

Chiral dynamics in systems with strangeness

E. Oset¹, D. Jido¹, J. Palomar¹, A. Ramos², C. Bennhold³ and S. Kamalov⁴

¹Departamento de Fisica Teorica and IFIC, Universidad de Valencia,
Institutos de Investigacion de Paterna, Valencia, Spain

²Departament d'Estructura i Constituents de la Materia,
Universitat de Barcelona, Diagonal 647, Barcelona, Spain

³Center for Nuclear Studies, Department of Physics,
The George Washington University, Washington D. C. 20052

⁴Laboratory for Nuclear Physics, JINR Dubna, Russia

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Abstract

In this talk a brief review of several problems involving systems with strangeness is made. In the first place one shows how the $\Lambda(1405)$, $\Lambda(1670)$ and $\Sigma(1620)$ states, for $S = -1$, and the $\Xi(1620)$ for $S = -2$ are generated dynamically in the context of unitarized chiral perturbation theory. The results for the $\bar{K}N$ interaction are then used to evaluate the K^-d scattering length. Results obtained for the kaon selfenergy in a nuclear medium within this approach, with application to K^- atoms, are also mentioned. Finally a few words are said about recent developments in the weak decay of Λ hypernuclei and the puzzle of the Γ_n/Γ_p ratio.

1 Spectra of low lying strange baryons

The combination of unitary techniques together with chiral dynamics of meson and baryon systems already used in [1] and [2] to study low-energy K^-N scattering, has reached a certain maturity, it has been made more systematic and it has also been applied to the study of a large variety of physical processes [3]. The idea behind this work is the use of the unitarity constraints in coupled channels, which provide the imaginary part of the inverse of the scattering T matrix. From there, by means of dispersion relations, or equivalent techniques, one can construct the whole T matrix. In the strangeness $S = -1$ sector the N/D, or dispersion relation method has been applied in [4] with the result that the T matrix in coupled channels can be written as

$$T = [1 - V G]^{-1} V \quad (1)$$

with V obtained from the lowest order chiral Lagrangian for meson baryon interaction and G a properly regularized loop function of the meson baryon propagators of the intermediate states. The function V is given by

$$V_{ij} = -C_{ij} \frac{1}{4f^2} (2\sqrt{s} - M_{B_i} - M_{B_j}) \left(\frac{M_{B_i} + E}{2M_{B_i}} \right)^{1/2} \left(\frac{M_{B_j} + E'}{2M_{B_j}} \right)^{1/2}, \quad (2)$$

with C_{ij} coefficients evaluated in [5] and the G function given by

$$\begin{aligned} G_l &= i2M_l \int \frac{d^4q}{(2\pi)^4} \frac{1}{(P-q)^2 - M_l^2 + i\epsilon} \frac{1}{q^2 - m_l^2 + i\epsilon} \\ &= \frac{2M_l}{16\pi^2} \left\{ a_l(\mu) + \ln \frac{M_l^2}{\mu^2} + \frac{m_l^2 - M_l^2 + s}{2s} \ln \frac{m_l^2}{M_l^2} + \right. \\ &\quad \left. + \frac{\bar{q}_l}{\sqrt{s}} [\ln(s - (M_l^2 - m_l^2) + 2\bar{q}_l\sqrt{s}) + \ln(s + (M_l^2 - m_l^2) + 2\bar{q}_l\sqrt{s})] \right. \\ &\quad \left. - \ln(-s + (M_l^2 - m_l^2) + 2\bar{q}_l\sqrt{s}) - \ln(-s - (M_l^2 - m_l^2) + 2\bar{q}_l\sqrt{s}) \right\}, \quad (3) \end{aligned}$$

where μ is the scale of regularization and $a_l(\mu)$ is a subtraction constant which is chosen by fits to the data. Eq. (1) is nothing but the Bethe Salpeter equation where the Kernel V is given by the lowest order chiral amplitude. In [4] it was also found that the subtraction constant is easily related to the cut off employed in [5], and hence the equivalence of the N/D method of [4] and the Bethe Salpeter equation of [5] was established. Yet, the N/D method with the dimensionally regularized G function is preferable to extend the approach to higher energies. The structure of the T matrix in Eq. (1) allows for the existence of poles which correspond to resonances that we call dynamically generated, since they appear thanks to the multiple scattering implicit in the Bethe Salpeter equation, with the lowest order amplitudes playing the role of the potential. In this sense, both in [5] and [4], as well as in [2], one finds very clearly the $\Lambda(1405)$ resonance (see fig. 1), which has been claimed for long to be a quasibound state of $\bar{K}N$.

More novel have been the findings of [6] where the same approach of [4], with the subtraction constants evaluated from the unique cut off in all channels of [5], has lead to two new resonances, which we identify with the $\Lambda(1670)$ and the $\Sigma(1620)$. In the amplitudes in Fig. 2 one can see how the $\Lambda(1670)$ shows up both in the real and imaginary parts of the amplitudes.

One of the interesting findings concerning the $\Lambda(1670)$ state is that it couples very strongly to the $K\Xi$ states, and quite weakly to the other channels, which allows one to identify the $\Lambda(1670)$ with a quasibound state of $K\Xi$. Even more interesting are the findings of [7], where using also subtraction constants of the natural size found in the study of the $S = -1$ sector, one finds a resonance for $S = -2$ which could be identified in principle with the $\Xi(1620)$ or $\Xi(1690)$ $I = 1/2$ resonances. However, a detailed study of the partial decay widths of the found resonance (which are obtained from the residues of the transition amplitudes at the pole in the second Riemann sheet of the complex plane), clearly shows that this resonance is at odds with the properties of the $\Xi(1690)$,

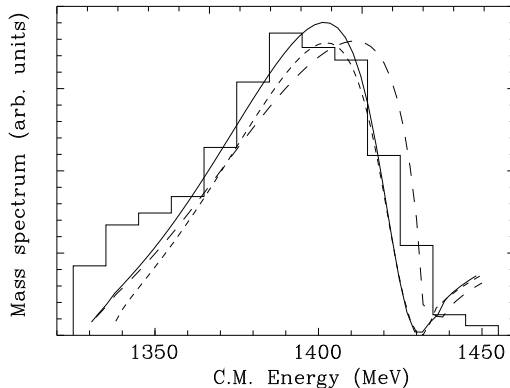


Figure 1: $\Lambda(1405)$ resonance as obtained from the invariant $\pi\Sigma$ mass distribution, with the full basis of physical states (solid line), omitting the η channels (long-dashed line) and with the isospin-basis (short-dashed line).

and by elimination can only correspond to the $\Xi(1620)$ state, hence allowing one to theoretically determine the spin and parity for this resonance as $1/2^-$, which is unknown in the particle data book. At the same time one makes predictions for the partial decay rates of this resonance which are also unknown so far.

2 K^- deuteron scattering length

One of the results in the study of [5] is the good description of the low energy cross sections of K^-p to different channels. The success of this theory has allowed us to revise the problem of the scattering length of K^-d , which has been approached before [8, 9]. Using the fixed centre approximation to the Faddeev equations, proved to be excellent for this problem in [10], we have studied this scattering length in [11]. The problem is subtle since there is no convergence of the expansion of the multiple scattering series implicit in the Faddeev equations. Second, the results are quite sensitive to the input used for the $\bar{K}N$ amplitudes. The chiral approach has allowed one to readdress this latter issue from a new perspective in which special attention is given to questions of unitarity, analyticity, and resonance properties, which make the new amplitudes quite accurate in principle. The results obtained in our approach are $A_{Kd} = -1.61 + i 1.91$ fm, which differ appreciably from the results quoted as best in Ref. [9] in their multichannel approach of $A_{Kd} = -1.34 + i 1.04$ fm. This quantity is one of the important quantities to be measured in the near future at Frascati in the DEAR experiment [12] and should put further constraints on the theoretical approaches, and, in particular, a challenge to the chiral unitary theory which makes these novel predictions.

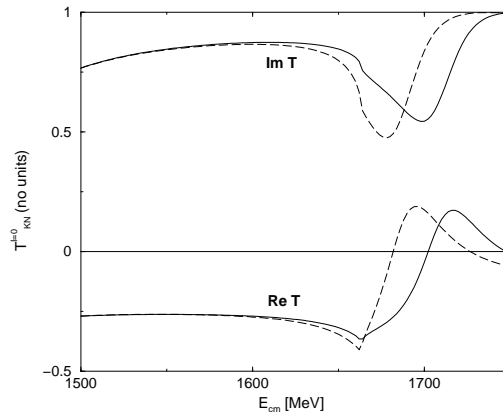


Figure 2: Real and imaginary parts of the $\bar{K}N$ scattering amplitude in the isospin $I = 0$ channel in the region of the $\Lambda(1670)$ resonance.

3 K^- interaction in nuclei

Another of the applications of this chiral unitary approach in the strange sector is the evaluation of the K^- selfenergy in the nuclear medium. Pauli exclusion effects in the intermediate states were taken into account in [13, 14], which lead to a shift of the $\Lambda(1405)$ resonance to higher energies and a considerable attraction on the kaon. A further selfconsistent treatment of the problem, including the calculated kaon selfenergy in the intermediate meson baryon loop functions, [15], moved the resonance back and produced a moderate attraction. Further work in [16] taking into account the renormalization of the intermediate pions and also the baryon selfenergies, produced new modifications leading to wider K^- spectral functions and still a moderate K^- attraction. This attraction is only of the order of $(40 - i 50)$ MeV at $\rho = \rho_0$ and threshold, and moderately dependent on the energy. It is surprising that this potential turns out to be so small when it was claimed in the past to be of the order of 200 MeV to be able to interpret the data on K^- atoms. Yet, it was proved in [17] that with this potential one could obtain a good description of K^- atoms, something that has been corroborated later on in [18] and [19]. This potential also leads to very deeply bound K^- states, with about 30-40 MeV binding, but with very large widths of the order of 80-100 MeV. With a potential of this type there are no hopes that one can obtain narrow deeply bound K^- states as claimed in [20]. The reason for the claim in that latter work is that a large binding energy is obtained, of the order of those used in the absence of selfconsistency in previous works, and also that many decay channels, which would be still open at these energies (like Σph), and which are evaluated in [16], are omitted in [20].

Another outcome of these calculations is that kaon condensation in neutron stars is far more unlikely than has been assumed in the past.

4 Weak decay of Λ hypernuclei

The weak decay of Λ hypernuclei and particularly, the neutron to proton induced decay ratio, Γ_n/Γ_p , has been a battlefield for years, with simple models based on just one pion exchange providing values around 0.1 for this ratio, while experimentally one had values around unity or bigger, albeit with large errors. A thorough recent study of this process, including kaon exchange and correlated and uncorrelated two pion exchange, was done in [22], where good results for the total rates were found for different nuclei and a ratio Γ_n/Γ_p of the order of 0.54 was found for all nuclei. The contribution of the correlated two pion exchange was done following the lines of the work for σ exchange in the NN interaction of [21], where no σ was put but was simulated by the interaction of two pions in the scalar isoscalar sector. Similar results for Γ_n/Γ_p have also been obtained more recently in [23]. The still puzzling thing is that, in spite of the apparently quite thorough work done in [22], there seems to be still discrepancies with the latest and most accurate analysis from the experimental point of view of [24], which provides values bigger than one for the Γ_n/Γ_p ratio, with errors small enough to make the results incompatible with those of [22]. The puzzle has been solved recently. The proton spectra of [24] were analyzed using the code of [25] that takes into account the final state interaction of the nucleons after the Λ decay. This code contained one fatal error and has been corrected recently [25], leading to quite different spectra than those obtained in the original work. The experimental results of [24] have also been corrected to the light of the new results in [25], with the outcome that the new values for Γ_n/Γ_p are of the order of 0.5-0.6 [26], which are in perfect agreement with the theoretical results in [22].

5 Conclusions

A short overview of different problems related to the field of few body physics in strong and weak interactions have been made, with the common denominator that they could be faced with fresh light from the new perspective provided by the unitary extensions of chiral perturbation theory. The short overview here has served to show the potential of this approach to face different problems at intermediate energies, allowing one to establish connections which could not be done prior to the introduction of these techniques. Unitarized chiral perturbation theory is thus proving to be a quite useful tool to address hadron and nuclear physics at intermediate energies, providing both a systematic working technique, as well as some novel understanding on the nature of those mesonic and hadronic resonances which could not be accommodated in the traditional quark models.

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