Density Dependent Hadron Field Theory

H. Lenske[1] and C. Keil[1]

[1]Institut für Theoretische Physik, Universität Giessen

In symmetric nuclear matter and stable nuclei one uses very often strictly phenomenological approaches, both in non-relativistic and relativistic formulation. In this contribution, a fully microscopic approach to nucleon-nucleon (NN) interactions in symmetric and asymmetric nuclear matter and extensions to hypernuclear matter will be discussed. Dirac-Brueckner theory is used to derive in-medium interactions [1] from well established free-space NN meson exchange potentials. By means of the Density Dependent Relativistic Hadron ($DDRH$) field theory [2, 3] the nuclear matter results for the in-medium interactions are used in a theoretically well defined approach in calculations for infinite nuclear matter, neutron stars and ground states of finite nuclei [3, 4] and hypernuclei [5].

In DDRH field theory interactions of baryons in a nuclear environment are described by density dependent meson-baryon vertices. They are introduced as functionals depending on Lorentz-scalars of the baryon field operators. In this way correlations and many-body effects are taken into account in an elegant and transparent formulation [3] by a Lagrangian $\mathcal{L} = \mathcal{L}_B + \mathcal{L}_M + \mathcal{L}_{int}$ with baryonic ($\mathcal{L}_B$), mesonic ($\mathcal{L}_M$) and interaction ($\mathcal{L}_{int}$) parts which for non-strange systems is:

$$\mathcal{L}_B = \overline{\Psi}\left[i\gamma_\mu\partial^\mu - M\right]\Psi \quad (1)$$

$$\mathcal{L}_M = \frac{1}{2}\sum_{i=\sigma,\delta}\left(\partial_\mu\Phi_i\partial^\mu\Phi_i - m_i^2\Phi_i^2\right) - \frac{1}{2}\sum_{\kappa=\omega,\rho,\gamma}\left(\frac{1}{2}F^{(\kappa)}_{\mu\nu}F^{(\kappa)\mu\nu} - m_\kappa^2 A^{(\kappa)}_\mu A^{(\kappa)\mu}\right) \quad (2)$$

$$\mathcal{L}_{int} = \overline{\Psi}\hat{\Gamma}_\sigma(\hat{\rho})\Psi\Phi_\sigma - \overline{\Psi}\hat{\Gamma}_\omega(\hat{\rho})\gamma_\mu\Psi A^{(\omega)\mu} + \overline{\Psi}\hat{\Gamma}_\delta(\hat{\rho})\tau\Psi\mathbf{\Phi}_\delta - \overline{\Psi}\hat{\Gamma}_\rho(\hat{\rho})\gamma_\mu\tau\Psi\mathbf{A}^{(\rho)\mu} - e\overline{\Psi}\hat{Q}\gamma_\mu\Psi A^{(\gamma)\mu} \quad . \quad (3)$$

Basic principles as the covariance of the field equations and thermodynamical consistency are retained. An important contribution are rearrangement terms obtained by the variational derivation of the field equations [2, 3]. The resulting field equations are solved in mean-field approximation.

The formulation is held general allowing for the flexibility required for a unified description of interactions within flavour multiplets. For baryon octet physics this means to include isospin and strangeness exchange channels as described by the pseudo-scalar and vector meson octets (or, more precisely, nonets). In addition, a more hypothetical nonet of scalar mesons with $S = 0, \pm 1$ is required. For $S = 0$ the physically closest realization realized is possibly found in the (low energy) f_0 spectrum. In practice, the vertex functionals are obtained from Dirac-Brueckner theory. The in-medium K-matrix K is represented in terms of renormalized meson exchange potentials [3]

$$K(q', q|q_s, k_F) = \sum_m z_m(q_s|k_F)V_m(q', q) \quad . \quad (4)$$

As shown in [3] the renormalization factors z_m are in fact determined by the underlying interactions. In Fig.1 results for the in-medium vertices $\Gamma^2(\rho) = z(k_F)g^2$ are shown. Generally, the interaction strengths decline with increasing density, except in the scalar-isoscalar $\delta/a_0(980)$ channel showing a more complicated behavior. The DDRH theory provides a parameter-free and successful scheme for interactions in nuclear environments once the free space NN interaction is chosen. Calculations for symmetric and asymmetric nuclear matter, binding energies of nuclei and hypernuclei reproduce data rather well and have shown their potential for predictions in the unexplored mass regions up to neutron stars. [3, 4]. More recently, the approach has been used by several groups on a phenomenological level by assuming functional forms and adjusting the parameters in data fits, e.g. [6].

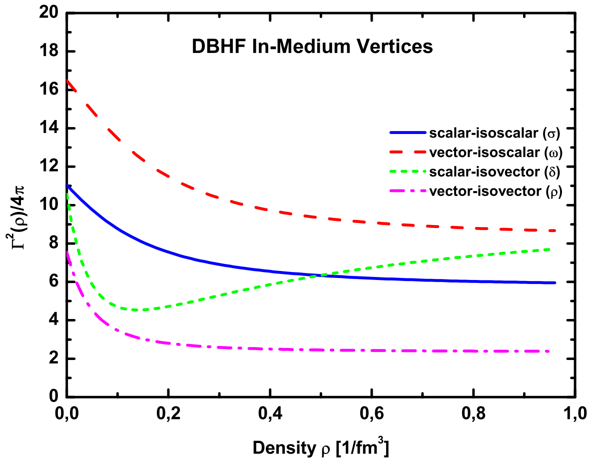

Figure 1: DDRH in-medium interactions. Dirac-Brueckner vertices for the mean-field producing meson field are shown [3].

References

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