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RESONANCE SPECTROSCOPY (THEORY) *

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I. INTRODUCTION: TWO KINDS OF QUARKS

The rich spectrum of hadrons is best described in terms of quarks: two for a meson ($q\bar{q}$) and three for a baryon (qqq). This picture can then be tested via hadronic transitions (long-range probes) and deep-inelastic scattering or $e^+e^- \rightarrow$ hadrons (short-range probes). Today I shall describe some encouraging results from the long-range tests. They confirm the classification scheme for multiplets which are solidly observed. The disarray in the short-range tests, viewed from the "parton" standpoint, is not welcome but is largely separate from the long-range effects we shall discuss. Perhaps some of the experience we gain at large distances may be helpful at smaller ones. (The complementary statement is also true, as certain short-range ideas have been very helpful in spectroscopy.)

The quarks involved in hadron structure are assumed to be spin- $\frac{1}{2}$ fermions belonging to a triplet of SU(3). With six degrees of freedom they then belong to the lowest non-trivial representation (6 or $\bar{6}$) of SU(6). The hadrons thus appear to be in relatively pure representations of this "constituents" group.

A different SU(6) is associated with the local currents of hadrons. It is these currents that one measures in hadronic transitions such as $\Delta \rightarrow N\pi$ or $\gamma N \rightarrow N^*$. (Relativistic kinematics is sufficient to show that the two SU(6)'s must be different.)

The mismatch between the SU(6), constituents used for classification and the SU(6), currents used for transitions has been realised since the earliest days of the quark model. The recent progress involves a systemization of the effects obtained in transforming between the two languages in the free quark case, and phenomenological applications of the free quark results to the real world. In this latter, we have been helped tremendously by recent data on inelastic pion-nucleon scattering and on single-pion photoproduction in the resonance region. The success of these analyses seems to justify the leap from free quarks to real hadrons.

The previous rapporteurs (Litchfield [1974a], Wagner [1974]) have given a "real" view of the spectrum. I shall be content with organizing and speculating some.

Fig. 1: Ratings of meson multiplets. The symbol $q\bar{q}$ stands for $(6, \bar{6})$ of $U(6)_q \times U(6)_{\bar{q}}$. Four stars: firmly established (complete multiplet). Three stars: good evidence for a nearly complete multiplet. Two stars: a likely multiplet; some of the states likely to be most prominent are well-established. One star: a possible multiplet, characterized by one or two states whose existence or assignment is not yet established. L^P : $q\bar{q}$ orbital angular momentum and parity; $J=L \pm 1, L$.

These considerations are relevant to "constituent quarks". Then I shall turn to "current quarks", and their importance in describing transitions.

II. CONSTITUENT QUARKS

The ground rules for classifying particles according to the quark model (Gell-Mann[1964]; Zweig[1964]; Greenberg[1964]) have been laid today by Litchfield[1974a]. The group in question according to which particles at rest are labelled is really

$$G(\text{constituents}) = U(6)_{\text{quarks}} \times U(6)_{\text{antiquarks}} \times O(3)_L \quad (1)$$

This is sometimes called the "rest symmetry". The observed mesons belong to $(6, \bar{6})_L$ and baryons to $(N, 1)_L$ ($N=56$ or 70).

A. New developments in the spectrum.

As it has become fashionable to label individual resonances by stars, and these resonances can be put into multiplets almost by fiat, one can also do the same for such multiplets. Fig. 1 shows the result for mesons. The lowest $(6, \bar{6})$ is solid. Some question has been raised whether the η' belongs to it, and the weight of the evidence (to be mentioned in Sec. III.D) indicates

that it does. The positive-parity $L=1$ group (2^+ , 1^+ , and 0^+) is beset by confusion and ambiguities (in the A_1 and 0^+ nonets) from which I hope the new generation of spectrometers will lead a speedy recovery. On the other hand, the 2^+ nonet is in fine shape, and a healthy 3^- nonet (a candidate for $L=2$ membership) seems to be emerging. The $E(1420)$ meson, if its J^P is 0^- , is a candidate for a radial excitation of the lowest $(6, \bar{6})$. A ρ^+ ($J^P=1^-$) could belong either to $L=0$ or $L=2$ multiplets.

1 $\pi\pi$, $K\pi$ scattering (see also Morgan [1974a,b])

The absence of firm resonance parameters is a hallmark of 0^+ states. The phase shifts seem much better determined, however. These may be all we need in saturating sum rules. As an example, the need for a large $I_S=0$ contribution to $\sigma_T(\pi^-\pi^+) - \sigma_T(\pi^+\pi^+)$ was anticipated by Adler[1965] from the standpoint of current algebra. This certainly seems to be the case, as the $I=J=0$ phase hovers not far below 90° for a considerable region below $K\bar{K}$ threshold, while $I=2$ S-wave scattering is small. Similarly, in $K\pi$ scattering the $I_S = \frac{1}{2}$, $J=0$ phase shift is appreciable (if not resonant) in the range 1100-1400 MeV. The discussion in Section III will encourage us to put the new, more precisely determined parameters back into the corresponding Adler-Weisberger[1965] relations to see if they are saturated better. Precise resonance parameters may be unnecessary until we have a better idea of what masses to expect.

2. The A_1 crisis and its implications

The positive-parity mesons seem to have regressed since the hopeful days of the corresponding 1966 Conference in Berkeley. Like embryo rabbits in an overcrowded warren, they are being reabsorbed by their progenitors. While the B meson seems to have resisted this decline, the situation for the A_1 is grave indeed.

Fig. 2 represents the mesons as extrapolated from our picture in 1966 (Dalitz[1966]). This has been the conventional view. It is supported by various pieces of evidence each of which by itself is not particularly

	I=1	I=1	I=0	I=0
2^{++}	A_2 1310	K^* 1420	f 1270	f^* 1515
1^{+-}	B 1235	(Q_B) 1360	?	?
1^{++}	(A_1) 1100	(Q_A) 1240	(D) 1285	?
0^{++}	(6) 975	(K_N) $\sim 1100-1200$	(ϵ') 1240	S^* 993

Fig. 2: "Conventional" picture of the $L^P=1^+$ mesons.

The numbers at the left refer to J^{PC} . The mass of each state in MeV is written below the corresponding symbol. Parentheses denote states whose existence, J^P , or resonant interpretation is questionable. Question marks denote missing states.

convincing. A parenthesis around a state indicates that something crucial is missing, e.g. statistics, J^P determination, or confirmation of resonant behaviour. The absence of a degenerate $I=0$ partner of the $A_1(1070)$ would suggest that this particle belonged not to an "ideal" nonet but to an octet, as suggested by broken duality (Mandula et al.[1970]). Note that the 2^{++} , 1^{++} , and 0^{++} central masses are very different. This is a "spin orbit" effect which is also consistent with the B mass if the "spin-spin" splitting is small, as pointed out by Dalitz[1966].

The trouble with this conventional picture is that the $A_1(1070)$ has steadfastly refused to be produced in any non-diffractive channel with any statistical significance. As an example, the reaction

$$\pi^+ p \rightarrow (3\pi^0) \Delta^{++} \quad (2)$$

shows a fine A_2 but no hint of an $A_1(1070)$, whereas it should be visible (Kane[1974]).

A hopeful note has been struck by the speculation of Bowler and Game[1974] that the A_1 is alive and well and hiding under the A_2 . (Fritz Wagner may have managed to demolish this suggestion by now, but let me entertain it anyway.) In that case we might expect the $L=1$ mesons to look like Fig. 3.

	I=1	I=1/2	I=0	
2^{++}	A_2 1310	K^* 1420	f 1270	f' 1515
1^{+-}	B 1235	(Q_B) 1360	$\underline{8}$ (?) 1370	$\underline{1}$ (?) ?
1^{++}	(A_1) 1310	(Q_A) 1420	(D) 1285	?
0^{++}	(δ) 1310	(K_N) 1420	(ϵ') 1270	?

Fig. 3: A speculative picture of the $L^P=1^+$ mesons that might hold in the absence of L·S (spin-orbit) splittings. The symbols $\underline{8}$ and $\underline{1}$ for the $I=0$ $J^{PC}=1^{+-}$ states refer to possible octet and singlet members. This picture is motivated by the suggestion (Bowler and Game [1974]) that the A_1 might be hiding under the A_2 .

Fig. 3 is an attempt to make the $L=1$ mesons look as much like the $L=1$ baryons as possible: no spin-orbit splitting (degenerate 2^{++} , 1^{++} , and 0^{++} nonets) and about 100 MeV in spin-spin splitting (depressing the B below the other $I=1$ members). If the A_1 is really hiding under the A_2 , it is hard not to imagine the δ doing so too. Unfortunately I know of no evidence for this. Also, the S^* (993) falls by the wayside, and becomes a threshold effect not associated with any quark model state. The B (1P_1 in the quark model) could belong to an octet, as does the pion (1S_0): perhaps all singlets belong to octets and triplets to nonets. In that case one might expect an $I = 0^- 1^{+-}$ state around 1370 MeV, perhaps the $\omega\omega\pi$ object suggested by the data of Karshon et al [1974a].

	I=1	I=1/2	I=0	
2^{++}	A_2 1310	K^* 1420	f 1270	f' 1515
1^{+-}	B 1235			
1^{++}				
0^{++}				S^* 993

Fig. 4: Where the $L^P=1^+$ mesons are headed, given present experimental trends.

Fig. 5: Ratings of baryon multiplets. Star ratings as in Fig. 1. Knife and fork denotes a multiplet appreciated by theorists but not supported by concrete experimental fact.

A third possibility for the $L=1$ mesons is shown in Fig. 4. This seems the direction in which we are headed unless important states like the δ and the D receive more attention.

3. Baryon analyses

The "Michelin Guide" to the baryons is shown in Fig. 5. [I have listed some "zero-star" (knife-and fork) multiplets. These appeal to theorists (see II.D, below) but there is no real experimental evidence for them.] The existence of $\underline{56}$, $L=0$, $\underline{70}$, $L=1$, and $\underline{56}$, $L=2$ multiplets is without question, and the missing Λ and Σ states in the latter two (and in the "two-star" multiplets) are gradually being seen. (Ross et al. [1974]; Gopal et al. [1974]; Clayton et al. [1974]; Baillon and Litchfield [1974]; Litchfield [1974a,b].)

So far there is no firm evidence for Z^* 's. If and when they are established, they would provide a welcome spur to those theorists (like myself) who would like to see the successes of bootstrap ideas (see, e.g. Goebel [1966]) and those of the quark model more closely related to one another. A $\underline{27}$ member would show up in $\pi^+ p \rightarrow K^+ \Sigma^+$ as a "wrong" phase in an Argand diagram. This channel is interesting and deserves more attention.

B. $SU(6)_{W, \text{constituents}}$

The group $SU(6)_{W, \text{constituents}}$ (Lipkin and Meshkov [1965]) was invented to allow hadrons to decay. (The "rest symmetry" forbids this.) $SU(6)_W$ is just the subgroup of the generators of the "rest symmetry" which commute with Lorentz boosts in the z -direction.

