewritten as an effective Schrödinger-like equation,

$$\left[-\frac{\nabla^2}{2m_j}+V_j(E_j,r)\right]\Phi_j(r)=\frac{E^2_j-m^2_j}{2m_j}\Phi_j(r), \qquad (15)$$

where $\Phi_j(r)=2m_j\phi_j(r)$ and $V_j(E_j,r)$ is an effective energy-dependent potential which can be split into three pieces (Coulomb, vector, and scalar parts),

TABLE II. Calculated D^-, $\bar{D}^0$ and D^0 meson bound-state energies (in MeV) in ^{208}Pb for different potentials. The widths for the mesons are all set to zero, both in free space and inside ^{208}Pb. Note that the D^0 bound-states energies calculated with $\tilde{V}^q_\omega$ will be much larger than those calculated with V^q_ω (in absolute value).

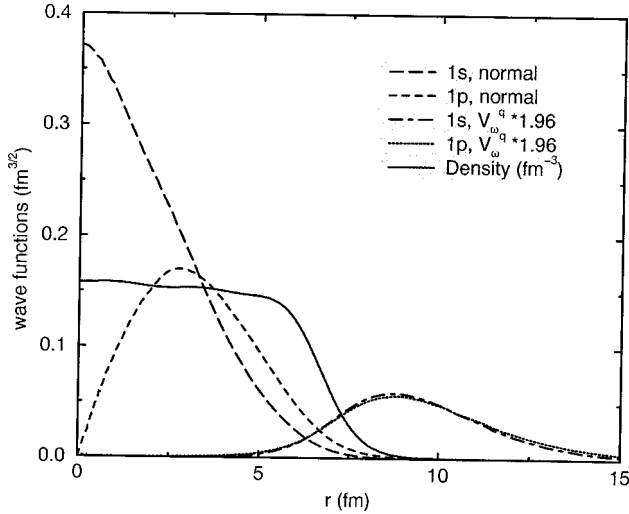| State	$D^-(\tilde{V}^q_\omega)$	$D^-(V^q_\omega)$	$D^-(V^q_\omega$, no Coulomb)	$\bar{D}^0(\tilde{V}^q_\omega)$	$\bar{D}^0(V^q_\omega)$	$D^0(V^q_\omega)$
$1s$	-10.6	-35.2	-11.2	Unbound	-25.4	-96.2
$1p$	-10.2	-32.1	-10.0	Unbound	-23.1	-93.0
$2s$	-7.7	-30.0	-6.6	Unbound	-19.7	-88.5

FIG. 3. The Schrödinger-like bound-state wave functions of the D^- meson in ^{208}Pb, for two different ω meson coupling strengths. See also the caption of Fig. 2. The wave function is normalized as follows: $\int_0^\infty dr 4\pi r^2 |\Phi(r)|^2 = 1$.

$$V_j(E_j, r) = \frac{E_j}{m_j} A(r) + \frac{2E_j V_{\omega\rho}^j(r) - [A(r) + V_{\omega\rho}^j(r)]^2}{2m_j}$$
$$+ \frac{m_j^{*2}(r) - m_j^2}{2m_j}. \tag{16}$$

Note that only the first term in this equation is a long-range interaction and thus needs special treatment, the second and third terms are short-range interactions. In practice, Eq. (15) is first converted into momentum space representation via a Fourier transformation and is then solved using the Kwon-Tabakin-Landé technique [24]. We would like to emphasize that no reduction has been made to derive the Schrödinger-like equation, so that all relativistic corrections are included in our calculation. The calculated meson-nucleus bound-state energies for ^{208}Pb, are listed in Table II.

The results show that both the D^- and $\bar{D}^0$ are bound in ^{208}Pb with the usual ω coupling constant. For the D^- the Coulomb force provides roughly 24 MeV of binding for the $1s$ state, and is strong enough to bind the system even with the much more repulsive ω coupling (viz., $1.4^2 V_\omega^q$). The $\bar{D}^0$ with the stronger ω coupling is not bound. Note that the difference between $\bar{D}^0$ and D^- without the Coulomb force is due to the interaction with the ρ meson, which is attractive for the $\bar{D}^0$ but repulsive for the D^-. For completeness, we also calculated the binding energies for the D^0, which is deeply bound since the ω interaction with the light antiquarks is attractive. However, the expected large width associated with strong absorption may render it experimentally inaccessible. It is an extremely important experimental challenge to see whether it can be detected.

The eigenfunctions for the Schrödinger-like equation are shown in Fig. 3, together with the baryon density distribution in ^{208}Pb. For the usual ω coupling, the eigenstates ($1s$ and $1p$) are well within the nucleus, and behave as expected at the origin. For the stronger ω coupling, however, the D^- meson is considerably pushed out of the nucleus. In this case, the bound state (an atomic state) is formed solely due to the Coulomb force. An experimental determination of whether this is a nuclear state or an atomic state would give a strong constraint on the ω coupling. We note, however, that because it is very difficult to produce D-mesic nuclei with small momentum transfer, and the D-meson production cross section is small compared with the background from other channels, it will be a challenging task to detect such bound states experimentally [25].

