$\overline{K}^*$ mesons in matter

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We study the properties of $\overline{K}^*$ mesons in nuclear matter. The $\overline{K}^*$ self-energy is evaluated in dense matter, which consists of two components: The interaction of $\overline{K}^*$ mesons with nucleons, and the renormalization of its decay channel, $\overline{K}\pi$, in nuclear matter. For the first part of the selfenergy, a unitary approach in coupled channels within the framework of the local hidden gauge formalism is used. The in-medium $\overline{K}^*N$ interaction accounts for Pauli blocking effects and the inclusion of the $\overline{K}^*$ selfenergy in a self-consistent manner. In addition, the ratio of the $\gamma A \to K^+ K^{*-} A'$ reaction is calculated, which will be useful for future observations. The results are rather spectacular since the $\overline{K}^*$ develops an in-medium width of 260 MeV, five times larger than in free space and much bigger than for the ρ meson.

1 Introduction

The investigation of the interaction of vector mesons with nuclear matter has been a matter of debate for a long time. In contrast to the model derived by Hatsuda and Lee [1], which predicts a 20% decrease in the ρ mass at ρ_0, $m = m_0(1 - 0.16\,\frac{\rho}{\rho_0})$, the Nambu Jona Lasinio model [2] tell us there is no shift of the vector masses. Moreover, detailed calculations show a broadening of the ρ, ω and ϕ mesons in nuclear matter and small changes in the masses [3–5]. However, no discussion has been made about the properties of strange vector mesons ($\overline{K}^*$) in the medium, which is the focus of attention of this work. The $\overline{K}^*$ selfenergy have two components, the in-medium $\overline{K}^*$ interaction with nucleons that accounts for Pauli-blocking and is incorporated in a selfconsistent way and the $\overline{K}\pi$ decay channel in matter. In this paper we evaluate the $\overline{K}^*N$ spectral function and analyze the $\gamma A \to K^+ K^{*-} A'$ ratio, which can give us valuable information for future experiments involving $\overline{K}^*$ in matter.

2 Formalism: The $\overline{K}^*$ selfenergy

In this section we briefly summarize the procedure in order to evaluate the $\overline{K}^*$ selfenergy. We refer to [6] for a detailed explanation. The two sources of modification of the $\overline{K}^*$ selfenergy in nuclear matter are:

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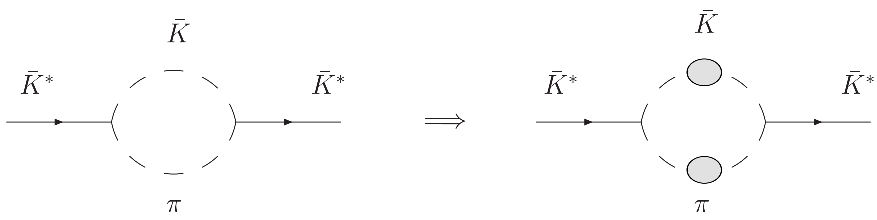


Figure 1: The $\overline{K}$ propagator renormalized to allow its decay into $\overline{K}\pi$, in the free space (left), and in the medium (right), including the self-energies of the $\overline{K}$ and π mesons.

a) **The contribution of the decay mode $\overline{K}\pi$ in dense matter**. In order to evaluate this part, we need to include the selfenergies of the $\overline{K}$ and π in the loop, as shown in Fig. 1. In the free space, for the first diagram in Fig. 1, we have

$$\Pi^0_{\overline{K}^*}(q^0,\vec{q}\,) = 2g^2\vec{\epsilon}\cdot\vec{\epsilon}\,'\int\frac{d^4k}{(2\pi)^4}\frac{\vec{k}^{\,2}}{k^2-m_\pi^2}\frac{1}{(q-k)^2-m_{\overline{K}}^2+i\epsilon}\,. \tag{1}$$