There are two contexts in which one may view

$SU(6)_W$ constituents: as a classification scheme for moving hadrons, and as a symmetry for collinear processes. Early applications used the latter. It soon became evident that one could obtain a number of good predictions by demanding $SU(6)_W$ - invariance of hadronic vertices. These successes, including f/d ratio predictions and many others, were unfortunately tempered by a few dismal failures in the description of decays of L-excited hadrons. Notable among these were the $B \rightarrow \omega\pi$ decay: exactly opposite in helicity structure ($\lambda_\omega = \pm 1$ dominant) to that predicted by $SU(6)_W$ ($\lambda_\omega = 0$ dominant.) Moreover, in a purely hadronic process the concept of a vertex symmetry is not an easy one to define precisely. The same qualification applies to the success of the collinear four-point relations (Johnson and Treiman[1965])

$$\begin{aligned} \sigma_T(\pi^- p) - \sigma_T(\pi^+ p) \\ = \sigma_T(K^- n) - \sigma_T(K^+ n) \\ = \frac{1}{2}[\sigma_T(K^- p) - \sigma_T(K^+ p)] \end{aligned} \quad (3)$$

which can be derived from $SU(6)_W$ and which seem to be working so beautifully at Serpukhov and NAL energies (Barger[1974]). We shall try to understand the successes of $SU(6)_W$ constituents from a slightly different point of view (which also explains its gross failures) in Section III.

C. Duality

1. Baryons. It has been known for some time that a dual baryon spectrum requires 70's and 56's of both signatures along the leading trajectory. (See Mandula et al.[1970]). The lowest 56 and the lowest 70 are clearly non-degenerate. Their unwanted companions (a 70, $L=0$ and a 56, $L=1$) can be suppressed at the expense of allowing the duality constraints to vary along the leading trajectory (Mandelstam[1970]). The crucial multiplets are then 70, $L=2$, and 56, $L=3$, for which no evidence exists. If these multiplets aren't found, baryon duality is dead.

The crucial states are the following:

a) $N(2050, 7/2^+)$. This state is indeed a reasonable 70, $L=2$ candidate. The previous speaker (Litchfield [1974a]) has assigned it for reasons of economy to a 56, $L=4$. These two assignments predict very different decay rates in inelastic channels, as noted qualitatively in Table 1.

TABLE I

POSSIBLE ASSIGNMENTS OF $N(2050, 7/2^+)$
PHASE SPACE AND BARRIER FACTORS NOT INCLUDED

Channel AB	$\Gamma(N_{70, L=2} \rightarrow AB)$	$\Gamma(N_{56, L=4} \rightarrow AB)$
$N\pi$	1 (defn)	1 (defn)
ΛK	0	9/25
ΣK	4	1/25

This table is based on the $SU(6)$ considerations of Section III. A 70, $L=2$ member should also have an

appreciable $(\Delta\pi)_{L=3}$ decay mode (Faiman et al[1973]). If the $N(2050, 7/2^+)$ belongs to 56, $L=4$, and thus is the Regge recurrence of $N(1700, 3/2^+)$, its $(\Delta\pi)_{L=3}$ decay may be quite hard to see. [The corresponding $(\Delta\pi)_{L=1}$ decay of the $N(1700, 3/2^+)$ is invisible.]

b) $\Lambda(2100, 7/2^+)$. This state should decouple from $\bar{K}N$ and couple strongly to $\Sigma\pi$ if it is the 70, $L=2$ member. Its $\Sigma\pi/\bar{K}N$ branching ratio should be 2/3 aside from kinematic factors if it belongs to 56, $L=4$. The observed state is seen in $\bar{K}N$ and apparently not in $\Sigma\pi$; this speaks ill for the 70 assignment. A 70 member might have a $\Lambda(1385)\pi$ partial width as large as 60 MeV. (See Rosner[1973]). Thus again, inelastic channels are crucial.

c) $\Lambda(2200, 9/2^-)$. A negative parity Λ in this mass range has been claimed necessary to fit backward $\pi^+ p$ scattering. (Rey et al.[1974]). The new backward data have not been put into the Ayed et al analysis [1973], which sees a weak $\Lambda(2170, 9/2^-)$. This should be done.

If the baryon spectrum predicted by duality exists it allows a clever assignment of parity partners spaced

by a minimal amount (Igi and Shimada[1974b]). Members of the 70 , $L=1$ are parity partners of members of a (higher-lying) 70 , $L=2$ and 70 , $L=0$. The relation between $SU(6) \times O(3)$ multiplets is not one-to-one, so that a complicated interweaving of daughter states results.

The Igi-Shimada model is an example of how parity doubling may be avoided using non-analytic trajectories which are almost linear in the resonance region. Similar behaviour has been obtained in the Reggeon calculus by Bartels and Savit[1974] applying renormalization group techniques. They find $\alpha(u) \sim u^{13/12}$ near $u=0$. Neither of these models has been applied yet to backward scattering, however.

2. Mesons. None of the exotics coupling to baryon-antibaryon pairs predicted by duality has been found. The reaction $\pi^+ p \rightarrow n(X^{++})$ at 8 GeV/c sees no evidence for any exotics up to about $2\frac{1}{2}$ GeV with production cross sections of greater than $1\mu b$ (See Alam et al[1974]). The authors expect to increase their accuracy considerably, as well as to calibrate their apparatus by looking for $\pi^- p \rightarrow nX^0$, in the next year or two. (For other exotic searches see Cohen [1974].)

If there was any residual need for $\rho'(1250)$ in dual meson models, it has been removed by the example of Igi and Shimada[1974a], who explicitly construct a model without odd daughters that is at least as plausible as any with them. (See also Mandula et al. [1974].)

D. Confinement of quarks and other models for the spectrum.

Various field-theoretic models of hadrons have been constructed to explain why quarks haven't been seen but describe the hadron spectrum so well. Bender et al[1974] describe permanently bound quarks by means of an effective long-range potential. The result is a set of Green's functions which are defined only in momentum space; they are singular everywhere in position space. Meson states may be formed, and by explicit checking they do not decay to quark pairs.

The "MIT bag" (Chodos et al[1974]) confines quarks by adding a constant energy density B to the usual energy-momentum tensor:

Fig. 6: Baryon spectrum associated with spherical "bags" in the model of Chodos et al [1974].

$$T^{\mu\nu} = T^{\mu\nu}_{\text{fields}} - g^{\mu\nu} B \quad (4)$$

inside the bag. $T^{\mu\nu}$ vanishes outside the bag. The uncertainty principle strikes a balance between a small bag ($\int d^3x B$ small, constituent kinetic energies large) and a large one ($\int d^3x B$ large, constituent kinetic energies small).

As an example, the "bag equations" are solved in the static, spherically symmetric limit for baryons (three-quark systems). The spherically symmetric Dirac equation admits of only $j = \frac{1}{2}$ quark states. Consequently, the model has a rich spectrum of $\frac{1}{2}^+$ and $3/2^+$ N and Δ states but no higher excitations, which would correspond to non-spherical bags. As shown in Fig. 6, the spherical bag spectrum has little relation to the real world, but the authors cannot be faulted for trying. Some of the ground state predictions ($\mu_p = 2.6$ ($e/2M_N$), $g_A/g_V = -1.09$, and $\alpha_p^2 = 1.0$ f) are intriguing. The high-mass spectrum has an exp (m/To) (thermodynamic!) behavior. The authors note that similar results in a spherical potential (without the idea of a bag constant to provide confinement) were obtained earlier by Bogoliubov [1968].

The "SLAC bag" (Bardeen et al [1974]) is based on a fermion field ψ interacting with a scalar field σ whose non zero vacuum expectation value $\langle \sigma \rangle = \pm f$ gives the fermion a large mass. In a small region of

space, $\langle \sigma \rangle$ can fall to zero, and the fermion then appears massless. Clearly the fermion will like to spend its time in such a region. "Color" can be introduced to push all but zero-triality states arbitrarily high in mass.

The above models succeed in imposing the SU(6) structure on the lowest baryons by fiat. They do not discuss how the pion can be both a Goldstone boson and a $q\bar{q}$ bound state (Nambu and Jona-Lasinio [1961]). In such a picture, can an approximate SU(6) symmetry hold in addition? So far, attempts in this direction (see, e.g. Böhm et al [1974]) have relied on ad hoc assumptions about Bethe-Salpeter kernels, but perhaps they illustrate something general.

Singular potentials to confine quarks could arise from the exchange of many mesons, as stressed by Filippov [1974] at this conference. One can also view quarks as quasi-particles in a hadronic medium. (See, e.g. Lipkin [1973]). This idea has been taken seriously at this conference by Bando et al [1974], who discuss some of its consequences for classification and decays.

The spectrum of the hadrons is often described as an "oscillator" spectrum, and detailed mass predictions have now been made on that basis (Horgan and Dalitz [1973]; Horgan [1974]). The low mass of the $N(1470, \frac{1}{2}^+)$ ("Roper") resonance, and of the P-wave hyperons which accompany it, indicates that this oscillator pattern cannot be too exact. Nevertheless in any approximate oscillator model one would expect the Roper resonance to belong to a 56-plet. This assignment is supported by the observed resonant phase of the Roper in $\pi N \rightarrow \pi \Delta$ (see Faiman and Rosner [1973]; Gilman et al [1973]).

By demanding that the attractive harmonic forces between quarks be present only in symmetric states, Mitra [1974] has constructed a spectrum in which the 70's behave in a manner different from the harmonic oscillator quark model while the 56's remain unchanged.

A central point of this exercise is that the Roper resonance then becomes a 70, 0^+ member.¹⁾

Mitra's model is claimed to give the same counting as the usual quark model, but to shift around the states. Manifestly it appears to have extra ones, however, and I am not able to gain a clear picture of its predicted spectrum. The low-lying 70 is an unlikely suggestion because it leads to the wrong $\pi N \rightarrow \pi \Delta$ phase and because an $N(3/2^+)$ or $\Delta(\frac{1}{2}^+)$ are not observed anywhere near the Roper resonance.

E. Charm

The leptonic weak and electromagnetic charges are consistent with a triplet of left-handed charges and a singlet of right-handed ones, as in the Salam-Weinberg theory. If one tries to form a triplet out of the Cabibbo charges Q_c , by means of:

$$[Q_c, Q_c^+] \equiv 2 Q_{co} \quad (5)$$

one obtains neutral strangeness-changing currents, which are not observed. In order to suppress these currents, while still defining the neutral triplet member via (5), one must introduce new hadronic degrees of freedom into Q_c .

The simplest mechanism for introducing the new degree of freedom is to extend SU(3) to SU(4) by introducing a fourth "charmed" quark: (Glashow et al [1970]). This quark cannot be too heavy, or induced (second-order) neutral strangeness-changing currents will become too large. These effects would be visible as an enhanced $K_L^0 \rightarrow \mu^+ \mu^-$ rate or a $K_L^0 - K_S^0$ mass difference which was of order higher than $G_F^2 M_K^3$. Estimates (Lee and Gaillard [1974]) place the mass of the charmed quark below a few GeV. Reliable estimates of charmed particle mass limits have not been made, however.

The charmed quark u' decays preferentially to the strange one s : under the action of the weak charge-changing current,

$$u' \rightarrow s \cos \theta - d \sin \theta \quad (6)$$

whereas

1) A prime motivation for Mitra's model was the absence of 20's of SU(6). These do not couple to 56 x 35 (the lowest states) in the single-quark-

transition picture to be described shortly.

