Density Dependent Relativistic Mean Field Theory for Nuclear Matter and Finite Nuclei with Large Charge Asymmetry ◊

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Relativistic mean field theory (RMFT) has remarkable success in describing nuclear matter and finite nuclei near the valley of stability [1,2]. The extrapolation of nuclear properties to large charge asymmetry is of considerable interest. Nuclei near the proton and neutron driplines display interesting new phenomena like halos and provide a test of the isovector part of nuclear interaction.

In order to obtain a quantitative agreement between theory and experiment one has to go beyond the simple assumption of linear equations for the free meson fields. One possibility is to consider nonlinear self-couplings of the meson fields. This approach was succesfully applied in nonlinear parametrizations, e.g. NL3 [3], but the question of the physical foundation arises. A more natural alternative is the introduction of a density dependence in the couplings, which is suggested from Dirac-Brueckner theory of nuclear matter, where the scalar and vector self-energies are density dependent. This can be represented as a density dependence of the couplings in the mean field approximation, which simulates the effective in-medium interaction. The assumption of a density dependence of the couplings in the Lagrangian leads to additional "rearrangement" contributions in the self-energies, which also guarantee thermodynamical consistency of the theory [4].

Our Lagrangian includes σ-, ω- and ϱ-meson fields. We omit a δ-meson field since its inclusion does not improve our results. The nuclear mass and meson masses are fixed to standard values. For symmetric nuclear matter we assume a saturation density of 0.153 fm^{-3}, a binding energy per nucleon of -16.247 MeV and a compressibility of 240 MeV [5]. Only the density dependence of the coupling constants was taken to be variable in the fit. The calculated binding energies of a set of nuclei were fitted to their experimental values. The couplings show a decrease with increasing baryon density in accordance with the results from Dirac Brueckner theory. The asymmetry energy of nuclear matter results to be 33.39 MeV.

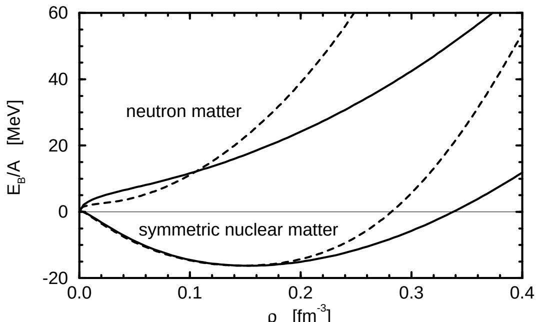

Fig. 1: Equation of state for symmetric nuclear matter and neutron matter for the density dependent parametrization (solid lines) and NL3 (dashed lines).

In Fig. 1 we compare the equation of state (EOS) of nuclear matter of our parametrization with the NL3 parametrization. At higher densities the NL3 parametrization shows a much stronger increase than our parametrization. A large difference appears in the EOS for neutron matter which is of importance for the description of neutron stars and neutron halos in nuclei. The differences in the EOS will also have significant consequences in calculations of heavy ion collisions with relativistic transport equations, like BUU etc., [6].

We describe semi-closed shell nuclei in Hartree approximation assuming spherical symmetry. We apply an improved center-of-mass correction and a charge correction. Pairing effects are considered in the BCS approximation. Binding energies and separation energies (Fig. 2) are very well described in our parametrization, even for very light systems. Charge and neutron radii turn out to be slightly smaller than in the NL3 parametrization, but exhibit the same systematic trends. Spin-orbit splittings decrease with increasing neutron number. They show, like density distributions, effects of shell structure.

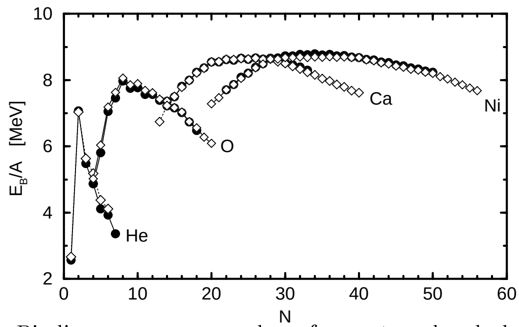

Fig. 2: Binding energy per nucleon for proton closed shell nuclei with our parametrization (diamonds) in comparison with experimental data (solid points) [7].

Relativistic mean field theory with density dependent couplings is very successful in describing various properties of nuclear matter and finite nuclei, not only for stable nuclei but also for nuclei near neutron and proton driplines. A density dependence of the couplings seems to be the preferential approach to a realistic description.

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