Natural Effective Lagrangians in Dense Hadronic Matter from Nuclei up to Neutron Stars

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Following QCD dramatic modifications of the degrees of freedom are expected with increasing density of nuclear matter: at typically $\rho = 10\rho_0$ (with ρ_0, the saturation density of nuclear matter), a complete restauration of chiral symmetry together with the deconfinement of hadrons into quarks and gluons is anticipated. Information on such a phase transition is presently intensively studied in heavy ion collisions or delineated from the structure of neutron stars [1].
We investigate the transition from effective hadronic degrees of freedom to quarks and gluons at intermediate densities, where it is expected the main dynamics of dense nuclear matter up is still dominated by baryonic and mesonic degress of freedom in the framework of Quantum Hadrodynamics (QHD) as a renormalizable effective field theory [2]. Besides the inclusion of the full baryon octet (including Λ, Σ and Ξ hyperons), the main medium modifications are introduced in the mean-field (Hartree) approximation by the nonlinear self couplings of scalar σ and ω mesons. Recent developments in effective field theories provide a systematic ground for their inclusion to increasing orders [3].
Explicitly, we investigate the $\sigma^m\omega^{2n}$ couplings in a microscopic nonrelativistic quark model, including mesonic fluctuations via nonperturbative gluon exchange (with a typical gluon mass around 650 MeV) or instanton induced interactions; actual calculations are performed both in the zero range and the finite range limit of the pair-creation potentials for the σ^3 and $\sigma\omega^2$coupling; higher order selfcouplings are estimated from the leading spin and colour matrix elements. Assuming naturalness of the hierarchy of nonlinear couplings, we extract from a comparison with the expansion of Manohar and Georgi [4] bounds on the effective quark-gluon coupling and discuss their possible extrapolation to higher nuclear densities, summing them up in a compact form.
Within systematic numerical applications we attempt to map out the role of mesonic and baryonic degrees of freedom and their density dependence in the the equation of state from ordinary nuclear matter up to neutron stars [5].

References

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