Yaffe et al. [1973] claim to have observed a 20 coupling to 70 x 35, however.

$$u \rightarrow d \cos \theta + s \sin \theta \quad (7)$$

Charmed hadrons thus should tend to produce strange particles in their weak decays. One imagines the lowest charmed hadron to be stable against strong and electromagnetic decays. Its semileptonic decay rate can be estimated by scaling with respect to the muon mass:

$$\Gamma_{SL} \approx 5 \times 10^{10} \text{ sec}^{-1} [M(\text{GeV})]^5, \quad (8)$$

where strictly speaking one should use the charmed quark mass in Eq (8). For the total decay rate one might multiply Γ_{SL} by anywhere from 2 to 20, the last estimate from analogy with known nonleptonic decays. Thus, for a mass of 4 GeV, one might expect a lifetime anywhere from 10^{-14} to 10^{-15} sec. Emulsion searches are certainly worthwhile at NAL and SPS energies. If the lifetime is too short for the particle to leave an observed track even in emulsion, one could look for other signatures: direct lepton production (eg. with μ -e pairs, or μ -strange-particle pairs), apparent strangeness violations, and peaks in exotic mass combinations like $K^- \pi^+ \pi^+$. (The last can arise from the non-leptonic decay of a charmed $u\bar{d}$ meson). It is this "bump-hunting" aspect of charmed particle searches that places the subject here; it is also being covered in detail by another rapporteur (Iliopoulos [1974]). Several suggestions for charmed particle searches have been made by Carlson and Freund [1972] and by Snow [1973].

III. CURRENT QUARKS

The pion is nearly massless in comparison with other hadrons. (This special role is not fully described by the quark model, in which it is simply an S-wave $q\bar{q}$ state. The ρ -meson, after all, is also an S-wave $q\bar{q}$ state, but it is not nearly as light.) The pion can be regarded as a Nambu-Goldstone boson of spontaneously broken chiral $SU(2) \times SU(2)$.²⁾ The relatively light mass of K and η suggests that

chiral $SU(3) \times SU(3)$ may also describe the hadron spectrum fairly well.

The two notions of a pion- $q\bar{q}$ bound state, and Nambu-Goldstone boson - are combined very neatly in the classic model of Nambu and Jona-Lasinio [1961] (to which we referred briefly earlier), in which spontaneous symmetry breakdown leads simultaneously to the emergence of a zero-mass bound state and to the development of a fermion mass (which would break chiral symmetry if clouds of massless pions weren't around to restore it.)

The symmetries $SU(2) \times SU(2)$ and $SU(3) \times SU(3)$ in the above discussion are exact in the limit of zero pseudo-scalar mass, but are no longer characteristic of the Lagrangian as a whole when the mass is taken to be non-zero. On the other hand, one can still imagine the vector and axial-vector charges associated with this Lagrangian to generate exact chiral algebras at equal times (Gell-Mann [1962]):

$$[Q_a(t), Q_b(t)] = i f_{abc} Q_c(t) \quad (9)$$

$$[Q_a(t), Q_b^5(t)] = i f_{abc} Q_c(t) \quad (10)$$

$$[Q_a^5(t), Q_b^5(t)] = i f_{abc} Q_c(t) \quad (11)$$

These relations led to the Adler-Weisberger [1965] relation and many other successful applications after 1965. They may be abstracted from currents constructed out of quarks. There was then hope (Dashen and Gell-Mann [1966a,b]) that current algebra could serve as a precise basis for the quark model (see Weyers [1974]).

The relations (9) - (11) may be enlarged to an $SU(6)$ of "good" charges (charges whose matrix elements do not vanish at infinite momentum) by including tensor currents as well as vector and axial vector ones. The resulting symmetry has current densities transforming as (here we follow Gilman [1974]):

2) This excuses chiral symmetry from being realized via multiplet degeneracy (i.e. via parity doubling in baryons and mesons: see Dao and Nguyen [1974]; Marshak [discussion after talk].)

$$V_a^0 \equiv q^\dagger(x) \frac{\lambda_a}{2} q(x) \quad (12)$$

$$A_a^z \equiv q^\dagger(x) \sigma_z \frac{\lambda_a}{2} q(x) \quad (13)$$

$$T_a^{yz} \equiv q^\dagger(x) \beta \sigma_z \frac{\lambda_a}{2} q(x) \quad (14)$$

$$T_a^{zx} \equiv q^\dagger(x) \beta \sigma_y \frac{\lambda_a}{2} q(x) \quad (15)$$

and is now known as $SU(6)_W$, currents to distinguish it from the $SU(6)_W$, constituents of Section II.

A. Transitions and sum rules

The infinite-momentum frame (Fubini and Furlan [1965]) was found convenient in applying Eqs. (9) - (11) to experiment. This was because the matrix element $\langle B | Q_5 | A \rangle$ of the axial charge between states A and B is related via PCAC to that for $A \rightarrow B\pi$ (massless) in such a frame:

$$\begin{aligned} q_\pi^2 &= (E_A - E_B)^2 - (p_A - p_B)^2 \\ &= \frac{M_A^2 - M_B^2}{2p} \quad (p = p_A = p_B) \\ &\rightarrow 0 \end{aligned} \quad (16)$$

Since massless pions are very close to real ones, the relation is useful. On the other hand, if $|p_A| = |p_B| = |p|$ does not approach infinity, the difference between E_A and E_B (and hence q_π^2) builds up as the mass difference between the two states increases, obviating the use of PCAC to evaluate $\langle B | Q_5 | A \rangle$.

The use of matrix elements of currents to define hadronic vertices has an important conceptual advantage. These matrix elements are measurable in principle to the order of weak or electromagnetic interactions. One can then pass to the appropriate meson pole (pion, ρ , etc.) to use these matrix elements to describe meson emission.

The contribution of a resonance to a sum rule is an excellent definition of a matrix element $\langle A | Q | B \rangle$. It bypasses the difficult questions (see Henyey and Kane [1973]) of the phase, magnitude, and existence of the residue of a resonance at a pole.

B. The need for mixed representations

If the quarks in Eqs. (12) - (15) were the same as "constituent quarks", we should be able to construct hadrons as pure representations of $SU(6)_W$, currents.

The same is true for the subgroup $SU(3) \times SU(3)_{\text{currents}}$ generated by (12) and (13) (or (9) - (11)) alone. This would lead to several contradictions with experiment:

a) The pion, being associated (via PCAC) with Q_a^5 , could be emitted or absorbed only in transitions between states in an irreducible representation of $SU(3) \times SU(3)$, since Q_a^5 is a generator of that symmetry. Thus, for example, only the N and Δ would couple to πN if the standard "quark model" assignment were made for these states.

b) The matrix element of Q_a^5 between nucleon states is a Clebsch-Gordan coefficient, leading to

$$G_A/G_V = -5/3 \quad (17)$$

Experimentally $G_A/G_V \simeq -1.23$.

c) The anomalous magnetic moment of the nucleon and the transitions $\gamma N \rightarrow \Delta$, $\omega \rightarrow \pi^0 \gamma$ all are predicted to vanish.

d) The decay $B \rightarrow \omega \pi$ is predicted to give $\lambda = 0$ ω mesons (as in $SU(6)_W$, constituents, mentioned in section II.) Experimentally $\lambda_\omega = \pm 1$ dominates.

These problems are ones we could presumably learn to live with in a "lowest-order" theory, though they indicate that such a theory would not be worth much phenomenologically. However, there are more fundamental difficulties with identifying the two groups. This has been pointed out by many people, including Grsey [1963], Dashen and Gell-Mann [1966a,b], Morpurgo [1968], Buccella et al. [1970], Gell-Mann [1972], Melosh [1974], and Bell and Hey [1974]. The free quark case (Grsey [1965]) illustrates the difficulty: a Pryce-Tani-Foldy-Wouthuysen transformation [1948, 1950, 1951] is needed to define both spin and orbital angular momenta for a moving quark.

This transformation will affect the currents of the quark if we choose to write them in the Foldy-Wouthuysen representation. Table II compares the two representations. This "kinematic" need for the two representations to differ has been sharpened by Bell and Hey [1974] to prove that the π and ρ cannot possibly belong to the same representation of $SU(6)_W$, currents, or the ρ will have pathological form factors. Basically this arises because the charges associated with $SU(6)_W$ currents must contain all spins, and not just spin: 0 or 1. (This is a restatement of the Dashen - Gell-Mann [1966 a,b] "angular condition"). This reminds us of what we suspected to be the case from experience in saturating Adler-Weisberger and similar relations: all spins contribute to pion-hadron or photon-hadron scattering.

A different argument for chiral mixing has been provided by Carlitz and Tung [1974], who ascribe it to spontaneous breakdown of chiral symmetry. Their approach is more akin to that of Weinberg [1969], describing massless pion emission in terms of matrix

TABLE II
COMPARISON OF DIRAC AND FOLDY-WOUTHUYSEN

	REPRESENTATIONS	
	Dirac	Foldy-Wouthuysen
Spin	$X_i = \frac{1}{2} U \sigma_i U^\dagger$ (nonlocal)	$\frac{1}{2} \sigma_i$
Position $\mathcal{R}$	nonlocal	$\mathcal{R}$
Dirac Hamiltonian	$\mathcal{R} \cdot \mathcal{P} + \beta m$	βp^0
Orbital angular momentum $\mathcal{R} \times \mathcal{P}$	nonlocal	local $[\mathcal{R} \times \mathcal{P}, \sigma_i] = 0$
Charges	Q	$\tilde{Q} = U^\dagger Q U$
	$U(p) = \sqrt{\frac{m^2 - \mathcal{R} \cdot \mathcal{P}}{p^0}}$ $O_{FW} = U^\dagger O_{Dirac} U$	

elements of light-like charges $\hat{Q}$. (These are the covariant generalization of the "good" operators at infinite momentum. They do not create pairs out of the vacuum. See Jersak and Stern [1968]; Bardakci and Halpern [1968]; Leutwyler [1969]; Weinberg [1969].)

Carlitz and Tung show that in the σ -model, the fundamental quark fields do not transform in a simple way under the $\hat{Q}$. Assuming hadrons to be made up in a simple way from these quark fields, they then conclude that the hadrons must belong to mixed representations of the group generated by the $\hat{Q}$.

Such problems led a great many authors (see e.g. Gilman and Harari [1968]) to devise simple schemes whereby the physical hadron states belonged to mixed representations of the "currents" group (whether $SU(6)_W$, $SU(3) \times SU(3)$, or $SU(2) \times SU(2)$.) Thus, one can write

$$|\text{hadron}\rangle = V |I.R., \text{currents}\rangle \quad (18)$$

where the operator V performs the mixing. The state "I.R., currents" is assigned as in the constituent quark model:

$$|\text{hadron}\rangle = |I.R., \text{constituents}\rangle \quad (19)$$

For example, the nucleon seems to belong to a $56, L=0$ of $SU(6)_W \times O(3)$ constituents. We then choose "I.R., currents" to be $56, L=0$ and construct V accordingly. The nucleon will end up as a mixture of 56 currents, 70 currents, and so on. (See, e.g. Harari [1966]). Obviously V itself cannot respect the "currents" group. Moreover, one must take mixtures of all spins in order to satisfy the Dashen-Gell-Mann angular condition properly: the matrix elements of the lightlike charges $\hat{Q}$ must connect all spins. Hence saturation schemes like those of Gilman and Harari can only be valid approximately. Despite this limitation they are still being used as the basis for possible exact models. (See Ida et al. [1974]; Kuroiwa et al. [1974].)

C. The Melosh transformation

The idea that "constituent quarks" and "current quarks" must be different (Gell-Mann [1972]) led to an attempt by Melosh [1973, 1974] to construct an explicit transformation between the two in the case of free quarks. The transformation relates lightlike charges (local, "bad" spin properties) to W-spin generators (non-local, spin ≤ 1) in much the same way as the Foldy-Wouthuysen transformation acts on the conventional charges. The explicit form of the unitary transformation is

$$V_{\text{free}} = e^{iY_{\text{free}}} \quad (20)$$

with

$$Y_{\text{free}} = \sqrt{2} \int d^2x_{\perp} dx_{+} q_{+}^{\dagger}(x) \times \arctan \frac{\chi_{\perp} \cdot \nu_{\perp}}{\kappa} q_{+}(x) \quad (21)$$

$$\text{and } \kappa = \sqrt{2} |\partial_{-}| + m \quad (22)$$

(Eq. (21) is strictly valid only in the quark's rest frame, and may be generalized to arbitrary frames. See, however, Osborn [1974a].)

