Composite octet baryons in nuclear Fermi liquids†

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As an extension of our previous work[1] on high density matter in an effective quark theory of QCD, we recently investigated the role of composite octet baryons in the same framework. We used methods based on the Faddeev equations and Landau's Fermi liquid theory to translate the results into an effective mean field theory for octet baryons. Here we wish to show a few results for the simplest case of hyperons dispersed in symmetric nuclear matter, and refer to our full paper for isospin asymmetric matter and neutron stars.

Our results for the baryon energies are shown as functions of the density in Fig. 1.

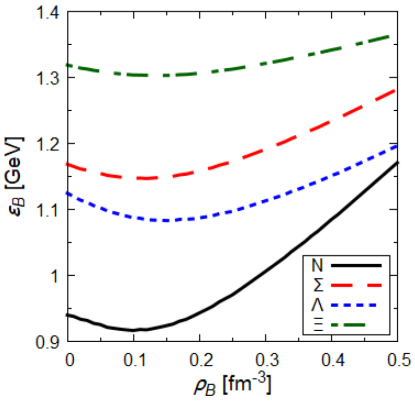

Fig. 1. Baryon energies $\varepsilon_B(k)$ as functions of the density. For $B = N$ we use $k = p_F$, for the other baryons $k = 0$.

The energy of a baryon b is related to spin averaged forward scattering amplitude between b and $\tau = p, n$ by $f_{b\tau} = \frac{\delta\varepsilon_b}{\delta n_\tau}$, where n_τ is the Fermi distribution function of nucleons. We can define $f_{bN} = \frac{1}{2}(f_{bp} + f_{bn})$, which is an isoscalar in the particle-hole channel and therefore the same for the members of a given isospin multiplet ($B = N$, Σ, Λ, or Ξ), and $f'_{bN} = \frac{1}{2}(f_{pb} - f_{bn})$, which is an isovector in the particle-hole channel proportional to t_b, the isospin 3-component of b. These amplitudes can be decomposed into terms with angular momentum transfer ℓ. This leads to the amplitudes $f_{\ell,bN}(k, p_F)$ and $f'_{\ell,bN}(k, p_F)$, where the momentum k of the baryon b is free but the nucleon momentum is fixed to the Fermi momentum p_F. For $b = N$ and $k = p_F$, these quantities agree with the familiar Landau-Migdal parameters f_ℓ and f'_ℓ.

The density dependence of the baryon energies shown in Fig. 1 reflects the general relation $\frac{\partial\varepsilon_b}{\partial\rho_B} = f_{0,bN}$: At low densities the bN interaction is attractive ($f_{0,bN} < 0$) with strength depending on b, while at high densities it is repulsive. The parameters $f_{1,bN}$ are particularly interesting because they are related to symmetries and conservation laws: Requirements of Lorentz invariance alone lead to the general relation $\varepsilon_b(k) = E_b(k)\left(1 - \frac{\varepsilon_N \rho_B}{k p_F} f_{1,bN}(k, p_F)\right)$, where $\varepsilon_N \equiv \varepsilon_N(p_F)$, and the "effective energies" E_b are defined via the velocities by $\vec{v}_b(k) = \vec{\nabla}\varepsilon_b(k) \equiv \frac{\vec{k}}{E_b(k)}$. (For $b = N$ and $k = p_F$, the above relation is the relativistic version of Landau's effective mass relation.) In relativistic mean field theories, the $E_b(k)$'s reflect the attraction from the scalar mean fields, and decrease with increasing density. The repulsive effects seen at higher densities in Fig. 1 can thus be viewed either as an effect of a contact interaction from ω^0 - exchange, or of a dipole-dipole interaction from $\vec{\omega}$ - exchange between b and N.

By combining Lorentz and gauge invariance requirements, general expressions for currents carried by baryons in the medium can be derived. For example, the baryon current carried by b becomes $\vec{j}_b^{(B)}(k) = \vec{v}_b(k) - \frac{\vec{k}}{\varepsilon_N}\left(\frac{\varepsilon_b(k)}{E_b(k)} - 1\right)$, where the second term is the backflow due to the nuclear medium. Consider then the electric current ($\vec{j}_b^{(E)}$) of a baryon with $t_b = 0$, like the Λ or the Σ^0. The Gell-Mann - Nishijima relation gives for this case $\vec{j}_b^{(E)} = \frac{1}{2}\left(\vec{j}_b^{(B)} + \vec{j}_b^{(S)}\right)$. The strangeness current is not modified by the backflow of the nuclear medium because nucleons have no strangeness, therefore $\vec{j}_b^{(S)}(k) = S_b\,\vec{v}_b(k)$ with $S_b = -1$. Then the electric currents of the neutral hyperons Λ and Σ^0 become generally $\vec{j}_b^{(E)}(k) = -\frac{1}{2}\frac{\vec{k}}{\varepsilon_N}\left(\frac{\varepsilon_b(k)}{E_b(k)} - 1\right)$, *i.e.*, they have a negative orbital g-factor in the nuclear medium, similar to the well known case of the neutron. Further applications to isospin asymmetric matter and neutron stars can be found in our full paper.

The Fermi liquid theory, when it was developed in the 1950s, was far ahead of its times. Indeed, according to Ref. 2), "Once we have the concept of the Fermi liquid theory, there is no need for the renormalization group." We therefore hope that the theory will attract more attention in current topics of nuclear and hadronic physics.

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