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DYNAMICS OF $\overline{K}$ AND MULTI-$\overline{K}$ NUCLEI

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Abstract

We report on self-consistent relativistic mean field calculations of single-K^- and multi-$\overline{K}$ nuclear states. In our recent works, we analyzed in detail the interplay between the underlying dynamical processes and the relevant kinematical conditions which determine the decay width of deeply bound $\overline{K}$–nuclear states. Further, we explored the behavior of the nuclear medium under the influence of increasing strangeness in order to search for $\overline{K}$ condensation precursor phenomena in the multi-$\overline{K}$ nuclei.

1 Model

We studied $\overline{K}$–nuclear states within the theoretical framework of relativistic mean field theory (RMF) [1,2]. The (anti)kaonic sector was incorporated by adding $\mathcal{L}_K$ to the standard RMF Lagrangian density:

$$\mathcal{L}_K = (\mathcal{D}_\mu)^\dagger (\mathcal{D}^\mu) - m_K^2 K^\dagger K - g_{\sigma K} m_K K^\dagger K \sigma \,, \tag{1}$$

where $\mathcal{D}_\mu = \partial_\mu + \mathrm{i} g_{\omega K}\omega_\mu + \mathrm{i} g_{\rho K}\tau\cdot\rho_\mu + \mathrm{i} g_{\phi K}\phi_\mu + \mathrm{i} e\frac{1}{2}(1+\tau_3)A_\mu$. This particular choice of interacting scheme induces the following equation of motion for the K^- field:

$$[-\nabla^2 - E_{K^-}^2 + m_K^2 + \mathrm{Re}\,\Pi_{K^-}]K^- = 0 \,, \tag{2}$$

where the K^- self-energy is given by:

$$\begin{aligned}\mathrm{Re}\,\Pi_{K^-} =& - g_{\sigma K} m_K \sigma - 2E_{K^-}(g_{\omega K}\omega + g_{\rho K}\rho + g_{\phi K}\phi + eA) \\ & - (g_{\omega K}\omega + g_{\rho K}\rho + g_{\phi K}\phi + eA)^2 \,.\end{aligned} \tag{3}$$

The generalization for nuclear systems containing $\overline{K}^0$ mesons is straightforward.

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To study the role of p waves in the K^-–nucleus interaction, we included a phenomenological isoscalar p-wave potential:

$$\mathrm{Re}\,\Pi_{K^-} \to \mathrm{Re}\,\Pi_{K^-} + 4\pi\,(1 + E_{K^-}/m_N)^{-1}\,c_0(\nabla\rho_N)\cdot\nabla\,, \tag{4}$$

where ρ_N is the nuclear density and c_0 is an energy-dependent strength parameter dominated by the contribution of the $\Sigma(1385)$ p-wave resonance [3].

We considered the K^- absorption in the nuclear medium, in order to evaluate the K^- decay width Γ_{K^-}. In our model, this was done by substituting $E_{K^-} \to E_{K^-} - \mathrm{i}\Gamma_{K^-}/2$ and $\mathrm{Re}\,\Pi_{K^-} \to \mathrm{Re}\,\Pi_{K^-} + \mathrm{i}\mathrm{Im}\,\Pi_{K^-}$. Since the imaginary part of the K^- self-energy is not addressed by the traditional RMF model, we adopted the optical model phenomenology by setting:

$$\mathrm{Im}\,\Pi_{K^-} = (0.7 f_{1\Sigma} + 0.1 f_{1\Lambda}) W_0 \rho_N(r) + 0.2 f_{2\Sigma} W_0 \rho_N^2(r)/\rho_0\,, \tag{5}$$

with contributions both from (i) single-nucleon absorption processes ($\sim \rho_N$): $\overline{K}N \to \pi\Sigma, \pi\Lambda\,(70\%, 10\%)$ and (ii) conversion processes on two nucleons ($\sim \rho_N^2$): $\overline{K}NN \to \pi\Sigma\,(20\%)$. The strength of the potential W_0 was fitted to kaonic atom data [1]. We note that the nuclear density $\rho_N(r)$ is a dynamical quantity affected by the presence of a K^- meson. The kinematical suppression factors f_{iY} $(Y = \Sigma, \Lambda)$ were introduced to accomplish the reduction of the phase space available for decay products of the K^- deeply bound states.

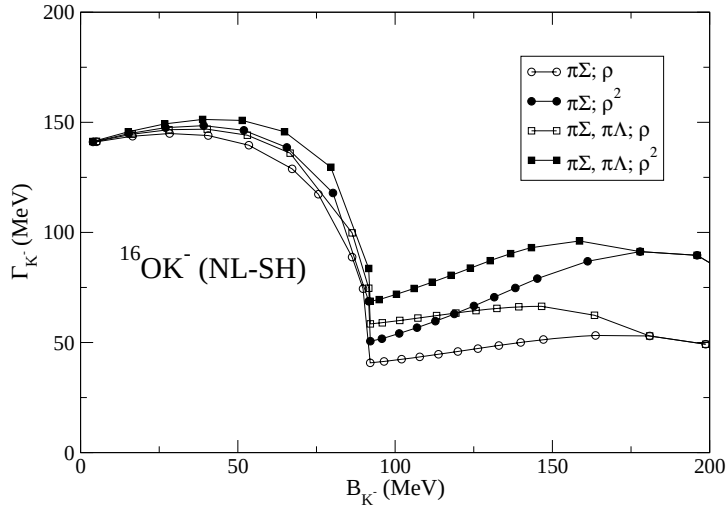

Figure 1: Width of the $1s$ K^--nuclear state in ${}^{16}_{K^-}\mathrm{O}$ as function of the K^- binding energy, for absorption through $\overline{K}N \to \pi\Sigma$, with and without $\overline{K}NN \to \pi\Lambda$, and assuming ρ or ρ^2 dependence for $\overline{K}NN \to \Sigma N$.