Let us simply remind the reader that lightlike charges, rather than the conventional ones, are useful because, being defined by integration over $x_{\perp}$ and x_{+} , they commute with $P_{\perp}$ and P_{+} . Their matrix elements $\langle B | \hat{Q} | A \rangle$ then automatically describe the emission of massless (not $q = 0$!) particles in the $-z$ direction, if the initial particle A is taken at rest. It is precisely the non-rotationally-invariant region of integration that gives the lightlike charges their pathological spin properties, and necessitates a transformation to the constituent quark basis where these spin properties are again well-defined. (I am indebted to John Babcock for discussions on this point.)

The properties of the free quark charges in the "constituent quark" basis are complicated (and nonlocal!) in space-time structure but remarkably simple in SU(6) properties. The single-quark structure of Eq. (21) then leads to single-quark structures in the transformed charges, as shown in

Table III.

The transformation induces all possible single-quark contributions into $\hat{Q}_5$ (the transformed axial charge, relevant for pion emission) and $\hat{D}_{+}$ (the transformed dipole operator, relevant for electromagnetic transitions involving real photons.)

TABLE III
TRANSFORMED CHARGES $V_{\text{free}}^{\dagger} \hat{Q} V_{\text{free}} \equiv \hat{Q}$
IN THE FREE QUARK MODEL

Operator		Transformation Properties	
	ΔL_z	SU(3) x SU(3)	SU(6) [SU(3), 2W+1]
$\hat{Q}_5 = V_{\text{free}}^{\dagger} Q_5 V_{\text{free}}$	0^a	(8,1)-(1,8)	<u>35</u> (8,3)
	± 1	(3,3)-(3,3)	<u>35</u> (8,3)
	1^a	(8,1)+(1,8)	<u>35</u> (8,1)
$\hat{D}_{+}$	0	(3,3)	<u>35</u> (8,3)
	1	(8,1)-(1,8)	<u>35</u> (8,3)
	2	(3,3)	<u>35</u> (8,3)

a): Present in untransformed charges $\hat{Q}_5$ and $\hat{D}_{+}$.

In the free quark model:

$$\hat{Q}_5^a = \sqrt{2} \int d^4x \delta(x_{+}) q_{+}^{\dagger}(x) \sigma_3 \frac{\lambda_a}{2} q_{+}(x);$$

$$\hat{D}_{+}^a = \sqrt{2} \int d^4x \delta(x_{+}) \left(\frac{-x_{-} - iy}{\sqrt{2}} \right) q_{+}^{\dagger}(x) \frac{\lambda_a}{2} q_{+}(x).$$

D. Phenomenological applications

Let us now return to the untransformed charges (Q or $\hat{Q}$, depending on whether we wish to work at infinite momentum or covariantly). Their matrix elements are related to pionic and photonic decays by (see Gilman et al. [1974]):

$$\Gamma(A \rightarrow B \pi) = \frac{1}{4\pi f_{\pi}^2} \frac{P_{\pi}}{2J_A + 1} \times$$

$$\times \frac{(M_A^2 - M_B^2)^2}{M_A^2} \sum_{\lambda} \left| \langle B, \lambda | \frac{Q_5 - iQ_5^2}{\sqrt{2}} | A, \lambda \rangle \right|^2 \quad (23)$$

$$\Gamma(A \rightarrow B \gamma) = \frac{e^2}{\pi} \frac{P_{\gamma}^3}{2J_A + 1} \times$$

$$\times \sum_{\lambda} \left| \langle B, \lambda | D_{+}^3 + \frac{1}{\sqrt{3}} D_{+}^8 | A, \lambda - 1 \rangle \right|^2 \quad (24)$$

The pionic decays depend on PCAC and thus are exact in principle only for zero-mass pions.³⁾ One might

3) The effective centrifugal barrier is hence a p-wave for pion emission in any partial wave; see Weinberg [1969], Laankan and Oneda [1974]; Oneda and

Takasugi [1974]. The correction for $m_{\pi} \neq 0$ is not well known; see Adler [1965], Weinberg [1969], and Hey et al. [1974] for examples.

expect corrections of up to 20% in Eq. (23). The electromagnetic transition formula, Eq. (24), is exact in principle. Here $f_\pi = 135$ MeV is the pion decay constant, and p_π, p_γ are 3-momenta in the rest frame of A.

In order to calculate the matrix elements (23) and (24), we need to know the transformation properties of the states A and B under $SU(6)_{W, \text{currents}}$ (or chiral $SU(3) \times SU(3)_{\text{currents}}$, if one does not wish to admit the higher symmetry). As mentioned before, the states must belong to mixed representations of this symmetry: so

$$\langle \text{hadron}' | Q | \text{hadron} \rangle = \langle I, R'_{\text{currents}} | V^{-1} Q V | I, R_{\text{currents}} \rangle \quad (25)$$

But we know that $V^{-1} Q V$ is still fairly simple in the free quark model. Why not abstract its algebraic properties in the present case, and continue to demand that $\tilde{Q} = V^{-1} Q V$ be a single-quark operator in the basis in which hadrons fall into approximately irreducible representations?

This idea is implicit in every calculation in "realistic" quark models. One works in a world where quarks can have anomalous magnetic moments, can recoil when emitting pions or photons, and can undergo spin-orbit interactions. Consequently, we should not register too much surprise that many of the "new" results have been known to some authors for a long time. What is new is the freeing of single-quark transitions from the confines of specific quark models. A language is thus created which, while imperfect, may be simple enough to be suitable for experimentalists. The harder "dynamical" questions are left for concrete models (Böhm et al. [1974]; Le Yaouanc et al. [1974].)

The algebraic use of single-quark selection rules to calculate matrix elements of Q seems to go back to Buccella et al. [1970]. More recently Gilman and Kugler [1973], Hey and Weyers [1973, 1974], Gilman et

al. [1973, 1974], Gilman and Karliner [1973, 1974], and others have been applying this prescription systematically to the calculation of as many possible experimentally known transitions as one can coax from existing or emerging data.

The pattern is very rich, and contains some surprises.

To summarize, one calculates

$$\langle A | Q | B \rangle = \langle I, R_{\text{currents}} | \tilde{Q} | I, R_{\text{currents}} \rangle \quad (26)$$

using standard Clebsch-Gordan techniques (see e.g. Hey et al. [1973] or Hey and Weyers [1974]), assigning a different reduced matrix element for each type of operator listed in Table III. Thus, pion emission is characterized by the reduced matrix elements of two operators for each pair of multiplets A and B, and photon emission is characterized by the matrix elements of four operators. Not all of these may occur in specific low-L processes.

The multiplets A and B are characterized by their $SU(6)_W \times O(3)$ content, as Melosh [1974] has shown can be done in a consistent way.

Good discussions of the detailed selection rules implied by the single-quark transitions of Table III are given by Gilman et al. [1974], Gilman and Karliner [1974], Lipkin [1974], and Weyers [1973]; many were noted previously.

1. Pionic decays A convenient (and equivalent) language for the single-quark transitions of Table III for pionic decays re-expresses the reduced matrix elements of the $(8, 1) - (1, 8)$ and $(3, \bar{3}) - (\bar{3}, 3)$ terms in terms of partial waves. (Colglazier and Rosner [1971]; Petersen and Rosner [1972]). When a multiplet (A) with $L \geq 0$ decays to one (B) with $L' = 0$ and a pion, the $(B)\pi$ system can have only $l = L \pm 1$. (This follows from parity conservation and from the fact that the emitted pion can carry at most quark spin 1.) For example,

$$\langle 56, L'=0 | [8, 1] - (1, 8) | 70, L=1 \rangle$$

$$\sqrt{S+2D} \quad (\Delta L_z=0) \quad (27)$$

$$\langle 56, L'=0 | [(3, \bar{3}) - (\bar{3}, 3) | 70, L=1 \rangle$$

$$\sqrt{S-D} \quad (\Delta L_z=\pm 1), \quad (28)$$

where S describes $L=0$ and D describes $L=2$ decays.

The vertex symmetry $SU(6)_W \times O(2)_{L_z}$ (Delbourgo et al [1965]; Freund et al [1967]; Lipkin [1967]) forbids the matrix element in Eq. (28), and thus constrains $S = D$. As we shall see for the $70, L=1$ decays, the second matrix element is actually much more important than the first, so that experimentally (in this normalization) $S \sim -2D$. Similarly, in the pionic transitions

$$35, L=1 \rightarrow 35, L=0 + \pi \quad (29)$$

the $\Delta L_z = \pm 1$ term also is much more important than the $\Delta L_z=0$ one. This can be gauged directly from $B \rightarrow \omega \pi$ decays: $\Delta L_z=0$ leads to $\lambda_\omega=0$, while $\Delta L_z=\pm 1$ leads to $\lambda_\omega=\pm 1$. Experimentally

$$\frac{\Gamma_{\lambda=0}(B \rightarrow \omega \pi)}{\Gamma_{\lambda=1}(B \rightarrow \omega \pi)} \sim 15\% \quad (30)$$

(see, e.g., Karshon et al. [1974b]).

Detailed fits to mesonic decays have been discussed most recently by Gilman [1974], and a recent fit to decays of the $70, L=1$ and $56, L=2$ multiplets has been presented to this conference by Hey et al [1974a]. We shall remark briefly, on the last work; see Hey [1974] for details. Earlier fits were made by Faiman and Plane [1972], Jones et al. [1973], and reviewed by Weyers [1973], Rosner [1974].

In the case of the $70, L=1$ decays, fifty-four resonant amplitudes and one partial width are fitted using two reduced matrix elements (corresponding to S and D waves) and fourteen mixing angles. The total widths are also allowed to vary and then fitted; this introduces an additional number of data points exactly equal to the additional number of degrees of freedom, and minimizes error propagation.

The χ^2 for the fit is not impressive, being 172 for 39 degrees of freedom. Most of the χ^2 comes from the "unmixable" states $(5/2^-)$, leading us to suspect that mixing is being used to hide disagreements in the lower-spin states. On the other hand, Fig. 7a-c indicates that resonant amplitudes indeed are being fit to the order of 0.1, which is perhaps all one can expect of PCAC. For a theory we know to be inexact, χ^2 is a poor measure of agreement. The one really bad number is the total width of $\Delta(1630, \frac{1}{2}^-)$. The theory expects it to be about a factor of three less than the observed value.

