PAULI BLOCKING EFFECT WITHIN THE RELATIVISTIC PION GAS

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We show that the $\Phi$-derivable formulation of the cluster virial expansion for quark–meson matter contains the quark Pauli blocking effect in a pion gas in the lowest order expansion with respect to the backreaction of pions on the quark dynamics.

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In the $\Phi$-derivable approach \cite{1} for the cluster virial expansion for quark-meson matter, the thermodynamic potential reads \cite{2}

$$
\Omega = \text{Tr} \left\{ \ln S_q^{-1} - \Sigma_q S_q + \frac{1}{2} \ln D_\pi^{-1} + \frac{1}{2} D_\pi \Pi_\pi \right\} + \Phi[S_q, D_\pi], \Phi[S_q, D_\pi] = 0.
$$

The $\Phi$ functional is a 2PI skeleton diagram with dressed quark and pion propagators that fulfill the Dyson–Schwinger equations $S_q^{-1} = S_{q,MF}^{-1} - \Sigma_q$ and $D_\pi^{-1} = G_\pi^{-1} - \Pi_\pi$, respectively. The self-consistent mean-field propagator is $S_{q,MF} = [\not{p} - m_0 - \Sigma_{q,MF}]^{-1}$ with the Hartree self-energy $\Sigma_{q,MF}$ and the coupling constant $G_\pi = 2G_S$ being determined within the PNJL model. The self-energies of quarks and pions are obtained by a functional derivative from the $\Phi$ functional

$$
\Sigma_q = \frac{\delta \Phi}{\delta S_q} \approx \cdots \approx \cdots + \cdots \quad (1)
$$

$$
\Pi_\pi = \frac{\delta \Phi}{\delta D_\pi} \approx \cdots \approx \cdots + 2 \cdots \quad (2)
$$

A fully self-consistent solution of the above thermodynamic potential would include the backreaction of pions in the medium on the propagation of

quarks [3] which is not present in the traditional rainbow-ladder scheme [4]. A first step towards a self-consistent solution is to expand the quark propagator in first order of the self-energy $\Sigma_q$

\[
S_q = S_{q,\text{MF}} + S_{q,\text{MF}} \Sigma_q S_{q,\text{MF}} + O(\Sigma_q^2). \tag{3}
\]

Inserting the expansion (3) into the pion self-energy (2) and dropping terms of $O(\Sigma_q^2)$, one obtains the rightmost diagram in (2) as a contribution to the pion self-energy. This term corresponds to the pion self-energy resulting from the quark box diagram in the NJL model description of $\pi\pi$ scattering [5], see also [6]. It is topologically equivalent to the quark exchange contribution in the meson–meson scattering [7, 8]

\[
\equiv \quad \text{(4)}
\]

which results in an excellent description of the repulsive isospin 2 phase shift $\delta_2^0$ of the $\pi\pi$ scattering which is very important for the phenomenology of hadron resonance gases since it approximately cancels the contribution from the broad $\sigma$ meson resonance in the $\delta_0^0$ channel [9, 10].

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