To summarize, we have calculated the $^{208}_{D^0}$Pb, $^{208}_{\bar{D}^0}$Pb, and $^{208}_{D^-}$Pb bound-state energies in QMC. The potentials for the mesons were calculated self-consistently in local-density approximation. In spite of possible model-dependent uncertainties, our results suggest that the D^- meson should be bound in ^{208}Pb due to two quite different mechanisms, namely, the scalar and attractive σ mean field even without the assistance of the Coulomb force in the case of the normal vector potential (V_ω^q), and solely due to the Coulomb force in the case of the stronger vector potential ($\tilde{V}_\omega^q$). (We recall that the kaon is a pseudo-Goldstone boson and expected to be difficult to treat properly with the usual bag model. Thus, the analysis of Ref. [6] on the vector potential for the light quarks inside the kaon bag may not be applicable to the light quarks inside the D meson.)

Thus, whether or not the $\bar{D}^0$-^{208}Pb bound states exist would give new information as to whether the interactions of light quarks in a heavy meson are the same as those in a nucleon. The enormous difference between the binding energies of the D^0 (~ 100 MeV) and the $\bar{D}^0$ (~ 10 MeV) is a simple consequence of the presence of a strong Lorentz vector mean field, while the existence of any binding at all would give us important information concerning the role of the Lorentz scalar σ field (and hence dynamical symmetry breaking) in heavy quark systems. In spite of the perceived experimental difficulties, we feel that the search for these bound systems should have a very high priority.

[1] J. D. Walecka, Ann. Phys. (N.Y.) **83**, 491 (1974); B. D. Serot and J. D. Walecka, Adv. Nucl. Phys. **16**, 1 (1986).
[2] P. A. M. Guichon, Phys. Lett. B **200**, 235 (1988).
[3] P. A. M. Guichon, K. Saito, E. Rodionov, and A. W. Thomas, Nucl. Phys. **A601**, 349 (1996).
[4] K. Saito, K. Tsushima, and A. W. Thomas, Nucl. Phys. **A609**, 339 (1996).
[5] K. Saito, K. Tsushima, and A. W. Thomas, Phys. Rev. C **55**, 2637 (1997); **56**, 566 (1997); K. Tsushima, K. Saito, J. Haidenbauer, and A. W. Thomas, Nucl. Phys. **A630**, 691 (1998).

[6] K. Tsushima, K. Saito, A. W. Thomas, and S. W. Wright, Phys. Lett. B **429**, 239 (1998); **436**, 453(E) (1998) (typos, $g^q_{K\omega} = g^K_\omega = 1.4 \times g^q_\omega$, should be replaced by $g^q_{K\omega} = g^K_\omega = 1.4^2 \times g^q_\omega$).

[7] K. Tsushima, D. H. Lu, A. W. Thomas, and K. Saito, Phys. Lett. B **443**, 26 (1998).

[8] P. G. Blunden and G. A. Miller, Phys. Rev. C **54**, 359 (1996).

[9] H. Müller, Phys. Rev. C **57**, 1974 (1998).

[10] X. Jin and B. K. Jennings, Phys. Lett. B **374**, 13 (1996); Phys. Rev. C **54**, 1427 (1996); **55**, 1567 (1997); H. Müller and B. K. Jennings, Nucl. Phys. **A626**, 966 (1997).

[11] Review of Particle Physics, Phys. Rev. D **54**, 1 (1996); Eur. Phys. J. C **3**, 1 (1998).

[12] For example, R. Machleidt, K. Holinde, and Ch. Elster, Phys. Rep. **149**, 1 (1987); R. Machleidt, Adv. Nucl. Phys. **19**, 189 (1989).

[13] H.-C. Jean, J. Piekarewicz, and A. G. Williams, Phys. Rev. C **49**, 1981 (1994).

[14] K. Saito, K. Tsushima, A. W. Thomas, and A. G. Williams, Phys. Lett. B **433**, 243 (1998); K. Saito, K. Tsushima, D. H. Lu, and A. W. Thomas, Phys. Rev. C **59**, 1203 (1999).

[15] M. Asakawa, C. M. Ko, P. Lévai, and X. J. Qiu, Phys. Rev. C **46**, R1159 (1992); M. Asakawa and C. M. Ko, Phys. Rev. C **48**, R526 (1993).

[16] T. Hatsuda and Su H. Lee, Phys. Rev. C **46**, R34 (1993); F. Klingl, N. Kaiser, and W. Weise, Nucl. Phys. **A624**, 527 (1997); Su H. Lee, Phys. Rev. C **57**, 927 (1998).

[17] G. Chanfray and P. Schuck, Nucl. Phys. **A555**, 329 (1993); M. Herman, B. L. Friman, and W. Nörenberg, *ibid.* **A560**, 411 (1993); R. Rapp, G. Chanfray, and J. Wambach, *ibid.* **A617**, 472 (1997); W. Petrers, M. Post, H. Lenske, S. Leupold, and U. Mosel, *ibid.* **A632**, 109 (1998).

[18] B. Friman, GSI-98-7, nucl-th/9801053.

[19] F. Klingl and W. Weise, hep-ph/9802211.

[20] R. S. Hayano *et al.*, Expt. proposal for GSI/SIS, 1997.

[21] R. S. Hayano, S. Hirenzaki, and A. Gillitzer, nucl-th/9806012.

[22] M. A. Ivanov *et al.*, hep-ph/9807519.

[23] W. Weise, talk given at Workshop on the Structure of Mesons, Baryons, and Nuclei, Cracow, Poland, 1998.

[24] R. H. Landau, *Quantum Mechanics II* (Wiley, New York, 1990); Y. R. Kwon and F. Tabakin, Phys. Rev. C **18**, 932 (1978); D. H. Lu and R. H. Landau, *ibid.* **49**, 878 (1994).

[25] R. S. Hayano (private communication).