The imaginary part of the $\overline{K}^*$ selfenergy at rest provides the theoretical value of the $\overline{K}^*$ width, $\Gamma_{K^{*-}} = -\mathrm{Im}\Pi^0_{\overline{K}^*}/m_{\overline{K}^*} = 42$ MeV, which is quite close to the experimental value of $\Gamma^{\mathbf{exp}}_{K^{*-}} = 50.8\pm0.9$ MeV. In the medium, we have, on one hand, the contribution of the $\overline{K}$ selfenergy that considers interactions of the type $\overline{K}N\to\pi\Sigma$, $\pi\Lambda$, $\overline{K}N$ ..., in s-wave and $\overline{K}N\to\Lambda$, Σ or Σ^* in p-wave. On the other hand, the pion selfenergy (mostly p-wave) includes particle(p)-hole(h), Δ-h and 2p-2h excitation. This is done through the Lehman representation of the propagators:

$$\begin{aligned} -i\Pi^{\rho,(a)}_{\overline{K}^*}(q^0,\vec{q}\,) = {}& 2\,g^2\vec{\epsilon}\cdot\vec{\epsilon}\,'\int\frac{d^4k}{(2\pi)^4}\vec{k}^{\,2}\int_0^\infty\frac{d\omega}{\pi}(-2\omega)\frac{\mathrm{Im}D_\pi(\omega,\vec{k}\,)}{(k^0)^2-\omega^2+i\epsilon} \\ & \times\int_0^\infty\frac{d\omega'}{\pi}(-)\left\{\frac{\mathrm{Im}D_{\overline{K}}(\omega',\vec{q}-\vec{k}\,)}{q^0-k^0-\omega'+i\eta}-\frac{\mathrm{Im}D_K(\omega',\vec{q}-\vec{k}\,)}{q^0-k^0+\omega'-i\eta}\right\}\,, \end{aligned} \tag{2}$$

where the real part of the free $\overline{K}^*$ selfenergy has been subtracted since we use the physical mass of the $\overline{K}^*$. Moreover, one has to implement the vertex corrections to guarantee the gauge invariance of the model, to which, one simply replaces the p-wave pion selfenergy with:

$$\Pi^{(p)}_\pi\Longrightarrow\frac{\Pi^{(p)}_\pi}{\vec{k}^{\,2}}\left(\vec{k}^{\,2}+\left[D^0_\pi(k)\right]^{-1}+\frac{3}{4}\frac{\left[D^0_\pi(k)\right]^{-2}}{\vec{k}^{\,2}}\right)\,, \tag{3}$$

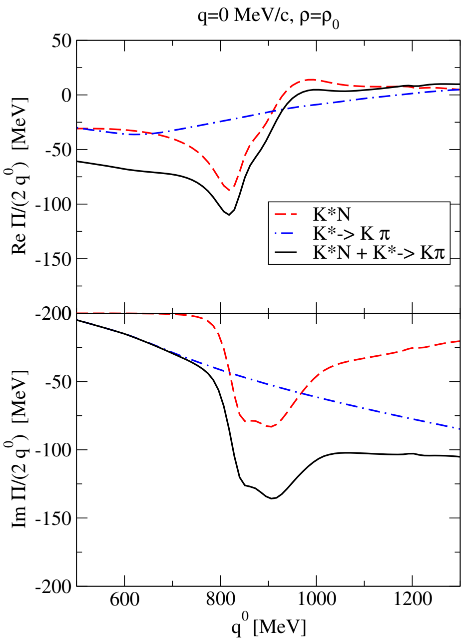
with $\left[D^0_\pi(k)\right]^{-1}=(k^0)^2-\vec{k}^{\,2}-m_\pi^2$.

b) $\overline{K}^*$ **self-energy from the s-wave $\overline{K}^*N$ interaction.** This includes quasi-elastic process, $\overline{K}^*N\to\overline{K}^*N$, and absorption channels, $\overline{K}^*N\to\rho Y,\omega Y,\phi Y,\ldots$ with $Y=\Lambda,\Sigma$. We follow the work of [7] for the interaction of a $\overline{K}^*$ with nucleons. In this framework the antikaon interacts with a nucleon by means of the exchange of a vector meson. The Lagrangian for the three-vector vertex is provided by the hidden gauge formalism and the constructed $VB \rightarrow VB$ transition potential is used as the kernel of the Bethe Salpeter equation, $T = [1 - V * 40 * G]^{-1} V$.

