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HEAVY ION PHYSICS

Representations in Density Dependent Hadronic Field Theory

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Abstract. Different representations of an effective, covariant theory of the hadronic interaction are examined. For this purpose we have introduced nucleon-meson vertices parameterized in terms of scalar combinations of hadronic fields, extending the conceptual frame of the Density Dependent Hadronic Field Theory. Nuclear matter properties at zero temperature are examined in the Mean Field Approximation.

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The fundamental state of matter within Quantum Chromodynamics (QCD), which is the accepted theoretical model for the strong interactions, corresponds to the non-perturbative regime. The confinement mechanism and the breakdown of symmetries make unfeasible the mathematical treatment in this regime. Different procedures have been proposed to overcome this difficulty, such as effective models, lattice simulations and QCD sum rules. An alternative scheme consist of matching continuously the descriptions corresponding to different theoretical frameworks. It was applied in the study of nuclear structure [1], by combining the nucleon self-energies evaluated with one boson exchange potential and the relativistic field theory of hadrons. For this purpose the vertices of the meson and nucleon fields are expanded in terms of in-medium nucleon condensates, giving rise to the Density Dependent Hadronic Theory (DDHT). The enlarged hadronic model keeps the mathematical versatility of the Quantum Hadrodynamic models [2], but is equipped with couplings reflecting the properties of the nuclear environment.
However, the procedure is not uniquely defined since given as input a set of physically meaningful self-energies, there is room for a full family of hadronic models, according to the field parameterization assumed for the vertices. In principle, this may lead to different predictions for nuclear observables.

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In this work we are concerned with symmetric nuclear matter, so that only iso-scalar meson fields $\sigma(x)$ and $\omega_\mu(x)$,are considered. The interaction vertices may depend on the scalar combinations: $s_1 = \sqrt{j_\mu j^\mu}$, $s_2 = \bar{\psi}\psi$, $m_1 = \sqrt{\omega_\mu \omega^\mu}$, and $m_2 = \sigma$. Here ψ stands for the nucleon field, and $j_\mu = \bar{\psi}\gamma_\mu\psi$. For the sake of concreteness, we have examined three possible parameterizations of the meson-nucleon vertices: *a)* $\Gamma_\sigma(s_1)$, $\Gamma_\omega(s_1)$; *b)* $\Gamma_\sigma(s_2)$, $\Gamma_\omega(s_1)$; and *c)* $\Gamma_\sigma(m_2)$, $\Gamma_\omega(m_1)$. Within these three prescriptions we have evaluated the nucleon self-energies in the relativistic Hartree approximation in terms of the baryonic density, and impossed its functional equality with the self-energies provided by some reliable calculations. The conditions are

$$\begin{aligned}
\text{a)}\,\Gamma_s &= \frac{\Sigma_s^{(in)}}{\tilde{\sigma}},\ \Gamma_w^2 = 2\left(\frac{m_w}{n}\right)^2 \int_0^{n_B} dn' \left[\Sigma_v^{(in)} + \left(\frac{n_s}{m_s}\right)^2 \Gamma_s \frac{d\Gamma_s}{dn'}\right];\\
\text{b)}\,\Gamma_s^2 &= 2\left(\frac{m_s}{n_s}\right)^2 \int_0^{n_B} dn' \frac{dn_s}{dn'}\,\Sigma_s^{(in)},\ \Gamma_w^2 = 2\left(\frac{m_w}{n_B}\right)^2 \int_0^{n_B} dn'\,\Sigma_v^{(in)};\\
\text{c)}\,\Gamma_s &= \Sigma_s^{(in)}/\tilde{\sigma},\ \Gamma_w = \Sigma_v^{(in)}/\tilde{\omega},
\end{aligned}$$

for details see the preliminary results of [4]. Specifically, we have taken as inputs the self-energies Σ^{in} of [3], which fit several Dirac-Brueckner computations, but avoiding the unphysical behavior they exhibit in the zero density limit.

As a result the functional dependence of the vertices are obtained within the cases $(a-c)$. They are used to study the energy density and the pressure of the dense nuclear matter in the mean field approximation. It is found that, despite the differing formal expressions for the energy and chemical potentials obtained within the approaches $(a-c)$, the final results are undistinguishable in the range of densities below four times the normal nuclear density. Another interesting property of the dense nuclear environment is the dispersion relation of the collective modes. We have examined this subject, in terms of the nucleon density, and we have found that although the results are qualitatively similar, significative differences arise as comparing the three cases $(a-c)$. In conclusion, DDHFT is a reliable scheme for studying the dense nuclear environment. Different field representations describe coherently the gross features of the nuclear matter, however some nuclear observables may depend on the field parameterization of the vertices.

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