Life and Death Among the Hadrons

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Abstract.
This talk covers two related topics: a quick review of the present evidence for, and especially against the exotic Θ^+ baryon, and a brief advertisement for the study of diquark correlations in QCD[1].

THE $\Theta^+(1540)$

In January of 2003 evidence was reported of a very narrow baryon resonance with strangeness one and charge one, of mass $\approx$ 1540 MeV, now dubbed the Θ^+, with minimum quark content $uudd\bar{s}$ [2, 3]. The first experiment was followed by evidence for other exotics: a strangeness minus two, charge minus two particle now officially named the Φ^{--} by the PDG, with minimum quark content $ddss\bar{u}$ [5] at 1860 MeV, and an as-yet nameless charm exotic $(uudd\bar{c})$ [6] at 3099 MeV. Many experimental groups published confirmations of the Θ^+. Theorists, myself included, descended upon these reports and tried to extract dynamical insight into QCD[1]. Other experimental groups began searches for the Θ^+ and some reported negative results, especially in higher energy, inclusive production environments. Recently the balance has been tipping toward the negative sightings. Late last year Dzierba, Meyer, and Szczepaniak (DMS)[4] summarized the experimental evidence for (their Table 1) and against (their Table 2) the Θ^+ and its exotic partners.

In April 2005 a new experiment undertaken at Jefferson Lab (G11@JLab) has reported null results[7]. This report is particularly significant because it comes in a channel where a positive signal was seen before. The reaction was $\gamma p \to K^0\ \Theta^+$, followed by $\Theta^+ \to K^+ n$ and $K_S \to \pi^+\pi^-$. The most compelling way to present their data is to compare the G11 signal for the $\Lambda(1520)$, a well known non-exotic resonance, with their null result for the Θ^+, and then contrast the G11 results with the earlier positive sighting from SAPHIR[8] (see Fig. 1). SAPHIR quote a ratio

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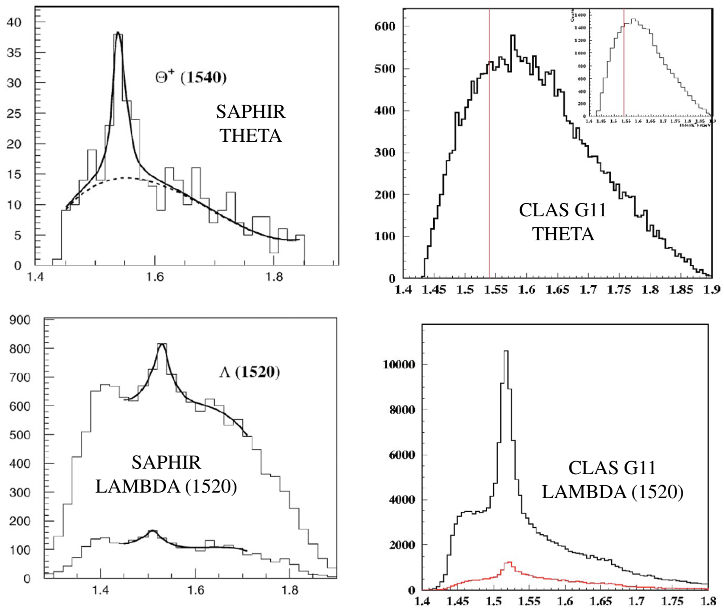
[*] Several other negative results have been reported since DIS05, including $\gamma D \to pK^+K^- n$ from G10@JLab [9] and in secondary kaon interactions at Belle[10]. Unofficial reports from BaBar indicate negative results from $\gamma A \to kK_S$ using beam-detector interactions. No *new* positive results were reported at the 2005 Lepton-Photon Symposium at Uppsala[11], although several of the first sightings survived reanalyses of the original data.

of production rates: $N(\Theta^+)/N(\Lambda(1520)|_{\text{SAPHIR}} \approx 9\%$. In contrast CLAS G11 quote $N(\Theta^+)/N(\Lambda(1520)|_{\text{G11@JLab}} < 0.5\%$, a striking disagreement[*]

Things do not look good for the Θ^+. Typically in our field, effects seen weakly in discovery experiments are quickly confirmed when they are real, especially in the next round of experiments expressly designed to find them (*e.g.* CLAS G11). While it is probably too early to declare it dead, it is not too early to think about life without the Θ^+. So, for the rest of this talk, I will assume that the Θ^+ is no more.

