Vol. 31 (2000) ACTA PHYSICA POLONICA B No 10–11

MESON PROPAGATION IN NUCLEAR MATTER WITH NON-LINEAR MESON–MESON COUPLINGS*

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(Received June 2, 2000)

Using the generating functional method, the σ and ω meson propagators in nuclear matter have been determined in relativistic non-linear models. The density dependence of the ω meson mass has been considered.

PACS numbers: 21.65.+f, 12.40.–y

1. Introduction

Since the original Walecka model [1], relativistic mean field models have been quite successful in describing nuclear matter and ground state properties of finite nuclei [1,2]. In these models, the nucleons are generally treated as Dirac particles interacting via scalar and vector meson fields in the mean field approximation through Yukawa or Dirac couplings. In addition, the most recent models (the so called non linear models) [3–6] include couplings between the mesonic fields in the Lagrangian. For example, the parameter sets obtained by Sugahara and Toki [5], TM1 (for medium and heavy nuclei) and TM2 (for light nuclei) lead to results which compare extremely well with the existing data for both stable and unstable nuclei. An another model which provides a good description of the nuclear properties is the Q2 model determined by Furnstahl, Serot and Tang [6]. The question that now arises is how do the mesons propagate in nuclear matter in these models. In this work, we have determined the in-medium propagators of the σ and ω mesons in the non-linear TM1, TM2 and Q2 models.

* Presented at the Meson 2000, Sixth International Workshop on Production, Properties and Interaction of Mesons, Cracow, Poland, May 19–23, 2000.

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2. Formalism

For these models, the part of the Lagrangian density which will contribute to the scalar and vector meson propagations in symmetric nuclear matter reads:

$$\begin{aligned}\mathcal{L} \;=\; & \overline{\psi}\left[\gamma_\mu(i\partial^\mu - g_{\omega 1}V^\mu) - (M_N - g_{\sigma 1}\phi)\right]\psi + \tfrac{1}{2}(\partial_\mu\phi\partial^\mu\phi - m_\sigma^2\phi^2) \\ & + \tfrac{1}{2}m_\omega^2 V_\mu V^\mu - \tfrac{1}{4}F_{\mu\nu}F^{\mu\nu} - \tfrac{1}{3}g_{\sigma 3}\phi^3 - \tfrac{1}{4}g_{\sigma 4}\phi^4 + \tfrac{1}{4}g_{\omega 4}\left(V_\mu V^\mu\right)^2 ,\end{aligned} \qquad (1)$$

where M_N is the nucleon mass, m_σ and m_ω the scalar and vector meson masses and, as usual, $F_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu$.

Following the standard procedure (see for example Ref. [1]), the action is evaluated approximately, keeping only linear and quadratic variations about the classical fields. Then, the generating functional $(\widetilde{W})$ for the Lagrangian density of Eq.1 is built, and, by performing variational derivatives of $\widetilde{W}$ with respect to the source functions, we can generate all the Green functions of the theory. We have neglected here the contributions quadratic in $g_{\sigma 3}$, $g_{\sigma 4}$ and $g_{\omega 4}$ since in realistic effective models in which the naturalness assumption is required, these contributions should be much smaller than the ones taken into account in this work. Finally, using the Dyson equations, the σ, ω and $\sigma\omega$ meson propagators (including the σ-ω mixing term) have been obtained with polarization operators including particle-hole excitations as well as the contributions arising from non-linear terms. These polarizations operators have been evaluated with an interacting nucleon propagator taking a form analogous to the non-interacting one but with an effective nucleon mass changed by the scalar component of the nucleon self-energy. Note that we have omitted the contribution arising from anti-nucleons.

3. Results

We have calculated the in-medium ω meson mass defined by the position of the mesonic branch at zero momentum, as a function of density. Note that in the limit $\overrightarrow{q}^2 \to 0$ the particle-hole excitations contribute nothing to the meson effective masses. Thus, the only contribution arises from the ω meson self-coupling. The curves in figure 1 represent the in-medium ω meson mass calculated with TM1, TM2 and Q2 models. As we can see, in TM1 and TM2 models, the effect of the non-linear ω coupling is to increase the ω mass as the density increases. On the other hand, when the Q2 model is considered, a decrease of the ω mass is obtained. The increase of the ω mass in TM1 and TM2 models is in contradiction with what is obtained in many other models. Indeed, many authors using either the Nambu–Jona–Lasinio model [7], or QCD sum rules [8, 9], or dilatational symmetry of the chiral Lagrangian [10] obtain a decrease of the ω meson mass when the density increases.

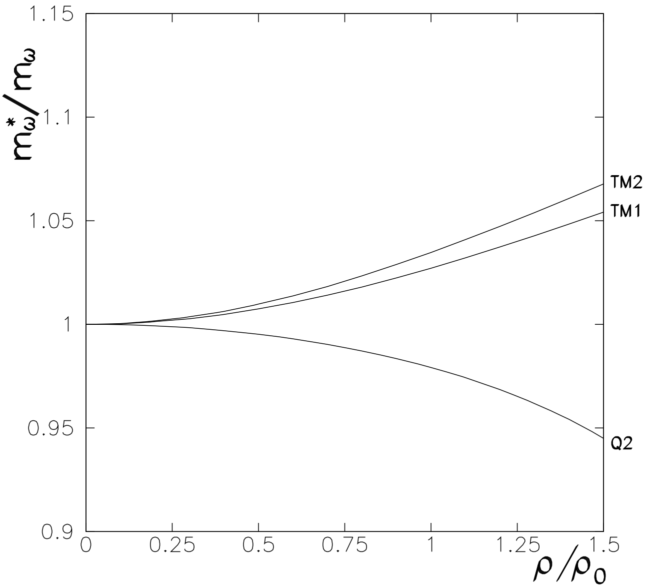

Fig. 1. The ω meson mass as a function of the baryonic density obtained with TM1, TM2 and Q2 models.

4. Conclusion

In this work, using the generating functional method, we have determined the in-medium propagators of the σ and ω mesons in the relativistic mean field non-linear TM1, TM2 and Q2 models. This study was motivated by the fact that, although non-linear models are known to provide a rather good description of nuclear properties, nothing was known on how the mesons propagate in nuclear matter with these models. We have considered here the density dependence of the ω meson mass. The Q2 model leads to a decrease of the in-medium ω meson mass as the density grows while TM1 and TM2 models lead to an increase. Although these models provide practically the same description of the ground state properties of finite nuclei (whereas the coupling constants in non-linear coupling models are very different from one model to another), the in-medium ω meson mass strongly depends on the model used. Thus, the meson propagation allows to distinguish between these models. As an application of this formalism, the determination of the response functions in inclusive electron–nucleus scattering (including relativistic RPA correlations evaluated with non-linear models) is in progress.

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