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Status and Prospects of Hypernuclear Studies*

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I. INTRODUCTION

The prospect of a Kaon-machine, the central objective in the JHP-project, will have a great impact on the importance of baryon-baryon studies, at low-, intermediate-, and high-energies. Beams of high intensity having strangeness will add a new dimension to the knowledge of the strong interactions. In the by now standard general physical framework: QCD, flavor $SU_f(3)$, and chiral $SU(3)_L \times SU(3)_R$, the interactions among hadrons, and their quark-gluon structure provides the guidelines of the interpretation of the experimental phenomena.

For high momentum transfer processes, i.e. high Q^2, the physics can be described directly by QCD and the quark-gluon density functions: the quark-gluon phase. For medium Q^2 there most naturally will be a mixed phase: quarks + gluons, and baryons + mesons. Finally, for low Q^2 the relevant degrees of freedom will be only baryons + mesons: the hadronic-phase. For low and intermediate energies both the mixed and the hadronic phase is of relevance. This in particularly for the description of phenomena that take place below $r \leq 1$ fm. Also, this region is important for a detailed understanding of the "hadronization" process, a necessary ingredient in the studies of deep-inelastic processes. For light nuclei and hypernuclei both the long- and the intermediate/short range interaction regions are important. However, for the heavier nuclei especially the intermediate and short regions are important. For the heavier nuclei the intermediate and short range regions are vital, because the 'healing distance' is ≤ 1 fm.

Progress has been made over the last 10 years, both experimentally and theoretically. First of all, new spectrometers have been developed, in particular at INS/KEK, BNL-AGS, and CEBAF. Recently new refined theoretical models have been developed, both the meson-exchange models and the quark-gluon exchange models. Also, much work has been done on the spectroscopic investigation of the hypernuclear spectra, both experimentally and theoretically. In this talk, we will try to discuss the general remarks made here in more detail. The emphasis will not be on reviewing at length the whole field. For this, we refer to the excellent reviews that already exist [2–6], and in particular to the very excellent collection of papers in [7].

II. EXPERIMENTS: KEK & BNL-AGS

The present status of the free YN data has, for example, been reviewed in [4,9]. In comparison to NN, where there are abundant scattering data on many kinds of observables, the YN data are only few. Nevertheless, with constrained models, it is not trivial to fit these YN data. Fitting the YN data means also no bound states and no undesirable resonances. In view of the meager YN data, to extract any information on the YN-interactions, it is neccessary to apply models which (i) fit the NN data, (ii) have only a few free parameters. Since, $SU(3)$ is a rather good symmetry, this way it is indeed possible to extract information from the free YN scattering data. Now, real progress mostly comes from new experiments having an higher precision compared to the old ones. Fortunately, the last years have shown a number of innovative experimental activities. New spectrometers have been developed at e.g. KEK, BNL, and LANL. For example the KEK experiment on $\Sigma^+ p \to \Sigma^+ p$ uses a novel visual image detector system, which is at the same time a scattering target with $3D$ visual capability: SCIFI [10]. This means a new generation of YN scattering experiments on $\Lambda p \rightarrow \Lambda p, \Sigma p \rightarrow \Sigma p, \Xi p \rightarrow \Xi p$.

A review on the Hypernuclear γ-ray spectroscopy has recently been given in [11]. Experiment E287 at KEK aims at detection of the M1 transition between the spin doublet of ${}^{7}_{\Lambda}Li$, produced as a hypernucleus from stopped K^-. For a recent review of the experiments at BNL-AGS see [8].

III. NN AND YN INTERACTION MODELS

In this section we discuss the current realistic $NN + YN$ models available at this time. Realistic models for the baryon-baryon interactions are necessary in order to make progress in a number of important areas: (i) the understanding of the interactions themselves, (ii) the understanding of the nuclear- and hypernuclear-structures, (iii) normal and neutron star matter, etc. As mentioned before, the experimental information on the YN interactions is rather limited, and therefore one has to use trustworthy theoretical input in studying these interactions using models. Also, the number of free adjustable parameters for the YN-systems must be limited, otherwise no important information can be expected to be extracted from such studies. The strategy is therefore to start from models that give a reasonable description of the NN data, and subsequently extend this to the YN-systems, using $SU(3)$ flavor symmetry. Many NN-models are not suitable for this procedure. This is the case with the very phenomenological Reidlike potentials. The models we will discuss here are (i) the Nijmegen Soft-core models, (ii) the Bonn-Jülich models, and (iii) the QCM-model of the Niigata-Kyoto group. They have excellent/reasonable fits to the NN data, and the YN data as well.