The absence of a Θ^+ has implications for phenomenological models of QCD. Chiral soliton models (CSM) need to be rethought. Diakonov, Petrov, and Polyakov used a version of the CSM to predict unequivocally a light, narrow, exotic baryon with $Y = 1$, $I = 0$ and $J^\Pi = 1/2^+$[12]. They defended their prediction against criticism of the formulation of their model[13, 14, 15] and of the accuracy of both the mass[13] and width[16] preditions. What could be wrong with the CSM? Here are some possibilities:



1: SAPHIR (left) and CLAS G11 (right) data on the Θ^+ (upper) and $\Lambda(1520)$ (right). The CLAS G11 upper limit on the $\Theta^+/\Lambda(1520)$ ratio is a factor of 20 smaller than measured by SAPHIR.

- Perhaps baryons are not chiral solitons in the first place! Witten introduced the idea into QCD as a *heuristic*, and it clearly fails in the case of 1-flavor and N_c colors, where there is no chiral sector at all, but there are perfectly good baryons (the analogue of the Δ^{++}).
- Perhaps it was not appropriate to truncate the chiral lagrangian after the “Syrme term”. The soliton is stabilized by balancing the dimension-four ($\mathcal{L}_4 = f_\pi^2 \partial_\mu U \partial^\mu U^\dagger$) term against the dimension-six Skyrme term, $\mathcal{L}_6$, ignoring other operators of dimension-six and higher. If two operators of different dimension are equally important in a particular regime, there is no *a priori* reason to ignore operators of arbitrarily high dimension.
- Perhaps collective coordinate quantization fails. Why should the soliton keeps its rigid profile as it is “spun up” in angular momentum and flavor space? Since there is only one scale in QCD, shape excitations should appear at the same scale as rotations.
- Perhaps $SU(3)$ violation cannot he treated perturbatively. This is the subject of Refs. [14, 15] and Refs. [17, 18] before them. Attempts to find and characterize the

Θ^+ on the lattice have been inconclusive: some studies report no K^+n resonance at all, some report a negative parity (presumably s-wave) resonance, and others report positive parity[1].

Most other phenomenological models — large N_c[19], and quark models[1, 20, 21, 22], for example — never predicted the mass of the Θ^+ in the first place. Not as ambitious as the CSM, they generally do not claim to determine the overall mass scale of a new sector of QCD (*eg.* $qqqq\bar{q}$) accurately. Pre-2003 estimates were typically hundreds of MeV heavier than 1540 MeV. After the Θ^+ was reported, its mass was used to tie down the $qqqq\bar{q}$ spectrum and other states were predicted relative to M_Θ. If the Θ^+ is gone, the correlations invoked to stabilize it in these models must be weaker than proposed.Attempts to find and characterize the Θ^+ on the lattice have been inconclusive: some studies report no K^+n resonance at all, some report a negative parity (presumably s-wave) resonance, and others report positive parity[1].

What, then, are the lessons of the "Θ-affair", if it is over? First, there *really are no light, narrow exotics in QCD*. Second, phenomenological models should not be taken too seriously, especially for the overall mass scale in untested regimes (recent surprises in the D_{sJ}-spectrum support this[23]). Third, lattice QCD has not yet got to the stage where it can provide reliable, quantitative insight into novel phenomena. Note, however, that the demise of the Θ^+ would not rule out exotics of a different character in the heavy quark sectors. In particular, the charm exotic baryons proposed in Ref. [24] remain interesting.

DIQUARKS

It is clear that exotics are very rare in QCD. Perhaps they are entirely absent. This remarkable feature of QCD is often forgotten when exotic candidates are discussed. The existence of any exotic has to be understood in a framework that also explains their overall rarity. Along the same line, the *aufbau* principle of QCD differs dramatically from that of atoms and nuclei: to make more atoms add electrons, to make more nuclei, add neutrons and protons. However in QCD the spectrum seems to stop at qqq and $q\bar{q}$.