Important new inputs to Fig. 7 include phase shift analyses of $Y = -1$ channels and of $\pi N \rightarrow \pi \pi N$ (mentioned below). The reaction $\pi N \rightarrow \pi \Delta$ is particularly crucial in determining whether the term with $\Delta L_z = 0$ (Eq. (27)) or $\Delta L_z = \pm 1$ (Eq. (28)) dominates. A number of signs are sensitive to the relative sign of S and D wave amplitudes, as indicated in the figure. They all indicate that the $\Delta L_z = \pm 1$ term is dominant in $70, L=1 \rightarrow 56, L=0 + \pi$ decays. (Faiman and Rosner

4) Certain $70, L=1$ hyperon mixing parameters of Hey et al. [1974] differ substantially from those of Faiman and Plane [1972]. They rely on the new (unconfirmed) analysis by Prevost et al. [1974] of $\bar{K}N \rightarrow \pi \Sigma(1385)$, and may not be very stable with respect to further data.

a) $\underline{70}, L=1: N, \Delta$		
$N(1520)$ $3/2^-$ $I: 0.1$		$\Gamma = 130 \pm 20$ (134)
$N(1670)$ $5/2^-$		$\Gamma = 150 \pm 10$ (132)
$N(1710)$ $3/2^-$		$\Gamma = 200 \pm 100$ (312)
$\Delta(1700)$ $3/2^-$		$\Gamma = 230 \pm 40$ (236)
$N(1510)$ $1/2^-$		$\Gamma = 75 \pm 25$ (99)

a) $\underline{70}, L=1: N, \Delta$ (continued)		
$N(1665)$ $1/2^-$ $I: 0.1$		$\Gamma = 135 \pm 20$ (171)
$\Delta(1610)$ $1/2^-$		$\Gamma = 150 \pm 20$ (53) ←
$N(1520)$ $3/2^-$	$N\eta$	$\Gamma = 130 \pm 20$ (134)
$N(1670)$ $5/2^-$	$N\eta$ ΛK	$\Gamma = 150 \pm 10$ (132)
$N(1510)$ $1/2^-$	$N\eta$	$\Gamma = 75 \pm 25$ (99)
$N(1665)$ $1/2^-$	ΛK	$\Gamma = 135 \pm 20$ (171)

b) $\underline{70}, L=1: \Lambda$		
$\Lambda(1690)$ $3/2^-$ $I: 0.1$		$\Gamma = 60 \pm 20$ (78)
$\Lambda(1830)$ $5/2^-$		$\Gamma = 90 \pm 20$ (90)
$\Lambda(1520)$ $3/2^-$		$\Gamma = 15 \pm 2$ (15)
$\Lambda(1670)$ $1/2^-$		$\Gamma = 30 \pm 5$ (30)
$\Lambda(1402)$ $1/2^-$	$\Gamma(\Sigma\pi) = 38 \pm 4$ (39)	

c) $\underline{70}, L=1: \Sigma$		
$\Sigma(1665)$ $3/2^-$ $I: 0.1$		$\Gamma = 45 \pm 10$ (40)
$\Sigma(1770)$ $5/2^-$		$\Gamma = 110 \pm 10$ (119)
$\Sigma(1580)$		$\Gamma = 12 \pm 4$
$\Sigma(1940)$ $3/2^-$		$\Gamma = 100 \pm 30$ (90)
$\Sigma(1750)$ $1/2^-$		$\Gamma = 60 \pm 20$ (55)

Fig. 7: Amplitudes at resonance $t = \pm \sqrt{x^2} = \pm \sqrt{\Gamma_e \Gamma^* / \Gamma_{tot}}$ and comparison with predictions of the constituent-current quark transformation. From Hey et al. [1974]. The scale is shown on each figure at the left. An elastic amplitude may vary between 0 and 1; an inelastic one between +0.5 and -0.5. Each amplitude is denoted by a shaded box corresponding to (experiment) $\pm$ (one standard deviation). The final channel is written over the corresponding amplitude; the initial channels are $N\pi$ (N or Δ), $N\bar{K}$ (Λ or Σ). In cases where two final partial waves are allowed, a subscript

denotes the incident and outgoing partial waves: e.g. $(\Delta\pi)_{DS}$ denotes $\ell(N\pi)=2$, $\ell(\Delta\pi)=0$. Black dots denote predictions of the theory. In each right-hand column, the first number refers to the experimental total width and the second to the fitted total width. a) N, Δ states in $\underline{70}$, $L=1$. b) Λ states in $\underline{70}$, $L=1$. c) Σ states in $\underline{70}$, $L=1$. d) N, Δ states in $\underline{56}$, $L=2$. e) Λ, Σ states in $\underline{56}$, $L=2$.

d) $56, L=2: N, \Delta$			
$N(1680)$ $5/2^+$	$\pi\pi$ $(\Delta\pi)_{FF}$ $(\Delta\pi)_{FP}$	$\Gamma = 130 \pm 15$ (114)	
$\Delta(1825)$ $7/2^+$	$\pi\pi$ $(\Delta\pi)_{FF}$ $(\Delta\pi)_{FP}$	$\Gamma = 230 \pm 30$ (275)	$N(1730)$ $3/2^+$ $\Gamma = 130 \pm 30$ (167)
$\Delta(1860)$ $5/2^+$	$\pi\pi$ $(\Delta\pi)_{FF}$ $(\Delta\pi)_{FP}$	$\Gamma = 240 \pm 30$ (220)	$\Delta(1900)$ $3/2^+$ $\Gamma = 200 \pm 30$ (184)
$N(1680)$ $5/2^+$	$\pi\pi$ $(\Delta\pi)_{FF}$ $(\Delta\pi)_{FP}$	$\Gamma = 130 \pm 15$ (114)	$\Delta(1850)$ $1/2^+$ $\Gamma = 210 \pm 50$ (202)
$\Delta(1925)$ $7/2^+$	$\pi\pi$ $(\Delta\pi)_{FF}$ $(\Delta\pi)_{FP}$	$\Gamma = 230 \pm 30$ (275)	
$\Delta(1860)$ $5/2^+$	$\pi\pi$ $(\Delta\pi)_{FF}$ $(\Delta\pi)_{FP}$	$\Gamma = 240 \pm 30$ (220)	

e) $56, L=2: \Lambda, \Sigma$			
$\Lambda(1820)$ $5/2^+$	$\pi\pi$ $(\Sigma\pi)_{FF}$ $(\Sigma\pi)_{FP}$	$\Gamma = 80 \pm 20$ (57)	
$\Lambda(1890)$ $3/2^+$	$\pi\pi$ $(\Sigma\pi)_{FF}$ $(\Sigma\pi)_{FP}$	$\Gamma = 100 \pm 20$ (108)	
$\Sigma(1905)$ $5/2^+$	$\pi\pi$ $(\Sigma\pi)_{FF}$ $(\Sigma\pi)_{FP}$	$\Gamma = 75 \pm 20$ (76)	
$\Sigma(2030)$ $7/2^+$	$\pi\pi$ $(\Sigma\pi)_{FF}$ $(\Sigma\pi)_{FP}$	$\Gamma = 170 \pm 20$ (195)	

[1973]; Gilman et al. [1973]).

Similar fits to the $56, L=2$ multiplet are shown in Figs. 7d,e. The χ^2 is much better, even without any mixing. (This has led Hey et al. [1974] to conclude that a $70, L=2$ multiplet is not called for.) It is not clear that resonant amplitudes are being fitted any more closely, however, since their errors are larger.

In the $56, L=2$ multiplet the signs of resonant amplitudes in $\pi N \rightarrow \pi \Delta$ again form a self consistent set. The resonant phase of $N(1680, 5/2^+)$ in the $FP15$ wave indicates that the $\Delta L_z=0$ term dominates in $56, L=2 \rightarrow 56, L=0 + \pi$. This is supported by the $\Lambda(1820, 5/2^+)$ phase in the reaction $\bar{K}N \rightarrow \pi \Sigma(1385)$, analyzed by Prevost et al [1974]. The reaction $\pi N \rightarrow \pi \pi N$ has now been analyzed by several groups: LBL-SLAC (Rosenfeld et al [1974], Cashmore et al [1974a,b], Longacre et al [1974]); Westfield-Imperial College (Baker et al. [1974], and Saclay (Dolbeau et al. [1974]). Generally similar results are obtained. One may hope for similar checks on $\bar{K}N \rightarrow \pi \Sigma(1385)$ in the near future.

An interesting contrast between the status of the $70, L=1$ and $56, L=2$ multiplets is shown in Fig. 8. In each case a scatter plot of $\Sigma_i \Gamma_i / \Gamma$ versus mass is shown. (The values of the partial widths Γ_i and total widths Γ are the fitted ones). These graphs were originally plotted to check that the Γ_i were consistent with unitarity. With a few exceptions, they are. In the $70, \langle \Sigma_i \Gamma_i / \Gamma \rangle$ is much higher than in the 56 . This leads us to suspect that important inelastic channels are missing in the 56 , and any complete theory of resonances will have to describe them. The 70 is in remarkably good shape, by contrast.

The $\pi N \rightarrow \pi \Delta$ resonant phases for $N(1470, 1/2^+)$ and $\Delta(1700, 3/2^+)$ confirm their assignment to a $56, L=0$ multiplet, presumably a radial excitation of the lowest one. Finally, the $N(1780, 1/2^+)$ ("second Roper") resonance appears to have a $\pi \Delta$ phase similar to that of the Roper resonance. It could then not belong to an unmixed $70, L=0$ multiplet, for which the sign is predicted to be the opposite (Faiman and Rosner [1973]).

Fig. 8: Scatter plot comparing sums of predicted partial widths ($\Sigma \Gamma_i$) with fitted total widths (Γ) in the constituent-current quark transformation fit of Hey et al. [1974]. The horizontal axis denotes the resonance mass. a) $70, L^P=1^-$. b) $56, L^P=2^+$.

The reaction $\pi N \rightarrow \pi \Delta$ is an example of an "SU(3)-inelastic" process (Moorhouse and Parsons [1973].) The phases of resonant amplitudes are all related to one another in SU(6)-like symmetries because the N and Δ belong to the same SU(6) multiplet. Clebsch-Gordan coefficients then relate the $\pi N \rightarrow \pi \Delta$ resonant amplitudes to those in $\pi N \rightarrow \pi N$, which must be positive by the optical theorem. A similar circumstance has been used in tests of SU(3) for some time, in "SU(3)-elastic" processes like $\bar{K}N \rightarrow \pi \Sigma, \pi \Lambda$, etc.

2. Radiative decays For the lowest multiplets ($L=0 \rightarrow L=0+\gamma$) the language of constituent-current transformations generally agrees with earlier phenomenological quark model predictions (Becchi and Morpurgo [1966], Dalitz and Sutherland [1966]). The predicted decay width for $\Delta \rightarrow N\gamma$ then may be evaluated in terms of the nucleon magnetic moment, and is in good agreement with experiment if one corrects for the asymmetric shape of the $\Delta(1236)$ (Gilman and Karliner [1974]); see also Olsson [1974].)

While on the subject, we would like to note that the prediction (for $\theta_p = -10.5^\circ$) (Gilman and Karliner [1974])

$$\Gamma(n' \rightarrow p\gamma) \simeq 120 \text{ keV} \quad (31)$$

obtainable from $\Gamma(\omega^0 \rightarrow \pi^0 \gamma)$ and the nonet coupling ansatz (or the assignment of n' to a $\underline{35}$ of SU(6)_W) implies a partial width

$$\Gamma(n' \rightarrow \gamma\gamma) \simeq 9 \text{ keV} \quad (32)$$

and a total width.

$$\Gamma(n' \rightarrow \text{all}) \simeq 0.5 \text{ MeV} \quad (33)$$

when one uses the ratios of observed decay rates. Eq. (32) is precisely the value one would obtain from the new $\pi^0 \rightarrow \gamma\gamma$ and $\eta \rightarrow \gamma\gamma$ widths (Browman et al. [1974]: $\Gamma(\eta \rightarrow \gamma\gamma) = 324 \pm 46 \text{ eV}$) with the η - η' mixing angle $\theta_p = -10.5^\circ$. Hence the η' is very desirable as a 0^- member. (See also Bramón and Greco [1974]; Rosner [1974].)