1. The Nijmegen soft-core models are now of two kinds: (i) the OBE-models [12,13] having NN and YN versions, and (ii) the ESC-model [14,15] having only an NN version thus far. The ESC-model is an extension of the OBE-model having two-meson exchange and meson-pair exchange included. This all in the similar context as the Nijmegen soft-core OBE-models. That is, gaussian form factors, but no nucleon resonances. The latter are implicitly included via the pair-interactions, invoking duality arguments. The following nonets are included in the $NN - YN$ models:

$$\begin{aligned} J^{PC} &= 0^{-+} : \pi; \eta; \eta'; K \ , \quad & J^{PC} &= 0^{++} : a_0; \epsilon; f_0; K_0^* \ , \\ J^{PC} &= 1^{--} : \rho; \omega; \phi; K^* \ , \quad & J^{PC} &= 2^{++} : a_2; P \oplus f_2; f_2'; K_2^* \ . \end{aligned}$$

   The OBE-models have e.g. been discussed recently [9,26]. They have an excellent fit to the NN data, and the YN data as well.

2. The Bonn-Jülich $NN = YN$ models [16–18] have two versions: (i) Bonn A, an OBE-model, and (ii) Bonn-B, which has $OBE+TME$. Moreover, they include second order contributions from the baryon resonances. The meson-baryon-baryon vertex functions are of the mono/dipole form. The following mesons are included in the Jülich YN-models:

$$J^{PC} = 0^{-+} : \pi; K \ , \quad J^{PC} = 1^{--} : \rho; \omega; K^* \ ,$$
$$J^{PC} = 0^{++} : \sigma(550) \ .$$

In the Bonn-Jülich models the σ-exchange is viewed as an effective substitute for the scalar, isoscalar part of correlated plus uncorrelated 2π-exchange processes. Therefore, in the Jülich models the $g_{\sigma\Lambda\Lambda}$ and $g_{\sigma\Sigma\Sigma}$ couplings are not constrained, as in the Nijmegen models, but are fitted to the YN-data.

3. The Niigata-Kyoto group has constructed a QC-model for $NN+YN$ [19,20]. Here the short-range is described by the Fermi-Breit-interaction from an effective Quark-Gluon-exchange (QGE). The medium and long-range part of the interactions is described by the nonets:

$$J^{PC} = 0^{-+} : \pi; \eta; \eta'; K \ , \quad J^{PC} = 1^{--} : \rho; \omega; \phi; K^* \ .$$

Also in this model, the $g_{\sigma\Lambda\lambda}$ and the $g_{\sigma\Sigma\Sigma}$ couplings are free parameters. In contrast to the meson-exchange models they have strong repulsion in all $NN + YN$-channels. The only exception is the $SU(3)$ singlet representation $\{1\}$ (the H-particle channel). Also, this model is characterized by having a very strong anti-symmetric spin-orbit force, which leads even to a P-wave resonance around the $\Lambda N \rightarrow \Sigma N$-threshold.

Another important class of models, from which already rather realistic NN-versions have appeared recently, are the Chiral-models. Ordóñez et al [21] gave a reasonable description of low energy NN for $T_{lab} < 100$ MeV, in the framework of chiral-perturbation theory. However, this apprach contains many free parameters, so that an extention to YN etc. will be impossible. Also, a variation on the ESC-model using pair-couplings from a chiral-Lagrangian gave a very good description of the NN for $T_{lab} \leq 320$MeV, in terms of no more free physical meson couplings as in OBE-models [22] Therefore, this model can easily be extended to YN etc.

