PUZZLES IN HYPERON, CHARM AND BEAUTY PHYSICS

Harry J. Lipkin[a] [b] [*] [c] [†]

[a]Department of Particle Physics, Weizmann Institute of Science, Rehovot, Israel

[b]School of Physics and Astronomy, Raymond and Beverly Sackler Faculty of Exact Sciences, Tel Aviv University, Tel Aviv, Israel

[c]High Energy Physics Division, Argonne National Laboratory, Argonne, IL 60439-4815, USA

Puzzles awaiting better experiments and better theory include: (1) the contradiction between good and bad SU(3) baryon wave functions in fitting Cabibbo theory for hyperon decays, strangeness suppression in the sea and the violation of the Gottfried Sum rule - no model fits all; (2) Anomalously enhanced Cabibbo-suppressed $D^+ \to K^{*+}(s\bar{d})$ decays; (3) anomalously enhanced and suppressed $B \to \eta' X$ decays; (4) the OZI rule in weak decays; (5) Vector dominance ($W \to \pi, \rho, a_1, D_s, D_s^*$) in weak decays (6) Puzzles in doubly-cabibbo-suppressed charm decays.(7) Problems in obtaining Λ spin structure from polarization measurements of produced Λ's.

1. PREAMBLE - CHALLENGING THE CONVENTIONAL WISDOM

1.1. The war for quarks

In the introduction to this session we were reminded of the war to convince the Physics Community that quarks are real.

We won that war.

1.2. The battle for science and education

My next war is to convince the University Community and University Departments of Education that Physics is real and not socially constructed. High school teachers should know and respect science, not only politically correct education ideology. It is not an easy battle. I participated in one round at the Peter Wall Institute for Advanced Studies here at UBC in May.

More about this war and similar approaches to understanding the structure of matter and understanding how to teach children can be found in my millennium essay "The Structure of Matter - like science, teaching should be the result of independent ideas converging"[1].

1.3. Following up experiments that challenge conventional wisdom

Just as we learned new things by following up the experimental evidence for quarks even though there was no theory, we can do the same today with new experimental puzzles. Look for new experiments that can bring new light and insight.

For example, the recent CP asymmetry in $B \to \Phi K_S$ decay, considered a hint of non-standard CP violation[2], suggests a search for a direct CP-violation in the charged B decays, $B^\pm \to \Phi K^\pm$, $B^\pm \to \Phi K^*$, where K^* denotes any K^* resonance, and $B^\pm \to \Phi K_S \pi^\pm$. The $\Phi K_S \pi^\pm$ analysis can use transversity to distinguish between different new physics models predicting different behaviors for a charge asymmetry as a function of the transversity and of the mass of the $K\pi$ system. A new-physics CP-violating contribution to $B^\pm \to \Phi K^\pm$ and $B \to \Phi K^*$ could arise from the $b \to s$ transition induced by gluino exchange[3] applied to the radiative decay $B \to X_s \gamma$, with the photon materialized into a Φ.

2. PUZZLES IN HYPERON PHYSICS

2.1. Good and bad $SU(3)$ baryons

So far no model for the flavor structure of the proton is simultaneously consistent with three established experimental results[4]:

1. $SU(3)$ Cabibbo theory good for weak semileptonic baryon decays

2. $SU(3)$ badly broken by the suppression of the strange component in the sea of $q\bar{q}$ pairs in the nucleon by a factor of two[5].

3. The observed violation of the Gottfried sum rule requires a positively charged sea $(u\bar{d})$. $SU(3)$ then requires a sea with net strangeness $(u\bar{s})$.

Explaining the observed violation of the Gottfried sum rule while keeping the good results of the Cabibbo theory requires unobserved net strangeness in the nucleon sea. Two possible directions for avoiding this conflict are[4]::

1. Quantitative analysis of how much violation of Cabibbo theory is allowed by the real hyperon decay data with real errors.

2. Small component of "valence like" strange quarks with large values of x in the proton; This can be checked by better measurements of the x-dependence of the strangeness in the proton.

2.2. Is the strange quark a heavy quark?

Most nontrivial strange hadron states mix $SU(3)$ and satisfy (scb) heavy quark symmetry with no flavor mixing; e.g. ϕ, ψ, Υ. The strange axial meson mixing is still open. HQET[6] couples the light quark spin to the orbital $L = 1$ to get two doublets with j=1/2 and j=3/2. SU(3) has triplet and singlet.spin states in the octets with the a_1 and b_1. Which is it?

2.3. The spin structure of the Λ

In the constituent quark model the strange quark carries the entire spin of the baryon. But in the picture where strange quarks carry some of the spin of the proton, the nonstrange quarks carry some of the spin of the Λ. Possible experimental tests of this description were discussed[7].

3. A VECTOR DOMINANCE MODEL

3.1. Vector dominance universality

The large branching ratios observed[8] for the appearance of the $a_1(1260)^{\pm}$ in all quasi-two-body decays $D \rightarrow a_1(1260)^{\pm}X$ and $B \rightarrow a_1(1260)^{\pm}X$ are comparable to those observed for $\pi^{\pm}X$ and $\rho^{\pm}X$ and contrast sharply with the much smaller branching ratios observed to a_2X, b_1X, and a_1^oX.

All 24 B decays of the form $B \rightarrow \bar{D}W^+ \rightarrow \bar{D}M^+$, where M can denote $a_1, \rho, \pi, \ell^+\nu_\ell, D_s, D_s^*$, are dominant with branching ratios above 0.3%. Other B-decay modes have upper limits in the 10^{-4} ball park, including the absence with significant upper limits of neutral decays $B^o \rightarrow \bar{D}^oM^o$ which are coupled by strong final state interactions to $B^o \rightarrow D^-M^+$.

These experimental systematics suggested a "vector-dominance" model[9] where the initial hadron state i decays to a final state f by emitting a $W^{\pm}$ which then hadronizes into an a_1^+, ρ^+ or π^+, along with a universality relation,

$$R[ifa] \equiv \frac{BR[i \rightarrow fa_1(1260)^+]}{BR[i \rightarrow f\rho^+]} \approx \left|\frac{W^+ \rightarrow a_1^+}{W^+ \rightarrow \rho^+}\right|^2 \quad (1)$$

$$R[if\pi] \equiv \frac{BR[i \rightarrow f\pi^+]}{BR[i \rightarrow f\rho^+]} \approx \left|\frac{W^+ \rightarrow \pi^+}{W^+ \rightarrow \rho^+}\right|^2 \quad (2)$$

These have been shown to hold experimentally[9] for all states i and f with corrections for phase space. The a_1 data have large errors. But the experimental ratios $R[ifa]$ are all consistent with 0.7, and more than order of magnitude higher than other upper limits. That such widely different decays should agree so well is impressive and suggests further investigation. e.g. reducing the experimental errors and looking for more decay modes like $D_s^+ \rightarrow \phi a_1$, $D^+ \rightarrow K^{*0}a_1$ and $D^0 \rightarrow K^{*-}a_1$.

3.2. Vector-Dominance Decays of the B_c

The B_c meson is identified against a large combinatorial background by decay modes including a J/ψ. Vector dominance decay modes including the J/ψ are expected to have relatively large branching ratios[9]. These include: $J/\psi\rho^+$, $J/\psi a_1^+$, $J/\psi\pi^+$, $J/\psi D_s^*$, $J/\psi D_{s1A}$, and $J/\psi D_s$.

The corresponding modes with a ψ' instead of a J/ψ are expected to have comparable branching ratios.

