Hyperon interaction in nuclear matter and neutron stars*

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The upcoming hypernuclear experiments planned for FAIR have renewed the interest in hypernuclear physics in general. A key part of all theoretical studies is the knowledge of hyperon interactions in free space and in nuclear matter. Their knowledge also plays a crucial role for solving the so-called *hyperonization puzzle* [1] in a heavy neutron star as PSR J1614-2230 [2]. Concerning hyperon interactions, we reconsider the flavor octet approach, but with special focus on in-medium interactions. A meson exchange model based on SU(3) symmetry is used for determining the free space interaction. The interaction is then used to solve the Bethe-Salpeter (BS) scattering equation to find physical observables. Medium effect has been incorporated into the free space equation by multiplying a two particle Pauli projector operator (Q_P) with the two particle Green function (G_F) resulting in the Bethe-Goldstone equation

$$\hat{T}(q',q) = \hat{V}(q',q) + \int \hat{V}(q',k) G_F(k,q) Q_P \hat{T}(k,q) d^3k \tag{1}$$

where $\hat{T}(q',q)$ is the full-scattering amplitude and $\hat{V}(q',q)$ contains all the irreducible two-particle Feynman diagrams. The density dependence of interaction has been clearly seen in the variation of the in-medium low energy parameters as a direct consequence of the medium effect (Figure 1).

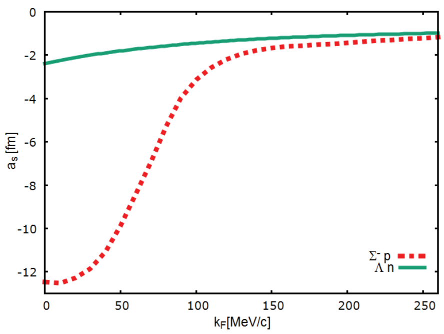

Figure 1: Λn (solid) and $\Sigma^- p$ (dashed) scattering length a_s with the variation of nucleon Fermi momentum $k_{FN}(\rho)$. It is clear from the plots that the scattering lengths attend a steady value as ρ approaches ρ_{sat}.

With increasing density, the Pauli-exclusion principle, are leading to a substantial reduction already at low and moderate densities. Thus, repulsive interactions are effectively increasing with density already on the level of ladder-diagrams. These results indicate the necessity for studying in more detail vector repulsion of hyperon interactions in high density matter as encountered in neutron stars. For a first case study, we use relativistic mean-field theory supplemented by an additional density dependence in the vector meson-hyperon vertices chosen as

$$g_{VY}(\rho) = g_{VY}\left(1 + \alpha_\rho \left(\frac{\rho}{\rho_{sat}}\right)^\beta\right) \tag{2}$$

where α_ρ is negligibly small at $\rho \leqslant \rho_{sat}$ and $\alpha_\rho = \alpha =$ constant above ρ_{sat}. At present, the density dependence is modelled phenomenologically. As constraints, we impose on the one hand the condition that the low-density $(\rho < 2\rho_{sat})$ behaviour of hyperon interactions should not be altered and on the other hand, a neutron star mass above two solar masses should be obtained.

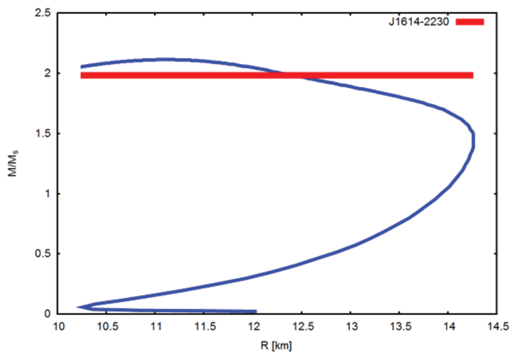

Figure 2: Neutron star mass-radius relation. The mass of J1614-2230 [2] is indicated by a horizontal bar.

Typical results of our calculations for the mass-radius relation are displayed in Figure 2. Already a moderate increase of the vector repulsion, $\alpha = 0.135$ and $\beta = 2$,results in a maximum mass above two solar masses. We find an interesting composition of the neutron star : the neutron star develops a hyperon shell at densities around $3\rho_{sat}$ which at higher density vanishes again.

References

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