IV. MESONS: $J^{PC} = 0^{-+}, 0^{++}, 1^{--}$

a. **pseudo-scalar mesons** $J^{PC} = 0^{-+}$: The coupling of the pseudo-scalar mesons to the $J^P = (1/2)^+$ baryons can be the ps-coupling, $\mathcal{L}_{ps} = \sqrt{4\pi} g \bar{\psi} i\gamma_5 \psi \cdot \phi$, the pv-coupling $\mathcal{L}_{pv} = \sqrt{4\pi}(f/m_\pi)\bar{\psi}\gamma_5\gamma_\mu\psi \cdot \partial^\mu\phi$, or a mixture of these couplings. When one assumes $SU(3)$ for the pv-couplings f, the Cabibbo theory of the weak interactions and the Goldberger-Treiman relation give $\alpha_{pv} = [F/(F+D)]_{pv} = 0.355(6)$. In the Nijmegen SC-model this value could be imposed and still keeping an excellent description of the YN-data, including the accurate datum on the capture ratio at rest. This SC-model has also a quite sizeable coupling to the baryons for the scalar ϵ. Nevertheless this OBE-model is compatible with the soft-pion constraints on the $\pi\pi$ scattering lengths, because the potentially dangerous ϵ contribution is cancelled by an opposite pomeron-exchange contribution [23].
b. **scalar mesons** $J^{PC} = 0^{++}$: The scalar meson $\sigma(550)$ was introduced in 1960-1962 by Hoshizaki et al [24] In the OBE- models for NN this scalar meson was necessary for providing

sufficient intermediate central attraction and for the spin-orbit required to describe the ^3P_J-splittings. In 1971 it was realized that the exchange of the broad $\epsilon(760)$ could explain the role of the fictiteous σ [25]. This broad $\epsilon(760)$ has been used in the Nijmegen OBE-models. For a more elaborate recent discussion we refer to [9,26], and [27]. Recent analysis of the π-production in πN scattering with polarized nucleons claimed to have found unambigeous evidence for a broad isoscalar $J^{PC} = 0^{++}$ state under the ρ [28]. This was based on an amplitude analysis using in the production mechanism besides π-exchange also a_1-exchange. In a similar analysis of data on $K^+n \rightarrow K^+\pi^-p$, one found evidence for an $I = 1/2, 0^+(887)$ strange scalar meson, under the $K^*(892)$. However, in [27] this analysis is cited with reserve, asserting that the ϵ-parameters of [28] can not be correct because the $f_0(980)$ is neglected in the analysis. However, since also the Helsinki group finds now an ϵ-meson and other members of a scalar nonet [29].

The Gilman-Harrari work [30] showed that all Adler-weisberger sum rules can be satisfied by saturation in the mesonic sector with the $\pi(140)$, $\epsilon(760)$, $\rho(760)$, $a_1(1090)$. They found the ϵ, degenerate with the ρ and having a width of $\Gamma(\epsilon \rightarrow \pi\pi) = 570$MeV. Similar phenomenology was derived by Weinberg requiring that the sum of the tree graphs for forward pion-scattering, generated by a chiral-invariant Lagrangian, should not grow faster at high energies than as permitted by Regge-behavior of the actual amplitudes [31]. Therefore, it seems that chiral-symmetry combined with Regge-behavior requires a broad scalar ϵ degenerate with the ρ [26]. In the QM the scalar mesons have been viewed as conventional $^3P_0$ $Q\bar{Q}$ states. Other views are the cryptoexotic $Q^2\bar{Q}^2$ states [32] and glueball states. For a recent discussion of these states and their role in baryon-baryon systems we refer to [9]. YN and ΞN studies will certainly give very valuable new information on the possible role of the scalar mesons and insight into how chiral-symmetry is manifested in nature.
c. **vector mesons** $J^{PC} = 1^{--}$: An important ingredient of the BB-force is the exchange of the vector meson nonet $(\rho, \phi, \omega, K^*)$. In making the chiral transformations local one incorporates the vector and axial mesons as the gauge-fields of this local symmetry, see e.g. [33]. A further interesting development has been to associate these gauge particles with a 'hidden' symmetry [34]. Writing $U = \exp[i\tau \cdot \pi(x)/f_\pi] = \xi_L^\dagger \xi_R$, the Lagrangian is invariant under the local gauge transformation $\xi_{L,R} \rightarrow h(x)\xi_{L,R}$, where $h \in SU(2)$ and $h^\dagger h = 1$. In the large N_c-limit one identifies the vector mesons with $V_\mu = \left(\partial_\mu \xi_L \xi_L^\dagger + \partial_\mu \xi_R \xi_R^\dagger\right)$. For $I = 1$ this gives on expanding the exponentials in U that $V_\mu \approx \pi \times \partial_\mu \pi + \ldots$. Now it is interesting to note that when $\rho \sim \pi \times \partial_\mu \pi$ etc., the vector-octet coupling to the baryon-octet has $\alpha_V^e = [F/(F+D)]_V^e = 0.44$ instead of $\alpha_V^e = 1$ as required by 'universality' [35]. So, it will be interesting to see whether this identification can be made in reality.
d. **heavy mesons** $J^{PC} = 1^{+-}, 2^{++}$: So far, these mesons, the axial- and the tensor-mesons, hardly have been explored in models on baryon-baryon for low energies. The axial mesons are very impartant in connection with chiral-symmetry and play an important role in sum-rules [36]. The tensor-mesons are very important at higher energies, lying on a dominant Regge-trajectory, exchange-degenerate with the vector mesons.

V. FINE STRUCTURE HYPERNUCLEI

The aim of the theory of nuclear structure is to understand energy levels, and transition rates on the basis of the underlying microscopic theory. Knowledge in this field is basic for the interpretation of experiments in all of high energy physics. Moreover, it is a crucial input in the design of sophisticated and expensive detectors, spectrometers etc. In order to make progress in this field the derivation of the so called 'effective interactions' from the baryon-baryon interaction in free space is important. This hopefully will ultimately lead to good enough wave functions for reliable applications, and which are needed to discern subnuclear effects, i.e. the role of mesons and quarks in light and heavy (hyper)nuclei. At present there are available results with a variety of reliable ab initio and effective interaction strategies: (i) Yakubowsky-Faddeev equations [37–39], (ii) GFMC-computations [40], (iii) CRCVM-method [41], (iv) ATSM-method [42], (v) G-matrix interactions [43], (vi) UMOA-method [44], often in combination with the shell-model or the cluster-model.

It is quite obvious that in order to obtain information out of the past, present, and future experiments on the fine structure of hypernuclei, one has to use one of the sophisticated methods alluded to above. If properly choosen, one can hope to extract the basic information from these experiments. This works two ways: (i) proper interpretation of these experiments, (ii) test of the applied methods of description of the (hyper)nuclei.

The general form of the basic BB-potential in local approximation reads

$$V(r) = V_C + V_\sigma \sigma_1 \cdot \sigma_2 + V_T S_{12} + V_{SO} L \cdot S + V_{ASO} \frac{1}{2}(\sigma_1 - \sigma_2) \cdot L + V_Q Q_{12}$$

where there are both direct and exchange forces present. In NN these potentials are virtually already completely determined by the differential X-sections alone, i.e. without the information from the spin correlation data. In YN there are, as already noted before, only very scarce scattering data. Therefore, the recent and future experiments at KEK, BNL, and CEBAF are of great importance for the progress in our field. The spin observables: polarization P, depolarization D, and the spin rotation parameters (A, R, R', A') are quite different for the Nijmegen and the Jülich models [45]. In the following we make some remarks as to the present situation w.r.t. the information we got sofar from hypernuclear studies on the central, the spin-spin, and the spin-orbit ΛN-interactions:

a. **central**: The Λ well depth U_Λ is from analyses of the (π^+, K^+) and (π^-, K^-) X-sections on nuclear targets with $A = 3 - 89$ [46] determined as $U_\Lambda = 27 - 28$ MeV. The Jülich models A and B give respectively 30 and 31 MeV [4], while the Nijmegen SC gives $U_\Lambda = 30.8$ MeV in [47] and $U_\Lambda = 32.3$ MeV in [48]. Also, it has been shown [49,50] that the Λ single particle energies agreed for the models, mentioned above, quite well with the BNL-AGS and the KEK data as a function of the mass number A.

b. **spin-spin**: The spin splittings of the levels for several hypernuclei have been analyzed recently extensively by Yamamoto et al [49] using the YNG-type G-matrix [47] based on the Nijmegen [51,13] and the Jülich [17] potentials. Recent experimental developments around the (π^+, K^+) reactions with the KEK-SKS spectrometer [52] and the BNL-AGS data [53] have provided detailed information on the fine structure within several hypernuclei. The results for the theoretical interactions show significant deviations from each other and from the data. From the overall picture one can not discriminate definitely between the different potentials. Therefore, as new experiments are planned, in particular those using hypernuclear γ-ray spectrometers [11] with the germanium detectors (E287 experiment at KEK) and the Toroidal spectrometer, there are good prospects for progress in this sector. In view of these developments, one can envisage that the ΛN spin-spin interaction will be established rather well in the coming years. For more recent work see [54].