4. PUZZLES IN CHARM DECAYS

4.1. Singly-Suppressed Charm Decays

Two Cabibbo suppressed D^+ decay modes have anomalously high branching ratios which are not simply explained by any model[10].

$$BR[D^+ \to K^*(892)^+ \bar{K}^o] = 3.2 \pm 1.5\% \qquad (3)$$

$$BR[D^+ \to K^*(892)^+ \bar{K}^*(892)^o] = 2.6 \pm 1.1\% \quad (4)$$

These show no Cabibbo suppression in comparison with corresponding Cabibbo allowed decays whose dominant tree diagrams differ only in the weak vertices $c \to W^+ + s \to \rho^+ + s$ and $c \to W^+ + s \to K^*(892)^+ + s$ from corresponding allowed decay diagrams and have the same hadronization of the strange quark s and spectator $\bar{d}$.

$$BR[D^+ \to \rho^+ \bar{K}^o] = 6.6 \pm 2.5\% \qquad (5)$$

$$BR[D^+ \to \rho^+ \bar{K}^*(892)^o] = 2.1 \pm 1.3\% \qquad (6)$$

No simple diagram can contribute to the anomalously enhanced decays without also enhancing one of the following others which show the expected Cabibbo suppression

$$BR[D^+ \to K^+ \bar{K}^*(892)^o] = 0.42 \pm 0.05\% \qquad (7)$$

$$BR[D^o \to K^*(892)^+ K^-] = 0.35 \pm 0.08\% \qquad (8)$$

$$BR[D^o \to K^*(892)^- K^+] = 0.18 \pm 0.01\% \qquad (9)$$

$$BR[D^o \to K^*(892)^o \bar{K}^o] < 0.08\% \qquad (10)$$

$$BR[D^o \to \bar{K}^*(892)^o K^o] < 0.16\% \qquad (11)$$

$$BR[D^o \to K^*(892)^o \bar{K}^*(892)^o] = 0.14 \pm 0.05\% (12)$$

A new physics explanation may be needed if the anomalously large branching ratios are confirmed with smaller errors. Present data show[8]

$$BR[D^+ \to K^*(892)^+ \bar{K}^*(892)^o] +$$
$$+BR[D^+ \to K^*(892)^+ \bar{K}^o] = 5.8 \pm 1.9\% \qquad (13)$$

This is still large even at two standard deviations.

4.2. SU(3) Relations between Cabibbo-Favored and Doubly-Cabibbo Suppressed D decays

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The SU(3) transformation[11] $d \leftrightarrow s$ relates Cabibbo-favored $\leftrightarrow$ doubly-Cabibbo-suppressed charm decays[12].

$$d \leftrightarrow s; \quad K^+ \leftrightarrow \pi^+; \quad K^- \leftrightarrow \pi^-;$$
$$D^+ \leftrightarrow D_s; \quad D^o \leftrightarrow D^o; \quad K^+\pi^- \leftrightarrow K^-\pi^+ \quad (14)$$

If strong interaction final state interactions conserve SU(3) the only SU(3) breaking occurs in the CKM matrix elements.

4.2.1. Relations between D^o branching ratios

Two simple easily tested.SU(3) symmetry relations involving no phases and only branching ratios of decay modes all expected to be comparable to the observed DCSD $D^o \to K^+\pi^-$ are

$$tan^4\theta_c = \frac{BR(D^o \to K^+\pi^-)}{BR(D^o \to K^-\pi^+)} =$$
$$= \frac{BR[D^o \to K^*(892)^+ \rho^-]}{BR[D^o \to K^*(892)^- \rho^+]} \qquad (15)$$

A similar relation

$$tan^4\theta_c = \frac{BR[D^o \to K^+ a_1(1260)^-]}{BR[D^o \to K^- a_1(1260)^+]} \qquad (16)$$

may have a different type of SU(3) breaking. A weak vector dominance form factor can enhance

$$D^o(c\bar{u}) \to (s\bar{u} \to K^-)_S \cdot (u\bar{d} \to a_1^+)_W \to K^- a_1^+ (17)$$

where the subscripts S and W denote strong and weak form factors. The largest SU(3) breaking may well arise here from the difference between a weak pointlike a_1 form factor and the strong hadronic a_1 form factor which is the overlap between a nodeless s-wave meson and a p-wave meson with a node. This suppression of the a_1 hadronic form factor should suppress

$$D^o(c\bar{u}) \to (d\bar{u} \to a_1^-)_S \cdot (u\bar{s} \to K^+)_W \to a_1^- K^+ (18)$$

In this case the SU(3) relation between the ratios of two Cabibbo-favored decays to two Cabibbo-suppressed decays involving the π and a_1 can be

expected to be strongly broken and replaced by the inequality

$$\frac{BR[D^o \to K^- a_1^+]}{BR(D^o \to K^- \pi^+)} = \frac{7.3 \pm 1.1\%}{3.83 \pm 0.09\%} \gg \quad (19)$$

$$\gg \frac{BR[D^o \to K^+ a_1^-]}{BR(D^o \to K^+ \pi^-)} = \frac{BR[D^o \to K^+ a_1^-]}{1.48 \pm 0.21 \times 10^{-4}}$$

Two aspects of this relation suggest interesting implications of any symmetry breaking:

(1) Experimental tests of the magnitude of SU(3) breaking will be relevant in the interpretation of information about the CKM matrix and the unitarity triangle obtained from standard model analyses of weak decays which assume SU(3) symmetry.

(2) In the standard model the Cabibbo-favored and doubly-suppressed charm decays are proportional to the same combinations of CKM matrix elements and no direct CP violation can be observed. Thus any evidence for new physics that can introduce a CP-violating phase between these to amplitudes deserves serious consideration[12].

4.2.2. SU(3) relations between D^+ and D_s decays

Both of the following ratios of branching ratios

$$\frac{BR(D_s \to K^+ K^+ \pi^-)}{BR(D_s \to K^+ K^- \pi^+)} \approx O(tan^4\theta_c) \qquad (20)$$

$$\frac{BR(D^+ \to K^+ \pi^+ \pi^-)}{BR(D^+ \to K^- \pi^+ \pi^+)} \approx O(tan^4\theta_c) \qquad (21)$$

are ratios of a doubly Cabibbo forbidden decay to an allowed decay and should be of order $tan^4\theta_c$. The SU(3) transformation $d \leftrightarrow s$ takes the two ratios (20) and (21) into the reciprocals of one another. SU(3) requires the product of these two ratios to be EXACTLY $tan^8\theta_c$[12].

$$tan^8\theta_c =$$
$$\frac{BR(D_s \to K^+ K^+ \pi^-)}{BR(D_s \to K^+ K^- \pi^+)} \cdot \frac{BR(D^+ \to K^+ \pi^+ \pi^-)}{BR(D^+ \to K^- \pi^+ \pi^+)} \quad (22)$$

Most obvious SU(3)-symmetry-breaking factors cancel out in this product; e.g. phase space. Present data[8] show

$$\frac{BR(D^+ \to K^+ \pi^- \pi^+)}{BR(D^+ \to K^- \pi^+ \pi^+)} \approx 0.65\% \approx 3 \times tan^4\theta_c \, (23)$$

Then SU(3) predicts

$$\frac{BR(D_s \to K^+ K^+ \pi^-)}{BR(D_s \to K^+ K^- \pi^+)} \approx \frac{tan^4\theta_c}{3} \approx 0.07\%. \quad (24)$$

If this SU(3) prediction is confirmed experimentally some new dynamical explanation will be needed for the order of magnitude difference between effects of the final-state interactions in D^+ and D_s decays.

If the final state interactions behave similarly in D_s and D^+ decays, the large violation of SU(3) will need some explanation.

New physics enhancing the doubly suppressed decays might produce a CP violation observable as a charge asymmetry in the products of above the two ratios; i.e between the values for D^+ and D_s decays and for D^- and $\bar{D}_s$ decays.

An obvious caveat is the almost trivial SU(3) breaking arising from resonances in the final states. But sufficient data and Dalitz plots should enable including these effects. In any case the SU(3) relation and its possible violations raise interesting questions which deserve further theoretical and experimental investigation. Any really large SU(3)-breaking final state interactions that we don't understand must cast serious doubts on many SU(3) predictions.

4.2.3. A problem with strong phases

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The $d \leftrightarrow s$ interchange SU(3) transformation also predicts[13] $D^o \to K^+ \pi^-$ and $D^o \to K^- \pi^+$ have the same strong phases. This has been shown to be in disagreement with experiment[14] showing SU(3) violation.

But the $K^+ \pi^-$ and $K^- \pi^+$ final states are charge conjugates of one another and strong interactions conserve charge conjugation. SU(3) can be broken in strong interactions without breaking charge conjugation only in the quark - hadron form factors arising in hadronization transitions like

$$D^o(c\bar{u}) \to (s\bar{u} \to K^-)_S \cdot (u\bar{d} \to a_1^+)_W$$
$$\to K^- a_1^+ \to K^- \pi^+ \qquad (25)$$

$$D^o(c\bar{u}) \to (d\bar{u} \to a_1^-)_S \cdot (u\bar{s} \to K^{*+})_W$$
$$\to a_1^- K^+ \to \pi^- K^+ \qquad (26)$$

with the SU(3) breaking given by the inequality (19).

The a_1 and π wave functions are very different and not related by SU(3). The $K^{\mp} a_1^{\pm} \to K^{\mp} \pi^{\pm}$ transition can proceed via ρ exchange

5. Puzzles and Challenges in B Decays

Weak Decays need hadron models and QCD to interpret decays, but have too many diagrams and too many free parameters. Use of flavor topology can simplify analyses on one hand and challenge QCD to explain them if they work.

5.1. OZI in Heavy Flavor Decays

Two flavor topology predictions which challenge conventional wisdom[15];

$$BR(B^{\pm} \to K^{\pm}\omega) = BR(B^{\pm} \to K^{\pm}\rho^{o}) \qquad (27)$$

$$\tilde{\Gamma}(B^{\pm} \to K^{\pm}\phi) = \tilde{\Gamma}(B^{\pm} \to K^{o}\rho^{\pm}) \qquad (28)$$

where $\tilde{\Gamma}$ denotes the predicted partial width when phase space differences are neglected. The first (27) assumes only the exclusion of "hairpin diagrams" and holds even in presence of strong final state rescattering via all other quark-gluon diagrams. The second (28) also assumes SU(3) flavor symmetry between strange and nonstrange pair production

5.2. Anomalously high η' in many final states

The large experimental branching ratio[8] $BR(B^+ \to K^+\eta') = 6.5 \pm 1.7 \times 10^{-5}$ as compared with $BR(B^+ \to K^+\eta) < 1.4 \times 10^{-5}$ and $BR(B^+ \to K^o\pi^+) = 2.3 \pm 1.1 \times 10^{-5}$ still has no completely satisfactory explanation and has aroused considerable controversy[16,17] Also the large inclusive $B^+ \to K^+\eta'X$ branching ratio is equally puzzling.

A parity selection rule can separate the two types of models proposed to explain this high η' appearance and the high η'/η ratio.

1. The OZI-forbidden hairpin diagram[15] predicts a universal *parity*-independent enhancement for all final states arising from the flavor singlet component of the η' [18,19].

2. Parity-dependent interference between diagrams producing the η' via its strange and nonstrange components[15] predicts a large η'/η ratio

for even parity final states like $K\eta$ and $K\eta'$ the reverse for odd parity states like $K^*(892)\ \eta$ and $K^*\ \eta'$[16]. So far this selection rule agrees with experiment.

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