2 Results and Discussion

We performed fully self-consistent calculations of $\overline{K}$–nuclear states across the periodic table. Wide range of $\overline{K}$ binding energies was spanned by varying the K^- couplings to the meson fields.

We verified that the interaction of K^- with the ρ-meson mean field affects negligibly the K^- binding energy. For all nuclei and RMF parametrizations considered in our calculations, the ρK^- coupling slightly decreases the K^- binding energy by less than about 5 MeV for $B_{K^-} < 200$ MeV. Similarly, the ϕ-meson contribution in systems with several K^- mesons reduces the K^- binding energy by a few MeV. Calculations involving the p-wave interaction revealed that p waves play a secondary role for deeply bound K^--nuclear systems where the mean field concept is acceptable. The p-wave interaction enhances the binding energy of a K^- meson, bound initially by 100 MeV due to the purely s-wave interaction, by about 10 MeV and 5 MeV in the case of ${}^{12}_{K^-}$C and ${}^{40}_{K^-}$Ca, respectively.

We found that implementation of the $\pi\Lambda$ decay channel in the single-nucleon absorption mode enhances the K^- conversion width for $B_{K^-} \leq$ 170 MeV. This enhancement is almost uniform for both linear and non-linear parametrizations and all nuclei under consideration. The most remarkable contribution occurs for binding energies $B_{K^-} \simeq 100 - 160$ MeV where it reaches values of approximately 20 MeV. The assumption of ρ^2 density dependence for the two-nucleon absorption mode adds further conversion width

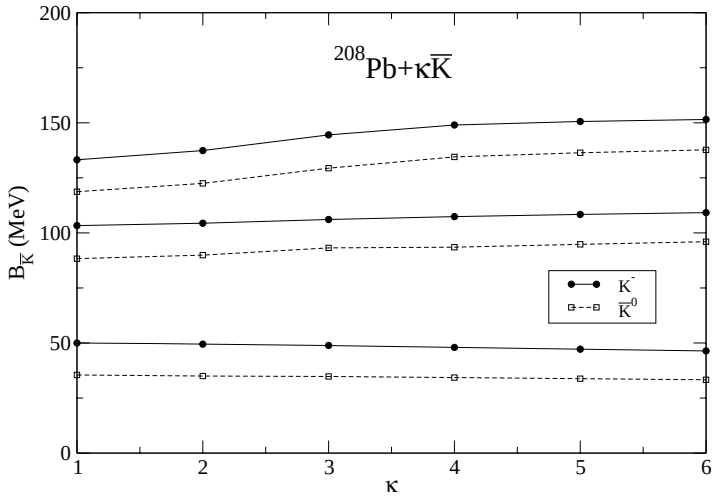

Figure 2: 1s $\overline{K}$ binding energy $B_{\overline{K}}$ in ${}^{208}\mathrm{Pb} + \kappa\overline{K}$ as function of the number κ of antikaons.

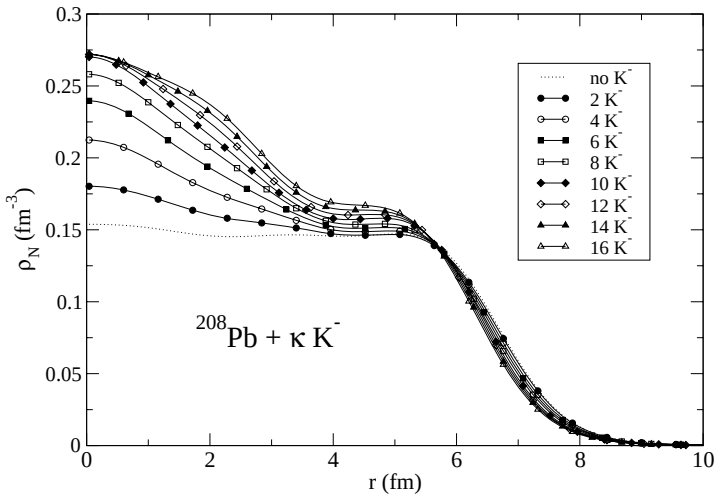

Figure 3: Nuclear density in ^{208}Pb+κK^- for $B_{K^-} = 100$ MeV in ^{208}Pb+$1K^-$. The dotted curve stands for the ^{208}Pb density in the absence of the K^- meson.

especially for deeply bound K^-–nuclear states ($B_{K^-} > 100$ MeV). Altogether, the results of these comprehensive calculations suggest that K^- total decay widths for deeply bound states are substantial, $\Gamma_{K^-} \sim 50 - 100$ MeV, as illustrated in Fig. 1. total decay widths

e studied also nuclear systems containing several antikaons. The $\overline{K}$ binding energies as well as the nuclear and $\overline{K}$ density distributions were found to increase only moderately or even saturate upon increasing the number of antikaons embedded in the nuclear medium, as shown in Figs. 2 and 3. It is therefore unlikely that multi-$\overline{K}$ nuclei may offer precursor phenomena in nuclear matter towards kaon condensation.

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