The medium modifications are incorporated in the loop function of the two vector mesons, G. One of the sources of density dependence comes from the Pauli principle acting on the nucleons and another source is the $\overline{K}^*$ self-energy incorporated in the $\overline{K}^* N$ intermediate states self-consistently. The in-medium $\overline{K}^*$ self-energy is then obtained by integrating $T^{\rho}{}_{\overline{K}^* N}$ over the nucleon Fermi sea,

$$\Pi^{\rho,(\mathrm{b})}_{\overline{K}^*}(q^0,\vec{q}\,) \quad = \quad \int \frac{d^3p}{(2\pi)^3}\, n(\vec{p}\,) \left[\, T^{\rho\,(I=0)}_{\overline{K}^* N}(P^0,\vec{P}) + 3T^{\rho\,(I=1)}_{\overline{K}^* N}(P^0,\vec{P}) \right] . \tag{4}$$

The self-energy $\Pi^{\rho,(\mathrm{b})}_{\overline{K}^*}$ is determined self-consistently since the in-medium amplitude $T^{\rho}_{\overline{K}^* N}$ depends also on $\Pi^{\rho,(a)}_{\overline{K}^*}$ and $\Pi^{\rho,(b)}_{\overline{K}^*}$.



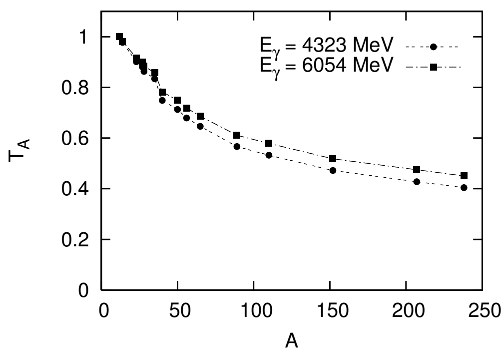


Figure 2: Left: real and imaginary parts of the $\overline{K}^*$ self-energy as functions of the meson energy q^0 for zero momentum and normal density ρ_0 showing the different contributions: (i) self-consistent calculation of the $\overline{K}^* N$ interaction (dashed lines), (ii) self-energy coming from $\overline{K}^* \rightarrow \overline{K}\pi$ decay (dot-dashed lines), and (iii) combined self-energy from both previous sources (solid lines). Right: transparency ratio

3 Results

We show in Fig. 2(left) the $\overline{K}^*$ self-energy at ρ_0 (solid line) due to the different processes, $\overline{K}^* \rightarrow \overline{K}\pi$ in the medium (dot-dashed lines), and $\overline{K}^*N$ interaction (dashed line). For $\overline{K}^*$ energies around 800-900 MeV we observe an enhancement of the width together with some structures in the real part of the self-energy. This comes from the coupling of the $\overline{K}^*$ to the dynamically generated $\Lambda(1783)N^{-1}$ and $\Sigma(1830)N^{-1}$ excitations. At low energies, the width of the $\overline{K}^*$ is governed by the $\overline{K}\pi$ decay mechanism in dense matter. At the $\overline{K}^*$ mass, the $\overline{K}^*$ feels a moderately attractive optical potential and acquires a width of 260 MeV, which is about 5 times its width in vacuum.

In Fig. 2(right), the transparency ratio is plotted for two different energies. We observe a very strong attenuation of the $\overline{K}^*$ production process due to the decay or absorption channels $\overline{K}^* \rightarrow \overline{K}\pi$ and $\overline{K}^*N \rightarrow VY$ with increasing nuclear-mass number A. This is due to the larger path that the $\overline{K}^*$ has to follow before it leaves the nucleus, having more chances to decay or get absorbed. The analysis of the transparency ratio is a very efficient experimental tool to study changes in the width of hadrons in dense matter.

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