c. **spin-orbit**: The CERN-PS [55] experiment $^{16}O(K^-,\pi^-)^{16}_{\Lambda}O$ and the BNL-AGS [56] experiment $^{13}C(K^-,\pi^-)^{13}_{\Lambda}C$ lead to $V_{SO}(\Lambda N)/V_{SO}(NN) = 0.05 \pm 0.05$ [5], which is claimed to be smaller than the OBE-models give. On the other hand, study of the heavier hypernuclei in $^{139}La(\pi^+,K^+)^{139}_{\Lambda}La$ and $^{89}Y(\pi^+,K^+)^{89}_{\Lambda}Y$ suggest larger spin-orbit forces in the ΛN-interaction [58,50]. However, these systems may show interesting many-body effects, which could influence the effective spin-orbit interaction. Of course, this could also be the case for the reactions on carbon and oxigen. Further experimental and theoretical activity concerning the spin-orbit interaction seems very promising to yield valuable information.

However, it must be pointed out that the Nijmegen SC-model satisfies the QM-relations quite closely [13]: $g_{\Sigma\Sigma\omega} \approx g_{\Lambda\Lambda\omega} \approx \frac{2}{3} g_{NN\omega}$, and $g_{\Sigma\Sigma\phi} \approx g_{\Lambda\Lambda\phi}$, and $g_{NN\phi} \approx 0$. Also, the scalar mesons satisfy similar relations reasonably well. (see also the discussion in [26]). Now, the SC-model fits the NN P-waves very accurately, and also for the triplet P-wave potentials we have $V_{\Lambda N} = (9V_{27} + V_{8s})/10$, i.e. very similar to the NN, which is purely V_{27}. So, the question is what can possibly be very wrong with the ΛN P-waves in the SC-model?

Also information on the ΛN spin-orbit interaction can be expected from Λ-nucleus scattering [59]. Here it is emphasized that a small spin-orbit interaction can be expected if $(f+g)_{\Lambda\Lambda\omega} = 0$. In the SC-model there is indeed a tendency to suppress this quantity. It will be interesting to see whether such a constraint on the ω-couplings is confirmed by the experiments.

The spin-orbit has also given a puzzle in the Quark-Model. Namely, the P-wave baryons were hard to describe by the theory if one kept the full Fermi-Breit spin-orbit interaction from gluon-exchange [60]. For the literature since 1980, see Valcarce et al [61]. Here one finds the suggestion that meson-exchange ($\pi, \epsilon, \rho, \omega$, etc.) between quarks gives a possible solution. This, as suggested before in this paper would be a most natural course. Another possibility is that the explicit inclusion of the decay channels can contribute to solving the problem with the spin-orbit for P-wave baryons [62].

VI. TOWARDS MULTIPLE STRANGENESS: $S = -2$ ETC.

Multiple strange objects have attracted much interest in many theoretical studies [7]. They are of much importance for relativistic heavy-ion collissions [63] and for astrophysical objects [64], although the present information is limited to the ground states of ${}^{6}_{\Lambda\Lambda}He$, ${}^{10}_{\Lambda\Lambda}Be$, and ${}^{13}_{\Lambda\Lambda}B$. Perhaps even more important, is the fundamental new information that these systems can provide for the basic baryon-baryon interactions. It is quite likely that the $S = -2$ systems, if studied experimentally with much better statistics in the future, will have a large impact on our detailed understanding of the baryon-baryon interactions. From the double-Λ states, mentioned above, it is inferred that $\Delta B_{\Lambda\Lambda} = 4-5$MeV, which indicates a rather strong $\Lambda\Lambda$-attraction. The estimation for the ${}^{1}S_{0}$ $\Lambda\Lambda$-matrix element in ${}^{6}_{\Lambda\Lambda}He$ for model D [51] that $\Delta B_{\Lambda\Lambda} = 4$ MeV, in agreement with the experimental observation. Model F [51] gives a repulsive $\Lambda\Lambda$-interaction in this case, in contradiction to the data. For more details we refer to [49]. Yamamoto et al [49] predict $\Lambda\Lambda$-hypernuclei for $A = 7-16$ systems, based on a core $+\Lambda$ + Λ three-body model with Wood-Saxon interactions. Akaishi and collaborators [65] investigated the ${}^{5}_{\Xi}H$ and ${}^{5}_{\Lambda\Lambda}H$ systems. They predict a bound ${}_{\Lambda\Lambda}H$-state 6.3 MeV below the $t+\Lambda+\Lambda$-threshold. In the Ξ^{-}-channel they have a resonating ${}^{5}_{\Xi}H$-state at 1.7 MeV below the $\alpha+\Xi^{-}$-threshold, a 'halo' nuclear state The total conversion width is 0.76 MeV, i.e. extremely narrow. Also the analysis by Millener et al [66] gives, using Nijmegen model D, a rather small width ≈ 1.5 MeV. Therefore, it is believed that experiments can observe Ξ-hypernuclear states using the (K^{+}, K^{-})-reaction. The experimentally prospects at KEK and BNL are very interesting. For more details and references on realistic scenario's for the production of the $S = -2$-systems experimentally, see Yamamoto et al [67]. We conclude this section by mentioning the very interesting work of Schaffner et al [68] on multiple-strangeness. The techniques employed are a generalization of the Bethe-Weizsäcker mass-formula and MFT-models. Interesting remarks are made on SHM and SQM. The Kaon-factory of the JHP will, of course, have an enormous impact on our knowledge of the multiple-strange systems. But, with an active experimental as well as a theoretical program we can expect very significant progress in this field already before the first experiments at JHP will start.

VII. TOWARDS REALISTIC QQ-INTERACTIONS

Another important development is the tendency to consider besides gluon-exchange also meson-exchange between quarks [69,70,61]. This is a most natural course in the employment of QM's with constituent quarks. This was stimulated by the problems encountered when one tried to explain the P-wave baryons using the Fermi-Breit interaction due to OGE [60]. See also [71] In the case of constituent quarks there is no compelling reason to ignore meson exchange ($J^{PC} = 0^{-+}, 1^{--}, 0^{++}, 1^{++}$, etc.) between quarks.

This brings us to the issue of the realistic QQ-interactions. We envisage that for low and intermediate energies, as well as for high energy processes up to moderate momentum transfer, that meson exchange will play its natural role in the QQ-interactions, besides of course the pure QCD interactions based on gluonic exchanges: i.e. the quark-gluon and the hadronic phase are both present in the QQ-dynamics relevant to our field. If one accepts this view, then the soft-core Nijmegen interactions can be translated to the QQ-level. One only has to fold the meson-exchange between quarks using the gaussian $3Q$-wave functions of the baryons. Of course, this implies the assumption of some sort of impulse-approximation, similar to what is done in the QC-models.

The key problem for the coming years is: How to develop our understanding of the strong interactions such that we can bridge the gap between the observations of hadronic phenomena, whether in free space or in nuclear systems, and the quark-world. First of all, for doing this we will need very strict and at the same time also realistic and precise theoretical models. This will also link directly to MFT's dealing with nuclear and star matter. In this connection the future of a Kaon-factory, as foreseen in the JHP-project, is extremely promising for the obvious reasons: (i) high statistics experiments on YN-interactions in free space, (ii) mass production of hypernuclei, and (iii) both low-, intermediate-, and high-energy data.

The latter point is also very promising. Namely, the low and high energy regions are connected via Reggeon exchange. In developing models for both regions one can get extra information on the separation of meson-exchange processes and QGE. Also, the super convergence relations [30] saturation can be sharpened. This will contribute to resolving issues w.r.t. the scalar mesons and glue-balls. This in its turn will have a bearing of the understanding of broken chiral symmetry [31].

Also, the study of the pomeron can be continued. As it became apparent in the study of the $pp \to (\Lambda\phi K^+)p$ and $pp \to (\Lambda\bar{\Lambda}p)p$ reaction at $\sqrt{s} = 63$ GeV [72] the pomeron couples to individual quarks dominantly. In the Low-Nussinov two-gluon model one has contemplated the spreading of the two-gluon coupling over the quarks of a hadron [73]. The dominance of the one-quark coupling can be understood as due to the fact that in the case of a coupling to two quarks the loop momentum involved in such a coupling has to pass through at least one baryon. Thus, the baryon wave function is involved, which leads to a suppression of a^2/R^2, where a and R are respectively the quark and the baryon radius [74]. Now, it is interesting to know whether this is also true at lower energies.