The constituent-current transformation first obtains its full power when discussing photoproduction of L-excited resonances. Happily, three new analyses have been performed in the last year: one by Kneis et al [1974], another by Metcalf and Walker [1974], and a third by Devenish et al [1974]. These have been reviewed by Lyth [1974] in the parallel sessions. The operators of Table III can be used to fit the resonant photoproduction amplitudes $A_{\frac{1}{2}}^{p,n}$ and $A_{\frac{3}{2}}^{p,n}$ (defined by Copley et al. [1969] and discussed in

Fig. 9: Comparison of photoproduction helicity amplitudes for resonances in the $70, L=1$ multiplet with predictions of the constituent-current quark transformation (Hey et al. [1974]). The helicity amplitudes are those of Copley et al. [1969], discussed in detail by Walker [1969]. The radiative width of a resonance is $\Gamma(R \rightarrow N\gamma) = (p_\gamma^2/\pi) (M_N/M_R)^2 (2/[2J_R+1]) (|A_3|^2 + |A_1|^2)$. The scale is shown at the bottom.

On the left are listed the resonance, its mass, its J^P , and the orbital angular momentum ℓ of its $N\pi$ decay: $\ell=S, P, D, F, \dots$. Theoretical predictions are obtained by a fit to the amplitudes of Metcalf and Walker [1974], and are shown as dots. a) Amplitudes of Metcalf-Walker [1974]; b) amplitudes of Kneis et al. [1974], "KMORR"; c) amplitudes of Devenish et al. [1974].

detail by Walker [1969]). Typical simple results are shown in Table IV. These have been discussed in some detail by Close [1974c] at this conference. The $(8,1)-(1,8)$ term does not arise in conventional quark models, but it appears to be needed to explain the fact that $\frac{n}{2} A_3^P \neq -\frac{p}{2} A_3^P$ for $N(1520, \frac{3}{2}^-)$.

A fit to the amplitudes of Metcalf and Walker [1974] has been performed by Hey et al. [1974a] for the $70, L=1$. The results are shown in Fig. 9a. No serious discrepancies occur. To indicate the stability of the different data analyses, the same fit is compared in Fig. 9b with the couplings of Kneis et al. [1974] and in Fig. 9c with those of Devenish et al. [1974]. Aside from some variations discussed by Lyth [1974] and Close [1974c], the stability is

remarkable. (Note the recurrent problems with $\Delta(1630, \frac{1}{2}^-)$. As emphasized by Lyth, different analyses use different $N\pi$ couplings, and this could be part of the problem.)

The qualitative conclusions one draws from Fig. 9 are that: a) all three possible terms are needed to describe $70, L=1 \rightarrow 56, L=0+\gamma$, and b) the phases of pionic couplings (which enter into the definition of the sign of $A_\lambda^{P,n}$) are consistent with those learned from $n\pi \rightarrow \pi\Delta$.

The $56, L=2$ decays have been discussed in detail by Gilman and Karliner [1974]. At present, the data do not seem to require any terms beyond those of the conventional quark model: $(8,1)+(1,8), \Delta L_z=1$ and

Fig. 10: Same as Fig. 9 for resonances in the 56, L=2 multiplet. Predictions are those of Gilman and Karliner [1974], based on assuming absence of the

(8,1)-(1,8) and (3,3) terms (see Table III), and thus do not represent the best achievable fit. a) - c) as in Fig. 9.

TABLE IV

SOME RELATIONS AMONG BARYONIC PHOTOEXCITATION AMPLITUDES BASED ON SINGLE-QUARK TRANSITIONS

Resonance	Relation	Experimental value of right-hand side
56, L=0		
N(938, 1/2 ⁺)	$\mu_n/\mu_p = -\frac{2}{3} = -0.667$	-0.685
Δ(1236, 3/2 ⁺)	$\frac{A_3^P}{2} / \frac{A_1^P}{2} = \sqrt{3} = 1.73$	$\begin{cases} 1.80 \pm 0.04^a \\ 1.81 \pm 0.09^b \\ 1.86 \pm 0.09^c \end{cases}$
70, L=1		
N(1520, 3/2 ⁻)	$1 + \frac{A_3^N}{2} - \sqrt{3} \frac{A_1^P}{2} - 3\sqrt{3} \frac{A_1^N}{2} = 0$	$\begin{cases} 1.4 \pm 1.0^a \\ 1.0 \pm 0.5^b \\ 0.7 \pm 0.7^c \end{cases}$
N(1670, 5/2 ⁻)	$\frac{A_3^P}{2} = \frac{A_1^P}{2} = 0$	0 within errors ^{a,b,c}
56, L=2		
N(1680, 5/2 ⁺)	$1 + \frac{3}{2} \frac{A_3^N}{2} - \sqrt{2} \frac{A_1^P}{2} - \frac{3}{\sqrt{2}} \frac{A_1^N}{2} = 0$	$\begin{cases} 0.7 \pm 1.0^a \\ 1.0 \pm 0.4^b \\ 0.4 \pm 0.7^c \end{cases}$
Δ(1950, 7/2 ⁺)	$\frac{A_3^P}{2} / \frac{A_1^P}{2} = \sqrt{5/3} = 1.29$	$\begin{cases} 1.1 \pm 0.7^a \\ 1.6 \pm 0.6^b \\ 0.7 \pm 0.2^c \end{cases}$

- a) Kneis et al. [1974]
b) Metcalf et al. [1974]
c) Devenish et al. [1974]

(3,3), $\Delta L_z=0$. (See, e.g., Feynman et al. [1971] for the structure of such a model). A crucial question which we hope to learn when the data improve is the sign of the P-wave πN amplitudes. This will help check the $\pi N \rightarrow \pi \Delta$ FPI5 phase of N(1680, 5/2⁺), which we recall indicated the dominance of $\Delta L_z=0$ pionic transitions. So far the best possibility seems to be to see the photoproduction of the N(1700-1800, 3/2⁺). Fig. 10 shows the predictions of Gilman and Karliner applied to the three new sets of data.

It has been pointed out that at least one of the (8,1)-(1,8), $\Delta L_z=1$ or (3,3), $\Delta L_z=2$ terms is needed for saturation of the Drell-Hearn-Gerasimov sum rules (see Close et al [1974]).

3. Uses of vector meson dominance Suppose we could calculate $A \rightarrow B\gamma(q \neq 0)$. We could then let B be a pion, take $q^2 \rightarrow m_\pi^2$ ($V=\rho, \omega, \dots$) and calculate a hadronic transition in two ways: via $\langle A | J^{em} | \pi \rangle$ or via $\langle A | Q_5 | V \rangle$. Let us suppose that $A \rightarrow B\gamma(q=0)$ and $A \rightarrow B\gamma(q = m_\pi^2)$ are not too different, and can be described merely by factoring the vector meson pole out of the reduced matrix element. Then we can demand that Eqs. (27) and (28) give a consistent

Fig. 11: $70, L=1$ photoproduction helicity amplitudes versus oscillator-quark model predictions of "FKR": Feynman et al. [1971]. a) - c) as in Fig. 9.

result. What do we get?

The answer is amusing; I shall not quote the proof. One obtains no constraints on the pionic transitions, but one obtains a relation between the $(8,1)+(1,8)$ and $(8,1)-(1,8)$ $\Delta L_z=1$ pieces in the electromagnetic current. Moreover, the $\Delta L_z=2$ piece must vanish. Both of these constraints occur in a model proposed by Petersen and Rosner [1973], and appear to be roughly consistent with the observed couplings. (Note, however, that they have been derived only for $\pi\gamma$ decays, and must be postulated elsewhere).

The analyses of $\pi N \rightarrow \pi\pi N$ give couplings of resonances to ρN (and ϵN) as well as to $\pi\Delta$. While such couplings are much more subject to experimental uncertainties, they can be compared with photoproduction, and the vector dominance model seems to fare reasonably well for the $N(1520, \frac{3}{2}^-)$ and $N(1680, \frac{5}{2}^+)$. (These are the only resonances with clear-cut ρN and γN coupling signs; see Longacre et al. [1974]). In principle one is then able to extrapolate the predictions based on the constituent-current quark transformation to the ρ meson pole, to predict the phases of transverse ρ production amplitudes. This remains to be done.

E. Specific models

As mentioned, many results of the previous subsection have been obtained before. What is new about the more general language? To see this, we discuss two specific models: the oscillator-quark model of Mitra and Ross [1967], Faiman and Hendry [1968], Copley et al [1969], Feynman et al. [1971], and others; and the 3P_0 model of Micu [1969], Coyne and Meshkov [1969] Colglazier and Rosner [1971], and Petersen and Rosner [1972]. The fate of both illustrates both the fruits and the perils of model-building.

1. The oscillator-quark model specifies the relative amount of $(8,1)-(1,8)$ and $(3, \bar{3})-(\bar{3}, 3)$ in pion emission, as the second term comes essentially from quark recoil. It predicts that $\Delta L_z=\pm 1$ decays dominate in $70, L=1 \rightarrow 56, L=0+\pi$ (verified), but also in $56, L=2 \rightarrow 56, L=0+\pi$ (contradicted by the $\pi N \rightarrow \pi\Delta$ FP15 phase of $N(1680, \frac{5}{2}^+)$). Many other schemes (Le Yaouanc et al. [1974], Eguchi [1973]) also predict $\Delta L_z=1$ dominance in $56, L=2 \rightarrow 56, L=0+\pi$. The sole scheme which predicts $\Delta L_z=0$ here is that of Buccella et al. [1970], and it was constructed to do so.

Fig. 12: Same as Fig. 11 for $\underline{56}$, $L=2$ amplitudes.

The $(8,1)-(1,8)$, $\Delta L_z=1$ and $(\bar{3},3)$, $\Delta L_z=2$ terms in photoproduction are missing in most oscillator quark models, though the first has been put in from time to time. As mentioned, some evidence for the first appears in 70, $L=1$ photocouplings. As an example, Fig. 11 shows the Feynman et al. predictions for these couplings, indicating what happens when one leaves out such a term. Fig. 12 (for the $\underline{56}$, $L=2$) indicates that the data here are not sufficient to rule out the FKR model.

One should note that oscillator-quark models relate different reduced matrix elements to one another. In this respect they were not doing badly until the πN data and the pN data came along. (I shall not recount the spotty tale of pN disagreements in this model; see Moorhouse and Parsons [1973].) These data cast doubt on specific features of the models for which, no doubt, remedies will be found. But their first guess seems to have been wrong.

2. The 3P_0 model, although weaker (hence more general) than the oscillator-quark model, also is contradicted by present data. The model is based on the symmetric picture of hadron vertices

Fig. 13: Quark graph illustrating the 3P_0 model for hadronic vertices.

shown in Fig. 13. The created pair at the right can have $L_z=0$ or ± 1 . (Carter and Head [1968], Horn and Ne'eman [1970], and Carlitz and Kislinger [1970] considered similar models with $L_z=0$.) For pion emission, the 3P_0 model is algebraically identical to the constituent-current quark language, as shown by Hey et al. [1973]. It also bears a close resemblance to the phenomenological "2-broken $SU(6)_W$ " used by Faiman and Plane [1972], in a fit to all 70, $L=1$ baryon decays.⁵⁾

One concludes (as above) from pion emission that $\Delta L_z=1$ dominates in 70, $L=1$ decays and $\Delta L_z=0$ dominates in $\underline{56}$, $L=2$ decays. These conclusions clash violently, however, with an otherwise very successful fit to photoproduction by Petersen [1974] and a rather spotty fit to pN signs by Faiman [1974a] (It's not his fault!) The Petersen photoproduction

5) The models of Le Yaouanc et al. [1974] and Bohm et al. are based on using Fig. 13 with explicit wavefunctions.