Thinking about early reports of the Θ^+ in light of early work on multiquark correlations in QCD [25], Frank Wilczek and I [20][†] began to re-examine the role of diquark correlations in QCD. Diquarks are not new; they have been championed by a small group of QCD theorists for several decades [26, 27]. We already knew [25] that diquark correlations can naturally explain the general absence of exotics and predict a supernumerary nonet of scalar mesons which seems to exist. They appear in many successful pictures of soft QCD phenomenology. A light Θ^+ can be accommodated, but is not required, by diquark dynamics. Whether or not the Θ^+ survives, diquarks are here to stay.

Spectroscopy was at the cutting edge of high energy physics in the '60's and '70's. A great deal of effort and sophisticated analysis was brought to bear on the study of the hadron spectrum, and the conclusions remain important. In the decade that followed the first conjectures about quarks experimental groups studied meson-baryon and meson-

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[†] Closely related ideas have been explored by Nussinov [21] and by Karliner and Lipkin [22].

meson scattering, and extracted the masses and widths of meson and baryon resonances. Resonances were discovered in nearly all non-exotic meson and baryon channels, but no prominent exotics were found.

The zeroth order summary prior to January 2003 was simple: no exotic mesons or baryons. In fact the only striking anomaly in low energy scattering was the existence of a supernumerary (*i.e.*, not expected in the quark model) nonet of scalar, ($J^{\Pi} = 0^{+}$) mesons with masses below 1 GeV: the $f_0(600)$, $\kappa(800)$, $f_0(980)$, and $a_0(980)$ that is now widely considered to contain important $\overline{q}\overline{q}qq$ components [28].

QCD phenomena are dominated by two well known quark correlations: confinement and chiral symmetry breaking. Confinement hardly need be mentioned: color forces only allow quarks and antiquarks correlated into color singlets. Chiral symmetry breaking can be viewed as the consequence of a very strong quark-antiquark correlation in the color, spin, and flavor singlet channel: $[\overline{q}q]^{\mathbf{1}_c\mathbf{1}_f0}$. The attractive forces in this channel are so strong that $[\overline{q}q]^{\mathbf{1}_c\mathbf{1}_f0}$ condenses in the vacuum, breaking $SU(N_f)_L \times SU(N_f)_R$ chiral symmetry.

The "next most attractive channel" in QCD seems to be the color antitriplet, flavor antisymmetric (which is the $\overline{\mathbf{3}}_f$ for three light flavors), spin singlet with even parity: $[qq]^{\overline{\mathbf{3}}_c\overline{\mathbf{3}}_f0^{+}}$. This channel is favored by one gluon exchange and by instanton interactions. It will play the central role in the exotic drama to follow.

The classification of diquarks is not entirely trivial. Operators that will create a diquark of any (integer) spin and parity can be constructed from two quark fields and insertions of the covariant derivative. We are interested in potentially low energy configurations, so we omit the derivatives. There are eight distinct diquark multiplets (in color×flavor×spin) that can be created from the vacuum by operators bilinear in the quark field [1]. However, the interesting candidates can be pared down quickly: Color $\mathbf{6}_c$ diquarks would appear to have much larger color electrostatic field energy. Odd parity diquarks require quarks to be excited relative to one another. This leaves only two diquarks consistent with fermi statistics,

$$\begin{aligned} &\big|\{qq\}\ \overline{\mathbf{3}}_c(A)\ \overline{\mathbf{3}}_f(A)\ 0^{+}(A)\big\rangle \\ &\big|\{qq\}\ \overline{\mathbf{3}}_c(A)\ \mathbf{6}_f(S)\ 1^{+}(S)\big\rangle, \end{aligned} \tag{1}$$

where A or S denotes the exchange symmetry of the preceding representation. Both of these configurations are important in spectroscopy. In what follows I will refer to them sometimes as the "scalar" and "vector" diquarks, or more suggestively, as the "good" and "bad" diquarks. Remember, though, that there are many "worse" diquarks that we are ignoring entirely.

Models universally suggest that the scalar diquark is lighter than the vector. For example, one gluon exchange evaluated in a quark model gives rise to a color and spin dependent interaction that favors the scalar diquark. The matrix elements of this interaction in the "good" and "bad" diquark states are $-2\mathcal{M}$ and $+2/3\mathcal{M}$ respectively, where $\mathcal{M}$ is model dependent. To set the scale, the Δ–nucleon mass difference is $4\mathcal{M}$, so the energy difference between good and bad diquarks is $\sim \frac{2}{3}(M_\Delta - M_N) \sim 200$ MeV. Not a huge effect, but large enough to make a significant difference in spectroscopy. After all, the nucleon is stable and the Δ is 300 MeV heavier and has a width of 120 MeV!

Characterizing diquarks

The good scalar and bad vector diquarks are our principal subjects. Since the good diquarks are antisymmetric in flavor they lie in the $\bar{\mathbf{3}}$ representation of $SU(3)_f$. We will denote them by $[q_1,q_2] : \{[u,d]\ [d,s]\ [s,u]\}$ when flavor is important and by $\mathbb{Q}$ when it is not. Under flavor $SU(\underline{3})$ transformations they behave exactly like antiquarks, $[u,d] \leftrightarrow \bar{s},\ [d,s] \leftrightarrow \bar{u},\ [s,u] \leftrightarrow \bar{d}$. The bad diquarks are symmetric in flavor, forming the **6** representation of $SU(3)_f$. The notation $\{q_1,q_2\} : \{\{u,u\}\ \{u,d\}\ \{d,d\}\ \{d,s\}\ \{s,s\}\ \{s,u\}\}$ will do.

Although diquarks are colored states, their properties can be studied in a formally correct, color gauge invariant way on the lattice. To define the non-strange diquarks, introduce an infinitely heavy quark, Q, *i.e.* a Polyakov line. Then study the qqQ correlator with the qq quarks either antisymmetric ($[u,d]Q$) or symmetric ($\{u,d\}Q$) in flavor. The results, $M[u,d]$ and $M\{u,d\}$ — labelled unambiguously — are meaningful in comparison, for example, with the mass of the lightest $\bar{q}Q$ meson, $M(u) = M(d)$. $M\{u,d\} - M[u,d]$ is the good-bad diquark mass difference for massless quarks. It is a measure of the strength of the diquark correlation. The diquark-quark mass difference, $M[u,d] - M(u)$, is another. The same analysis can be applied to diquarks made from one light and one strange quark giving $M[u,s]$ and $M\{u,s\}$. These mass differences are *fundamental* characteristics of QCD, which should be measured carefully on the lattice[29].

In practice we can estimate these masses by replacing the infinitely heavy quark by the physical charm or bottom, or even the strange quark. The analysis is complicated by the fact that the spin interactions between the light quarks and the s, c or b quark are not negligible. Of course the scalar diquark has no spin interaction with the spectator heavy quark (Q), but the vector diquark does. In order to obtain estimates of diquark mass differences, it is necessary to take linear combinations of baryon and meson masses that eliminate these spin interactions [1].

A simple analysis of strange, charm, and bottom hadron masses leads to quite a consistent picture of diquark mass differences. First, for non-strange quarks and diquarks,

$$\begin{aligned} M\{u,d\}|_s - M[u,d]|_s &= 205\ \text{MeV} \\ M\{u,d\}|_{\mathrm{c}} - M[u,d]|_{\mathrm{c}} &= 212\ \text{MeV}, \end{aligned} \qquad \begin{aligned} M[u,d]|_s - M(u)|_s &= 321\ \text{MeV} \\ M[u,d]|_{\mathrm{c}} - M(u)|_{\mathrm{c}} &= 312\ \text{MeV} \\ M[u,d]|_b - M(u)|_b &= 310\ \text{MeV}, \end{aligned}$$

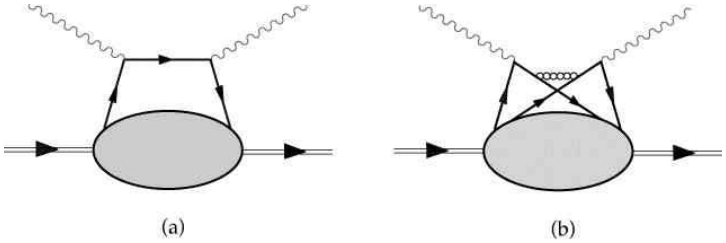
it appears that the properties of hypothetical non-strange diquarks are the pretty much the same when extracted from the charm and bottom, and even strange, baryon sectors. Second,

$$\begin{aligned} M\{u,s\}|_{\mathrm{c}} - M[u,s]|_{\mathrm{c}} &= 152\ \text{MeV} \\ M[u,s]|_{\mathrm{c}} - M(s)|_{\mathrm{c}} &= 498\ \text{MeV}, \end{aligned} \tag{2}$$

shows that the diquark correlation decreases when one of the light quarks is strange. This is certainly to be expected, since it originates in spin dependent forces. As the correlation decreases, the mass difference between the scalar and vector diquarks decreases (∼210→∼150 MeV) and the mass difference between the scalar diquark and the antiquark increases (∼310→∼500 MeV).

Diquarks and higher twist

Diquarks need not be pointlike. As we have seen, the energy difference between the good and bad diquarks is only $\sim$ 200 MeV, enough to be quite important in spectroscopy, but corresponding only to a correlation length of 1 fermi, the same as every other mass scale in QCD. It is interesting, nevertheless to ask whether other hadronic phenomena can constrain the correlation. Although many nucleon properties, like form factors, are often discussed in terms of quark correlations, as far as I know, the correspondence can only be made exact for deep inelastic scattering (DIS).



2: (a) Leading twist, single quark contribution to DIS (b) Twist-4, diquark contribution to DIS.

Any kind of quasi-pointlike, (*i.e.*, characterized by a mass scale $\Lambda_{\bar{q}q} \gg \Lambda_{\mathrm{QCD}}$) correlation in the nucleon is certainly excluded for $\Lambda_{\bar{q}q}$ ranging from $\sim$ 1 GeV up to the highest scales where deep inelastic data exist ($\sim$100 GeV). Diquarks would be especially obvious because as bosons they would generate an anomalously large longitudinal/transverse inelastic cross section ratio in DIS at scales below $\Lambda_{\bar{q}q}$, which would disappear above $\Lambda_{\bar{q}q}$. Such an effect is certainly ruled out by the early, and apparently permanent, onset of scaling seen in a multitude of experiments.

On the other hand one might think that the absence of large higher twist effects in DIS could be used to place an uncomfortably *low* limit on the mass scale of diquark correlations. This is not the case[30]. In fact measurements of $1/Q^2$ corrections to DIS *place no limits whatsoever* on scalar diquark correlations in the nucleon. To understand this it is necessary to review some of the basics of the twist analysis of deep inelastic scattering. "Twist" refers to the dimension (d) minus the spin (n) of the operators that contribute to DIS, $t = d - n$. The smaller the twist, the more important the contribution to DIS: A given operator contributes like $1/Q^{t-2}$. The leading operators are twist-2 and act on a single quark[**]. They have the generic structure

$$O^{(2)}_{\mu} \sim \bar{q}\gamma_{\mu}\mathcal{D}\mathcal{D}\ldots q \tag{3}$$

The covariant derivatives, their Lorentz indices suppressed, denoted schematically by $\mathcal{D}$, have $d(\mathcal{D}) - n(\mathcal{D}) = 0$, so they are irrelevant for counting twist. The quark fields have $d(q) = 3/2$ and the γ-matrix contributes $n(\gamma) = 1$, so in all, $t = 2(3/2) - 1 = 2$, and these operators' contributions to DIS are independent of Q (modulo logarithmic corrections from perturbative QCD). The $\bar{q}\gamma q$ operators sum up to give the "handbag" diagram shown in Fig. 2(a).

It is easy to write down operators with twist greater than two[31]. The most important are twist-four (twist-three does not contribute to spin average DIS for light quarks),

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[**] I am ignoring gluon operators, which do not figure in the argument.

which contribute corrections of order $1/Q^2$ to deep inelastic structure functions. The factor of $1/Q^2$ is accompanied by some squared mass-scale, M_4^2, in the numerator. Twist-four effects have been studied for years, and the qualitative conclusion is that M_4 is small. How small need not concern us, for we are about to see that it anyway places no limit on the good diquark that interests us.

Twist four operators invariably involve products of more than two quark and gluon fields (again ignoring pure-gluon operators). Examples include quark-gluon operators, $\bar{q}\mathcal{F}q$ and $\bar{q}\mathcal{F}\mathcal{F}q$, and four-quark operators, $\bar{q}q\bar{q}q$. The matrix elements of these operators in the target nucleon determine the magnitude of higher twist effects. The four quark operators are the culprits: they can be Fierz-transformed into diquark-antidiquark operators, $\overline{qq}\ldots qq$ and therefore measure the scale of diquark correlations in the nucleon. They can be summed (in a well-defined way) to give diagrams like Fig. 2(b), where two quarks are removed from the nucleon, scattered at high momentum, and then returned. The generic structure of four quark operators is (there are others, but the results are the same),

$$O^{(4)}_{\mu\nu} \sim \bar{q}\gamma_\mu\mathcal{D}\mathcal{D}\ldots q\;\bar{q}\gamma_\nu\mathcal{D}\mathcal{D}\ldots q. \tag{4}$$

The γ-matrices are necessary. With $d(q) = 3/2$ and $d(\mathcal{D}) - n(\mathcal{D}) = 0$ it is easy to see that the twist of $O^{(4)}$ would be six if it were not for the two factors of γ, each of which corresponds to a unit of spin. In other words: when Fierzed, the two diquarks in $O^{(4)}$ must be coupled to spin-2. So *only the vector diquark contributes at twist-four*. Bounds on twist four in DIS tell us that the bad, vector diquark cannot be tightly bound, but they do not constrain the good, scalar diquark at all. It contributes only to twist-six and beyond, where it cannot be separated from the flood of non-perturbative effects that emerge at low Q^2.

We can proceed without concern that correlations of the extent necessary to influence the spectrum are ruled out by deep inelastic phenomena.

Diquarks and the Absence of Exotics

I want to look at exotics assuming little more than that two quarks prefer to form the good, scalar diquark when possible. States dominated by that configuration should be systematically lighter, more stable, and therefore more prominent, than states formed from other types of diquarks. This qualitative rule leads to qualitative predictions — all of which seem to be supported by the present state of experiment. This is clearly an idealization — a starting place for describing exotic spectroscopy. To learn the real extent of $\mathbb{Q}$ dominance will require more models and more information from experiment.

The predictions that follow from $\mathbb{Q}$-dominance are simple, and striking. They capture all the important features of exotic spectroscopy and provide the conceptual basis of a unified description of this sector of QCD.

a) There should be no (light, prominent) exotic mesons: The good diquark, $\mathbb{Q}$, is a flavor $\bar{\mathbf{3}}$, just like the antiquark. Tetraquarks, $\overline{qq}qq$, potentially include exotics in $\mathbf{27}$, $\mathbf{10}$, and $\overline{\mathbf{10}}$ representations of flavor $SU(3)$. However $\overline{\mathbb{Q}}\otimes\mathbb{Q}$ contains *only non-*

exotic representations, **1** and **8**, just like $\bar{q}\otimes q$: $q^{\mathbf{3}}\otimes\bar{q}^{\bar{\mathbf{3}}}=(\bar{q}q)^{\mathbf{1}}\oplus(\bar{q}q)^{\mathbf{8}}$ compared with $\bar{\mathbb{Q}}^{\mathbf{3}}\otimes\mathbb{Q}^{\bar{\mathbf{3}}}=(\bar{\mathbb{Q}}\mathbb{Q})^{\mathbf{1}}\oplus(\bar{\mathbb{Q}}\mathbb{Q})^{\mathbf{8}}$. Other diquark-antidiquark mesons are heavier, where they would be buried in the meson-meson continuum. Probably they are not just "broad", but in fact absent[32].

b) The only prominent tetraquark mesons should be an $SU(3)$ nonet with $J^{\Pi}=0^{+}$. This prediction — a simple corollary of the one just above — dates back to the late 1970's[25]. Since the good diquarks, $\mathbb{Q}$, are spinless bosons, the spin$^{\text{parity}}$ of the lightest nonet is $J^{\Pi}=0^{+}$. Over the years evidence has accumulated that the nine 0^{+}-mesons with masses below 1 GeV (the $f_0(600)$, $\kappa(800)$, $f_0(980)$, and $a_0(980)$) have important tetraquark components[28]. Space does not permit me to present the evidence here. The interested reader can find more in Ref. [1].

c) If there are any exotic pentaquark baryons, they lie in a positive parity $\overline{10}$ of $SU(3)_{\mathrm{f}}$. This is also a simple consequence of combining good diquarks. To make pentaquarks it is necessary to combine two diquarks and an antiquark. The result is $\bar{\mathbf{3}}\otimes\bar{\mathbf{3}}\otimes\bar{\mathbf{3}}=\mathbf{1}\oplus\mathbf{8}\oplus\mathbf{8}\oplus\overline{\mathbf{10}}$. The only exotic is the $\overline{\mathbf{10}}$. Other exotic flavor multiplets, like the **27** and **35**, which occur in the uncorrelated quark picture and/or the chiral soliton models, should be heavier and most likely lost in the meson-baryon continuum.

d) Nuclei will be made of nucleons. To a good approximation, nuclei are made of nucleons — a fact which QCD should explain. If diquark correlations dominate, systems of $3A$ quarks should prefer to form individual nucleons, not a single hadron. The argument is based on statistics: Good diquarks are spinless color anti-triplet bosons. Only one, $[u,d]$, is non-strange. A six-quark system made of three of these, antisymmetrized in color to make a color singlet, would have to have fully antisymmetric space-wavefunction to satisfy Bose statistics. The simplest would be a triple-scalar product, $\vec{p}_1\cdot\vec{p}_2\times\vec{p}_3$, which should be much more energetic than two separate, color-singlet nucleons in an s-wave (*e.g.*, the deuteron). The argument generalizes to heavy nuclei. Of course it does not explain nuclear binding or the rich phenomena of nuclear physics.

CONCLUSIONS

There are two distinct, but related issues at the core of this discussion: first, a question: are there light, prominent exotic baryons, and if so, what is the best dynamical framework in which to study them? and second, a proposal: diquark correlations are important in QCD spectroscopy, especially in multiquark systems, where they account naturally for the principal features.

I believe the case for diquarks is already quite compelling. There are many projects ahead: re-evaluating the qqq spectrum [33]; systematically exploring the role of diquarks in deep inelastic distribution and fragmentation functions, and in scaling violation; seeing if diquarks can help in other areas of hadron phenomenology like form-factors, low p_T particle production, and polarization phenomena; developing a more sophisticated treatment of quark correlations, recognizing that diquarks are far from pointlike inside hadrons; establishing diquark parameters and looking for diquark structure in hadrons using lattice QCD; and — the holy grail of this subject — seeking a more fundamental and quantitative phenomenological paradigm for light quark dynamics at the confinement scale. Diquark advocates have considered many of these issues in the past [27]. No doubt many other important contributions, like the diquark analysis of the $\Delta I = 1/2$-rule [34], have already been accomplished. We can hope eventually to have as sophisticated an understanding of diquark correlations as we have of $\bar{q}q$ correlations, as expressed in chiral dynamics.

The situation with the Θ^+ is less clear. Evidence for the Θ^+ is not growing. Instead two (CLAS G10 & G11) second generation experiments have reported negative results. This is particularly disheartening because these experiments were designed after the initial reports of the Θ^+ and were optimized in light of them. High statistics, high energy experiments also report negative results, although they are too different from the low energy discovery experiments to be conclusive. Also, theorists' attempts to understand the Θ^+ have raised more questions than they have answered. To wit: (a) A negative parity (KN s-wave) Θ^+ is intolerable to theorists, but that is what most lattice studies find, if they find anything at all. (b) No one has come up with a simple, qualitative explanation for the exceptionally narrow width of the Θ^+. (c) The original prediction of a narrow, light Θ^+ in the chiral soliton model does not appear to be robust. (d) Quark models can accomodate the Θ^+, but only by reversing the naive, and heretofore universal, parity of the $q^{n_q}\bar{q}^{n_{\bar{q}}}$ ground state. It is necessary to excite the quarks in order to capture the correlation energy of the good diquarks. This does not sound like a way to make an exceptionally light and stable pentaquark. (e) When models are adjusted to accomodate the Θ^+, they predict the existence of other states that should have been observed by now: The diquark picture wants both a $\Theta^{\frac{1}{2}^+}$ and a $\Theta^{\frac{3}{2}^+}$; the CSM and large N_c want a relatively light **27**, which includes an $I = 1$ triplet: $\Theta^{*0}, \Theta^{*+}, \Theta^{*++}$.

Fortunately, ours is an experimental science, and the situation will eventually become clear — a virtue of working on QCD as opposed to string theory!

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