If that is the case, then there is also a question w.r.t. the QGE-process. Here also the loop momentum has to pass through a baryon, this in contrast to meson-exchange in the QCD-picture. (We consider here the meson as a $Q\bar{Q}$-bound states. The QCD ladder diagrams represent the mesons, which couple to the baryons.) A further interesting question is the role of the $B\bar{B}$-pairs. If one thinks that at short range the mesons couple directly to the quarks, then, two-meson exchange with in the intermediate state a $B\bar{B}$-pair has either additional gluon-couplings or the loop momenta pass through a baryon. In both cases this leads to a suppression. So, the conjecture that whenever the loop momenta involved in a process have to pass through a baryon wave function, then this process is suppressed, leads to (i) the pomeron couples to individual quarks, (ii) QGE is suppressed w.r.t. meson exchange, (iii) $B\bar{B}$-pair suppression. So far, this question has not been studied in the literature. In QGE one assumes simple gaussian wavefunctions for the quarks in the baryon, ignoring the possible singularities. How relevant these are remains to be seen.

VIII. CONCLUSION AND OUTLOOK

The definite establishment of the Σ-hypernucleus ${}^{4}_{\Sigma}He$ [75], in a recent BNL-AGS experiment, confirming the findings of the KEK-experiment [76], is an achievement of a combined experimental and theoretical cooperation. The subtle and complicated mechanisms, which make this Σ-hypernucleus possible, demonstrate the potential richness of the baryon-baryon interactions. It, in particularly stimulates the search for possible $S = -2$ hypernuclei, and also the possibilities for multiple strange objects. This requires, besides a lot of nuclear physics knowledge of all kinds, also a detailed knowledge of the ΞN-interactions. The latter are at present rather underdeveloped.

Progress in physics very often requires improvement of precision. Very notably this is true for experiments, but also for theoretical models. The study of hyperon-nucleon interactions, more generally of baryon- baryon interactions, is at a stage where both the experimental data and the theoretical computations need to be improved. Recent years have seen the development of several new experimental detectors and spectrometers at KEK, BNL, Los Alamos, and CEBAF. For example the development of hypernuclear γ-ray spectroscopy is getting into a new stage, using detectors of higher precision. This will lead to much improved knowledge of the hypernuclear level splittings, such that the effective spin-spin and spin-orbit interactions will become established.

Theoretically, we have seen the improvement of the NN phase shift analysis [77], and the development of Reidlike phenomenological potentials which have a $\chi^2_{d.o.f.} \approx 1$, as good as the PSA themselves. Calculations with these potentials still have the triton underbound , so that one has clearly a signall as to the relevance of 3BF's also in this system, see e.g. [78]. The importance of 3BF's in nuclear systems is well known. For example, in the case of the α particle it amounts to ca 5-6 MeV [42]. Simultaneous with this development there also a real prospect of getting theoretical potentials with $\chi^2_{d.o.f.} \approx 1.2$ [15] The latter potentials, in contrast to the Reidlike ones, can be extended to all baryon-baryon channels using (broken) flavor $SU(3)$ and chiral symmetry.

Since it is by now well known that the study of the YN-interactions is in particularly promising when performed in conjunction with NN, the development described above is relevant for the advancement in the YN-studies. The same kind of precision one would like to see in the QC-models. Here the description of the short-range forces is in terms of Quark-Gluon-Exchange. After some 15 years of pionering developments by several groups (Tokyo [79], Tübingen [80], ...) one now has reached the stage where realistic QGE-interactions exist, as the recent work of the Niiagata-Kyoto group [20] shows. Differences between models based on purely meson-exchange, like the Nijmegen and the Bonn-Jülich models, and those based on a combination of QGE and meson-exchange for the medium and long range [20], show up of course at $r \leq 1$ fm. This is especially so for e.g. the channels $\Sigma^+p(^3S_1)$,$pp(^3P_2)$, $\Lambda p(^3P_2)$. The KEK E251 Σ^+p scattering experiments by Ieiri et al, and its follow up, KEK(E289) experiment, could give already some insight in this difference. Also, a markedly difference in the spin-orbit interactions has been noted. The QC-models have a large anti-symmetric spin-orbit (ALS) force, whereas the meson-exchange models have not.

Of course, many interesting topics have not been discussed here. For example the decays of the hypernuclei (see the papers in [7]). For the possible role of instantons in the baryon-baryon interactions and its relevance for the H-particle we refer to [81].

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