Fig. 14: 70, L=1 photoproduction helicity amplitudes versus 3P_0 model productions of Petersen [1974].

a) - c) as in Fig. 9.

Fig. 15: Same as Fig. 14 for 56, L=2 amplitudes.

fit is shown in Figs. 14 and 15. It requires $\Delta L_z = 1$ dominance in both 70, L=1 and 56, L=2 pionic decays, as a result of the $\rho N, \omega N$, and πN couplings all being related and the large value of $A_{3/2}^P$ for the $N(1680, 5/2^+)$. Similarly, the Faiman fit can be characterized as requiring either $\Delta L_z = 0$ in both

70, L=1 and 56, L=2; or $\Delta L_z = \pm 1$ in both. (I am sorry to report that a few signs in the theory are still loose; only one of the above is true, but we don't yet know which.) Faiman [1974b] has shown that assumptions about the $\rho_{\lambda=0} N$ coupling can be relaxed somewhat without changing his conclusions too much.⁶⁾

6) Questions of principle in the application of "2-broken $SU(6)_W$ " to ρ couplings have been raised by Freund [1974].

To summarize the situation in the 3P_0 model, we wish the evidence for $\Delta L_z=0$ in ${}_{56}$, $L=2$ decays would go away. But it seems based on healthy resonances, and fairly solid.

Other models such as those of Le Yaouanc et al. [1974] or Böhm et al. [1974] can be expected to have similar problems. That is why I urge that model-builders have some idea of the algebraic structure of their model to be able to make the relevant comparisons immediately, rather than gradually sinking into the mire by a "left-foot, right-foot" approach.

F. Problems at $q^2 \neq 0$ and elsewhere

We have not discussed at all the most important aspiration of the transformation between constituent quarks and current quarks: to make contact with "parton" ideas. (It is not clear at this conference that we would gain much by the association, however!) A first step in this direction involves describing the electroproduction of resonances (Close et al [1974]; Goldberg [1974]), which shows some interesting patterns. (See Foster [1974]). One must understand the transformation properties of "bad" operators to do this, and it is no longer as clear that they describe single-quark transitions. Moreover, the $SU(6)$ structure of a hadron becomes very doubtful as one approaches the Bjorken scaling limit, especially toward $x=1$ (Close [1974a], Sehgal [1974]).

Problems of principle have been raised by Osborn [1974b] even at $q^2=0$, where he claims a "no-go theorem" based on a generalized Drell-Hearn-Gerasimov sum rule. This result is so new that I have not had time to reproduce it, but it is clearly a source of concern. Earlier considerations by Osborn [1974a] also raised the possibility of non-single-quark transitions, and showed that Melosh's derivation of $\nu_n/\nu_p = \frac{2}{3}$ was unsound.

We have blithely taken $SU(6)$ currents for granted, whereas only $SU(3) \times SU(3)$ is firmly established. The vector and axial charges are in a sense "more measureable" than their tensor counterparts. The near-masslessness of the 0^- mesons only points us toward $SU(3) \times SU(3)$, not $SU(6)$. The motivation for going all the way to $SU(6)$ is two-fold: a) $SU(6)$ embraces all the "good" charges, and b) $SU(6)$ works. Most of the predictions mentioned above: standard $SU(6)$ f/d values, M_1 dominance of $\Delta(1236)$ photo-production (Berends-Donnachie [1974]), the result

$$\Gamma(\Delta \rightarrow N\pi) = \frac{12}{25} \frac{G_{\pi NN}^2}{4\pi} \frac{P^*}{M_\Delta^2} \left\{ \frac{M_\Delta^2 - M_N^2}{2M_N} \right\}^2$$

$\approx 125 \text{ MeV}$ (Γ expt. $\approx 115 \text{ MeV}$), (34)

and so on, are lost if one retreats to chiral $SU(3) \times SU(3)$. (See Gilman and Kugler [1973]; Hey and Weyers [1973]; Love and Nanopoulos [1973]). It is still an open question whether $SU(6)$ is in fact any worse for calculating transitions than chiral $SU(3) \times SU(3)$, though, in terms of the spectrum, $SU(6)$ constituents is clearly not exact. We wonder, for example, how the 5 MeV quark of Leutwyler [1974] affects the results mentioned above, as it depends so crucially on $m_\pi \neq m_p$.

IV. SUMMARY AND CONCLUSIONS

A general language for describing hadronic transitions has come into being in the last couple of years. It seems verified by experiment, it has some theoretical basis, and it confirms many of the popular ideas about the classification of resonances. The basis of this language is the realization that the groups describing local charges and those describing particle classification are different, but possibly related by a unitary transformation. The general language has definite phenomenological (and possibly conceptual) advantages over earlier specific quark models, while at the same time allowing

7) For the $\frac{1}{2}^+$ baryons, the weak decays indicate a value of $d/(d+f)$ within 10% of that predicted by $SU(6)_W$ (Kleinknecht [1974]). The NAK coupling

obtained from new measurements of the real parts of forward K^+p amplitudes (Baillon et al. [1974]) now also agrees well with $SU(6)_W$.

for possible improvement of those models by those who wish to think in explicit terms. Moreover, the existence of a general (though perhaps imperfect) language for describing transitions⁸⁾ can serve as a guide to qualitatively new experiments in the resonance region. Finally, the fact that the language allows the reduction of a vast body of data to a few selection rules ensures that when a fundamental theory comes along, we will know it immediately. We have a Balmer spectrum; some would even claim we have a Bohr theory. Now we are waiting for quantum mechanics to be invented.

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REFERENCES

1. Adler [1965]: S. L. Adler, Phys. Rev. Letters 14(1965)1051; Phys. Rev. 140(1965)B736.
2. Alam et al. [1974]: M. S. Alam et al., paper no. 251, sessions C2, C5, this conference.
3. Ayed et al. [1973]: R. Ayed and P. Bareyre, "Baryon resonances with zero strangeness up to 2.4 GeV mass," paper no. 311, in Proceedings of the Second Aix-en-Provence International Conference on Elementary Particles, edited by M. S. Detoeuf, J. de Phys., 1973.
See also von Schlippe [1972]; Donnachie and Hamilton [1965]; and P. Bareyre, talk at 1973 Aix Conference, p. 91-224.
4. Baillon and Litchfield [1974]: P. Baillon and P. Litchfield, paper no. 441, session C4, this conference.
5. Baillon et al. [1974]: P. Baillon et al., paper no. 668, this conference. See also *ibid.*, papers no. 667, 669. For an earlier review of coupling constants see Pilkuhn et al. [1973].
6. Baker et al. [1974]: S. L. Baker et al., paper no. 383, session C4, this conference.
7. Bando et al. [1974]: M. Bando, T. Kugo and S. Tanaka, paper no. 257, session C5, this conference.
8. Bardakci and Halpern [1968]: K. Bardakci and M. B. Halpern, Phys. Rev. 176(1968)1686.
9. Bardeen et al. [1974]: W. A. Bardeen et al., "Heavy quarks and strong binding: a field theory

8) The single-quark transition rules of Table III have yet to be derived in any interacting theory. They may represent a first approximation to the true rules in the same manner as do the allowed Fermi and Gamow-Teller transitions in β -decay. I am indebted to F. Close and G. Morpurgo for discussions on this point.

- of hadron structure," SLAC report, presented to this conference.
10. Barger [1974]: V. Barger, rapporteur's talk on reaction mechanisms at high energy, this conference.
 11. Bartels and Savit [1974]: J. Bartels and R. Savit, "Why we don't see fermion parity doublets," National Accelerator Laboratory report FNAL-Pub-74/60. - Thy, June, 1974 (unpublished).
 12. Becchi and Morpurgo [1966]: C. Becchi and G. Morpurgo, Phys. Rev. 149(1966)1284; see also Phys. Rev. B140(1965)687; Phys. Letters 17(1965).
 13. Bell [1974]: J. S. Bell, "The Melosh Transformation and the Pryce-Tani-Foldy-Wouthuysen Transformation", 1974 Schladming Lectures, CERN report CERN.TH.1851, May 10, 1974 (unpublished).
 14. Bell and Hey [1974]: J. S. Bell and A. Hey, paper no. 1098, session C5, this conference. See also Bell [1974].
 15. Bender et al. [1974]: C. Bender, J. Mandula and G. Guralnik, paper no. 835, session C5, this conference.
 16. Berends and Donnachie [1974]: F. A. Berends and A. Donnachie, paper no. 1007, session B7, this conference.
 17. Böhm et al [1974]: M. Böhm, H. Joos, and M. Krammer, Nuclear. Phys. B69(1974)349; paper no. 188, sessions B1, B6, C5, this conference; M. Krammer, talk at parallel session C5, this conference.
 18. Bogoliubov [1968]: P. N. Bogoliubov, Ann. Inst. Henri Poincaré 8(1968)163.
 19. Bowler and Game [1974]: M. G. Bowler and M. A. V. Game, "The AI is alive and well, or 'The politician, the lighthouse, and the trained cormorant'," Oxford University report, this conference.
 20. Bramón and Greco [1974]: A. Bramón and M. Greco Phys. Letters 48B(1974)137.
 21. Browman et al. [1974]: A. Browman et al., Phys. Rev. Letters 32(1974)1067; proceedings of the 1974 Meson Conference, Boston, Mass., April 1974, to be published by American Institute of Physics.
 22. Buccella et al. [1970]: F. Buccella et al., Nuovo Cimento 69A(1970)133; F. Buccella, F. Nicolò, and A. Pugliese, Nuovo Cimento 12A(1972)640.
 23. Carlitz and Kislinger [1970]: R. Carlitz and M. Kislinger, Phys. Rev. D2(1970)336.
 24. Carlitz and Tung [1974]: R. Carlitz and Wu-Ki Tung, "The Origin of Chiral Representation Mixing", Enrico Fermi Institute report EFI 74/19, April 1974 (unpublished). See also Casher and Susskind [1974].
 25. Carlson and Freund [1972]: C. E. Carlson and P. G. O. Freund, Phys. Letters 39B(1972)349.
 26. Carter and Head [1968]: J. C. Carter and M. E. M. Head, Phys. Rev. 176(1968)1808.
 26. Casher and Susskind [1974]: A. Casher and L. Susskind, Phys. Rev. D9(1974)436.
 27. Cashmore et al. [1974]: R. Cashmore et al. "Ambiguity Resolved: A single continuous solution for $\pi N \rightarrow \pi \bar{\pi} N$ below 2000 MeV", SLAD preprint SLAC-PUB-1387, April 1974, submitted to Phys. Rev. Letters, paper No. 446, sessions C4, C5 this conference.
 28. Cashmore et al. [1974b]: R. J. Cashmore, D. W. G. S. Leith, R. S. Longacre and A. H. Rosenfeld, paper no. 467, sessions C4, C5, this conference.
 29. Chodos et al. [1974]: A. Chodos, R. L. Jaffe, K. Johnson, and C. B. Thorn, "Baryon structure in the bag theory", M.I.T. report CTP-#417, June, 1974, submitted to Phys. Rev., talks at parallel session G1, this conference.
 30. Chung et al. [1973]: S. U. Chung et al., Phys. Letters 47B(1973)526.

31. Clayton et al. [1974]: E. F. Clayton et al., paper no. 351, sessions C4 and C5, this conference.
32. Close [1974a]: F. E. Close, paper no. 261, sessions B1, B7, this conference.
33. Close [1974b]: F. E. Close, "On the transformation between current and constituent quarks and consequences for polarised electroproduction structure functions," CERN report TH.1875, May 1974.
34. Close [1974c]: F. E. Close, talk at parallel session B7, this conference.
35. Close et al. [1974]: F. E. Close, H. Osborn, and A. Thomson, paper no. 262, sessions B1 and B7, this conference.
36. Cohen [1974]: D. Cohen, paper no. 910, session C2, this conference.
37. Colglazier and Rosner [1971]: E. W. Colglazier and J. Rosner, Nucl. Phys. B27(1971)349. See also E. W. Colglazier, Thesis, California Institute of Technology, 1971 (unpublished).
38. Copley et al [1969]: L. Copley, G. Karl and E. Obryk, Phys. Letters 29B(1969); Nucl. Phys. B13(1969)303; Phys. Rev. D4(1971)2844.
39. Coyne and Meshkov [1969]: J. Coyne and S. Meshkov, 1969, unpublished (private communication).
40. Dalitz [1966]: R. H. Dalitz, in Proceedings of the XIII International Conference on High Energy Physics, Berkeley, California, 1966, edited by Margaret Alston-Garnjost, Berkeley, Univ. of California Press, 1967, p.215.
41. Dalitz and Sutherland [1966]: R. H. Dalitz and D. G. Sutherland, Phys. Rev. 146(1966)1180.
42. Dao and Nguyen [1974]: Dao vong Dyc and Nguyen van Hieu, paper no. 740, session C5, this conference.
43. Dashen and Gell-Mann [1966a]: R. Dashen and M. Gell-Mann, in Proceedings of the Third Coral Gables Conference on Symmetry Principles at High Energy, 1966 (W. H. Freeman and Co., San Francisco, 1966), p.168.
44. Dashen and Gell-Mann [1966b]: R. Dashen and M. Gell-Mann, Phys. Rev. Letters 17(1966)340.
45. Delbourgo et al. [1965]: R. Delbourgo, M. Rashid, A. Salam, and J. Strathdee, in High Energy Physics and Elementary Particles, International Atomic Energy Agency, Vienna, 1965, p.455.
46. Devenish et al. [1974]: R. Devenish, D. Lyth and W. Rankin, paper no. 620, session B7, this conference.
47. Dolbeu et al. [1974]: J. Dolbeu, F. A. Triantis, M. Neveu, and R. Longacre, paper no. 476, session C4, this conference.
48. Donnachie and Hamilton [1965]: A. Donnachie and J. Hamilton, Ann. Phys. (N.Y.) 31(1965)410.
49. Eguchi, [1973]: T. Eguchi, Nucl. Phys. B60(1973)277, Ibid., B70(1974)390. For other dual schemes relevant to $\pi\Delta$ couplings see Gell et al. [1971] and Inoue and Uehara [1974].
50. Faiman [1974a]: D. Faiman, "Phases of Resonant Amplitudes: $\pi N \rightarrow \pi N$ ", Weizmann Institute preprint 74/16, 1974 (unpublished).
51. Faiman [1974]: D. Faiman, "How large is the ρ -meson longitudinal coupling?" Weizmann Institute preprint 74/7 (unpublished).
52. Faiman and Hendry [1968]: D. Faiman and A. Hendry, Phys. Rev. 173(1968)1720; Phys. Rev. 180(1969)1572, 1609.
53. Faiman and Plane [1972]: D. Faiman and D. Plane, Nucl. Phys. B50(1972)379.
54. Faiman and Rosner [1973]: D. Faiman and J. Rosner, Phys. Letters 45B(1973)357.
55. Faiman et al [1973]: D. Faiman, J. Rosner and J. Weyers, Nucl. Phys. B57(1973)45.
56. Feynman et al [1971]: R. P. Feynman, M. Kislinger and F. Ravndal, Phys. Rev. D3(1971)2706.
57. Filippov [1974]: A. T. Filippov, paper no. 678, session C5, this conference.

58. Foldy and Wouthuysen [1950]: L. L. Foldy and S. A. Wouthuysen, Phys. Rev. 78(1950)29.
59. Foster [1974]: F. Foster, talk at parallel session B7, this conference.
60. Freund [1973]: P. G. O. Freund, Phys. Rev. D8(1973)4631.
61. Freund et al [1967]: P. G. O. Freund, A. N. Maheshwari, and E. Schonberg, Phys. Rev. 159(1967)1232.
62. Fubini and Furlan [1965]: S. Fubini and G. Ferlan, Physics 1(1965)229.
63. Gaillard [1974]: M. K. Gaillard, talk at parallel session B5, this conference.
64. Gell et al. [1971]: Y. Gell, D. Horn, M. Jacob, and J. Weyers, Nucl. Phys. B33(1971)379.
65. Gell-Mann [1962]: M. Gell-Mann, Phys. Rev. 125(1962)1067; Physics 1(1964)63.
66. Gell-Mann [1964]: M. Gell-Mann, Phys. Letters 8(1964)214.
67. Gell-Mann [1972]: M. Gell-Mann, Acta Physica Austriaca, Suppl. IX(1972)733. (1972 Schlading lectures).
68. Gilman [1974]: F. J. Gilman, "Symmetries of Currents as seen by hadrons," presented at 1974 Meson Conference, Boston, Mass., proceedings to be published by American Institute of Physics.
69. Gilman and Harari [1968]: F. Gilman and H. Harari, Phys. Rev. 165(1968)1803; see also Phys. Rev. Letters 18(1967)1150.
70. Gilman and Karliner [1973]: F. Gilman and I. Karliner, Phys. Letters 46B(1973)426.
71. Gilman and Karliner [1974]: F. Gilman and I. Karliner, SLAC report SLAC-PUB-1382, January 1974, submitted to Phys. Rev.
72. Gilman and Kugler [1973]: F. Gilman and M. Kugler, Phys. Rev. Letters 30(1973)518.
73. Gilman et al. [1973]: F. Gilman, M. Kugler and S. Meshkov, Phys. Letters 45B(1973)481.
74. Gilman et al. [1974]: F. Gilman, M. Kugler, and S. Meshkov, Phys. Rev. D9(1974)715.
75. Glashow et al. [1970]: S. L. Glashow, J. Iliopoulos, and L. Maiani, Phys. Rev. D2(1970)1285. See also: Carlson and Freund [1972]; Snow [1973].
76. Goebel [1966]: C. G. Goebel, Phys. Rev. Letters 16(1966)1130; Ibid., 17(1966)66(E).
77. Goldberg [1974]: H. Golberg, paper no. 172, session B7, this conference.
78. Gopal et al [1974]: G. P. Gopal et al., paper no. 350, sessions C4 and C5, this conference.
79. Greenberg [1964]: O. W. Greenberg, Phys. Rev. Letters 13(1964)598.
80. Gürsey [1965]: F. Gürsey, Phys. Letters 14(1965)330.
81. Harari [1966]: H. Harari, Phys. Rev. Letters 16(1966)964; Ibid., 17(1966)56.
82. Henyey and Kane [1974]: F. Henyey and G. Kane, paper no. 179, session C5, this conference.
83. Hey [1974]: A. J. G. Hey, talk at parallel session C5, this conference.
84. Hey and Weyers [1973]: A. J. G. Hey and J. Weyers, Phys. Letters 44B(1973)263.
85. Hey and Weyers [1974]: A. J. G. Hey and J. Weyers, Phys. Letters 48B(1974)69.
86. Hey et al. [1973]: A. J. G. Hey, J. Rosner and J. Weyers, Nucl. Phys. B61(1973)205.
87. Hey et al. [1974]: A. J. G. Hey, P. J. Litchfield and R. J. Cashmore, paper no. 626, sessions B7, C4, C5, this conference.
88. Horgan and Dalitz [1973]: R. Horgan and R. H. Dalitz, Nucl. Phys. B66(1973)135.

89. Horgan [1974]: R. Horgan, Nucl. Phys. B71(1974) 514. See also Jones et al. [1974].
90. Horn and Ne'eman [1970]: D. Horn and Y. Ne'eman, Phys. Rev. D1(1970)2710.
91. Ida et al. [1974]: M. Ida, T. Tajima and K. Yamawaki, paper no. 152, session C5, this conference.
92. Igi and Shimada [1974a]: K. Igi and T. Shimada, paper no. 163, session C5, this conference.
93. Igi and Shimada [1974b]: K. Igi and T. Shimada, paper no. 164, session C5, this conference.
94. Iliopoulos [1974]: J. Iliopoulos, rapporteur's talk on unified theory of weak and electromagnetic interactions, this conference.
95. Inoue and Uehara [1974]: K. Inoue and M. Uehara, paper no. 127, session C5, this conference.
96. Jersak and Stern [1968]: J. Jersak and J. Stern, Nucl. Phys. B7(1968)413; Nuovo Cimento 59A (1969)315.
97. Johnson and Treiman [1965]: K. Johnson and S. B. Treiman, Phys. Rev. Letters 14(1965)189.
98. Jones et al. [1974]: M. Jones, R. Levi Setti, and T. Lasinski, Nuovo Cimento 19A(1974)365; paper no. 560, session C4, this conference.
99. Kane [1974]: G. L. Kane, paper no. 184, sessions C2, C3, this conference.
100. Karshon et al. [1974a]: U. Karshon et al., paper no. 345, session C2, this conference.
101. Karshon et al. [1974b]: paper no. 291, sessions C2 and C3, this conference. See also Chung et al. [1973].
102. Kleinknecht [1974]: K. Kleinknecht, rapporteur's talk on weak interactions, this conference.
103. Kneis et al. [1974]: G. Kneis, R. G. Moorhouse, H. Oberlack, A. Rittenberg, and A. Rosenfeld, revised version of paper no. 957, session B7, this conference.
104. Kuroiwa et al. [1974]: T. Kuroiwa, K. Yamawaki, and T. Kugo, paper no. 312, session C5, this conference.
105. Laankan and Oneda [1974]: T. Laankan and S. Oneda, paper 913, session C5, this conference.
106. Lee and Gaillard [1974]: B. W. Lee and M. K. Gaillard, "Rare decay modes of the K-mesons in gauge theories," NAL report NAL-PUB-74/21 Thy, 1974. See also Gaillard [1974]; de Rujula [1974].
107. Leutwyler [1969]: H. Leutwyler, Springer Tracts in Modern Physics 50(1969)29.
108. Leutwyler [1974]: H. Leutwyler, Phys. Letters 48B(1974)431.
109. Le Yaouanc et al [1974]: A. Le Yaouanc et al., paper no. 415, sessions C4, C5, this conference. See also Phys. Rev. D8(1973)2223, Phys. Rev. D9(1974)1415.
110. Lipkin [1967]: H. J. Lipkin, Phys. Rev. 159(1967)1303.
111. Lipkin [1973]: H. J. Lipkin, Physics Reports 8C(1973) No. 3.
112. Lipkin [1974]: H. J. Lipkin, Phys. Rev. D9(1974)1579.
113. Lipkin and Meshkov [1965]: H. J. Lipkin and S. Meshkov, Phys. Rev. Letters 14(1965)670; Phys. Rev. 143(1966)1269.
114. Litchfield [1974a]: P. J. Litchfield, rapporteur's talk on baryon spectroscopy, this conference.
115. Litchfield [1974b]: P. J. Litchfield, paper no. 522, session C4, this conference.
116. Longacre et al [1974]: R. S. Longacre et al., paper no. 468, sessions C4, C5, this conference.
117. Love and Nanopoulos [1973]: A. Love and D. V. Nanopoulos, Phys. Letters 45B(1973)507.
118. Lyth [1974]: D. H. