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troyed. Therefore the complete inversion of these two levels cannot be generated from the pseudoscalar potential if consistency with the two-baryon system is required.

A solution to this problem can be obtained through the consideration of a three-quark force as proposed some time ago by Desplanques et al. [7]. The specific form of the interaction, on a pure phenomenological basis, is

$$V = \frac{1}{2} \sum_{i \neq j \neq k \neq i}^{3} \frac{V_0}{m_q^3} \frac{e^{-m_0 r_{ij}}}{m_0 r_{ij}} \frac{e^{-m_0 r_{ik}}}{m_0 r_{ik}} \tag{1}$$

where V_0 is taken to be $-$ 50.51 GeV^{-2} fm^{-6} and $m_0 = 250$ MeV. Certainly it is not much to relocate two levels of nucleon and Δ adding two more free parameters (V_0 and m_0). However, the effect of this potential on the whole spectrum is positive, see Fig. 2, it does not spoil the two-baryon results and allows to choose a bigger value for the spreading range of the Dirac delta in the OGE potential (r_0 = 2. fm) what eliminates in a great part its model space dependence, and also the cutoff for the pseudoscalar exchange that reproduces the deuteron binding energy, Λ = 4.2 fm^{-1}. The confinement constant is in this case a_c = 49.80 MeV fm^{-1}. Furthermore, three-body forces combined with Goldstone boson exchanges give baryon sizes bigger than those obtained in ref. [8], which may have beneficial effects on pionic strong baryon decay processes.

Then, we can conclude that it is possible to have a consistent precise description of the baryon spectrum and the baryon-baryon system in a chiral quark cluster model provided that a three-quark force has been incorporated.

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Exotic Hadrons

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Abstract. Among the exotic hadrons here I discuss multiquark systems formed of more than three quarks and/or antiquarks. Special attention is paid to pentaquarks containing a heavy (charmed) antiquark. These are being searched experimentally at Fermilab. Their stability is studied within a Goldstone boson exchange model. The results are compared to those obtained from conventional models based on one gluon exchange.

1 Introduction

QCD inspired models predict the existence of exotic hadrons formed of more than three quarks and/or antiquarks ($q^m \overline{q}^n$ with $m + n > 3$). Most studies are devoted to systems described by the colour state $[222]_C$. These are the tetraquarks $q^2\overline{q}^2$ [1], the pentaquarks $q^4\overline{q}$ [2, 3] and the hexaquarks q^6 [1].

Here we are concerned with the study of pentaquarks containing a heavy antiquark. The reason is that pentaquarks with one strange quark and a charmed antiquark are presently being searched at Fermilab [4]. An account of this searching is given by D. Ashery at this conference [5].

The first theoretical studies of pentaquarks [2, 3] have been performed within a constituent quark model based on one gluon exchange (OGE) interaction. Starting from simplifying approximations it was found that the pentaquarks $uuds\overline{c}$ and $udds\overline{c}$ and their conjugates are stable against strong decays. Better approximations [6] lead to instability. But more sophisticated calculations [7] suggested several candidates for stability and especially those with strangeness $S = -1$ or -2. In particular the $uuds\overline{c}$ system was bound by - 52 MeV. On the other hand the nonstrange systems $uudd\overline{Q}$ (Q = c or b) were found unbound. So far, the ongoing experiments [4, 5] had as guidelines the predictions of OGE based models. Within the confidence level of the analyzed experiments, no convincing evidence for the production of pentaquarks with the flavour content $uuds\overline{c}$ and $udds\overline{c}$ has been observed [4, 5].

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2 Stability of pentaquarks

In the stability problem we are interested in the quantity

$$\Delta E = E(q^4\overline{q}) - E_T \tag{1}$$

where $E(q^4\overline{q})$ represents the pentaquark energy and E_T is the lowest threshold energy for dissociation into a baryon + a meson. A negative ΔE suggests the possibility of a stable compact system.

The theoretical predictions are model dependent. Here we are concerned with constituent quark models which simulate the low-energy limit of QCD. I discuss the stability of pentaquarks within the Goldstone boson exchange (GBE) model [8, 9]. It will be shown that this model gives results at variance with OGE models. In the GBE model the hyperfine splitting in hadrons is due to the short-range part of the Goldstone boson exchange interaction between quarks, instead of the OGE interaction. The GBE interaction is flavour-dependent and its main merit is that it reproduces the correct ordering of positive and negative parity states in all parts of the considered spectrum of nonstrange and strange baryons in contrast to any OGE model. Moreover, the GBE interaction induces a strong short-range repulsion in the Λ-Λ system, which suggests that a deeply bound H-baryon should not exist [10]. This is in agreement with the high-sensitivity experiments at Brookhaven [11] where no evidence for H production has been found. On the other hand, in its present form, the GBE model does not apply to hyperfine splitting in mesons. According to ref. [8] there is no meson exchange interaction between quarks and antiquarks. It is assumed that the $q\overline{q}$ pseudoscalar pairs are automatically included in the GBE interaction. Therefore a light quark and the heavy antiquark interact via the confinement potential only and the model Hamiltonian contains GBE interactions only between light quarks.

For a comparative discussion it is useful to consider a schematic OGE interaction between the light quarks

$$V_{cm} = -C_{cm} \sum_{i<j} \lambda_i^c.\lambda_j^c \boldsymbol{\sigma}_i.\boldsymbol{\sigma}_j \tag{2}$$

with $C_{cm} = 293/16$ MeV determined from the $\Delta - N$ splitting, and a schematic GBE interaction

$$V_\chi = -C_\chi \sum_{i<j} \lambda_i^F.\lambda_j^F \boldsymbol{\sigma}_i.\boldsymbol{\sigma}_j \tag{3}$$

with $C_\chi = 293/10$ MeV determined also from the $\Delta - N$ splitting.

At this stage it is useful to note that one can have either positive or negative parity pentaquarks, as it will be explained below. Reference [12] considered pentaquarks of negative parity, by analogy to those proposed in the OGE model [2, 3]. The parity is given by the intrinsic parity of the antiquark. The light quarks are assumed identical. The ground state orbital (O) wave function is symmetric under permutation of any two light quarks, i.e. it corresponds to the partition $[4]_O$. Thus the parity of the pentaquark is equal to the parity of the antiquark because the q^4 subsystem has no internal angular momentum and there is no angular momentum in the relative motion between this subsystem and the heavy antiquark either. Note that the q^4 subsystem must be in a colour state $[211]_C$. As we look for the lowest state we have to take the spin S of the q^4 subsystem equal to zero. Then the totally antisymmetric state of q^4 must have the composition

$$|[4]_O([211]_F[22]_S;[31]_{FS})[211]_C> \tag{4}$$

In this case the expectation value of (3) is $< V_\chi >= -16C_\chi$. Inner product rules [13] also allow a flavour-spin (FS) state $[31]_{FS} = [31]_F \times [22]_S$. But this has higher energy because $< V_\chi >= -28/3C_\chi$. Therefore the lowest state must contain strangeness, i.e. has flavour symmetry $[211]_F$. Reference [12] shows that negative parity pentaquarks in this state are unbound by the GBE interaction. This is at variance with OGE based models.

The comparison of operators (2) and (3) suggests that the lowest state in OGE models is also of type (4) but with C and F interchanged, i.e. strangeness is also required. In the CS coupling scheme one gets $< V_{cm} >= -16C_{cm}$.

Now, to introduce positive parity pentaquarks one can consider a state like (4) but with an orbital symmetry [31] and a flavour-spin symmetry [4]. In this case the q^4 state of spin S = 0 has the structure $[4]_{FS} = [22]_F \times [22]_S$, thus it does not necessarily contain strangeness. The orbital state $[31]_O$ must have nonzero angular momentum. A state with an internal angular momentum L = 1 has been constructed in [14]. The parity of such a state is $P = (-)^{L+1} = 1$. The lowest positive parity state is then

$$|[31]_O([22]_F[22]_S;[4]_{FS})[211]_C> \tag{5}$$

with an expectation value $< V_\chi >= -28C_\chi$. Thus the GBE interaction brings a larger attraction for this state than for (4) i.e. the positive parity state should be lower than the negative parity one.

3 Results

Within the realistic model [9] and based on a simple variational solution it has been shown in [14] that the nonstrange positive parity pentaquarks $uudd\overline{Q}$ are bound by ΔE = - 75.6 MeV and - 95.6 MeV for Q = c and b respectively. The strange pentaquarks of type $uuds\overline{Q}$ or $udss\overline{Q}$ described by (5) turned out to be unbound. The reason is that the GBE interaction is weaker for strange pentaquarks due to the factor $1/(m_i m_j)$.

As the $uudd\overline{Q}$ pentaquarks of negative parity are predicted to be unbound by a chromomagnetic interaction [3, 7], the same system but with positive parity is expected to be even more unstable due to the increase in the kinetic energy produced by the excitation of a quark to the p-shell [14]. While the GBE interaction overcomes this excitation, the OGE interaction (2) does not make a distinction between the flavour symmetries associated to $[4]_O$ and $[31]_O$ orbital states so that the $[31]_O$ state appears higher than $[4]_O$, due to a higher kinetic contribution, thus nonstrange positive parity pentaquarks are unstable in OGE models.

One can see that the OGE and the GBE interactions predict contradictory results for anticharmed pentaquarks: while the GBE interaction stabilizes a given system, the OGE interaction destabilizes it and vice versa. A similar situation occurs for other exotic hadrons [15].

In conclusion the GBE model predicts that *nonstrange positive parity* pentaquarks with anticharm or antibeauty are the best candidates for stability against strong decays. If bound, they should be lighter than the strange ones of the same parity and should also have a longer weak decay lifetime. Experimentalists are encouraged to search for such pentaquarks.

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Describing the Nucleon Electromagnetic Form Factors at High Momentum Transfers

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Abstract. Electromagnetic form factors of the nucleon are calculated within the framework of a non-relativistic constituent-quark model. The emphasis is put on the reliability and accuracy of present day numerical methods used to solve the three-body problem. The high-q^2 behaviour of the form factors is determined by the form of the wave function at short distances and, due to the small absolute values that one deals with, an accurate solution is essential.

1 Introduction

Currently, there is some theoretical interest devoted to the nucleon form factor and, in particular, to its behaviour at high momentum transfers. From QCD in the perturbative regime, one expects the nucleon form factor to scale like q^{-4} up to log terms. Experimentally, this behaviour seems to be reached rather quickly, around $q^2 \sim 10$ GeV^2.

Simple descriptions in terms of constituent quarks have relied on the harmonic oscillator wave functions, where the calculated form factors drop exponentially to zero beyond $q^2 \sim 3$ GeV^2. Curiously, it has been deduced from this result that a constituent quark model does not lead to a power law behaviour of form factors at high q^2. As shown in details in a paper to appear [1], this is not true if one considers more realistic interquark potentials and their corresponding wave functions, however, due to the small values that one deals with, the problem becomes a considerable numerical task.

Structure calculations were performed with the same quark-quark force [2] in Grenoble (Faddeev equations) [3], Valencia (hyperspherical formalism) [4] and Graz (stochastic variational approach) [5]. The results show differences in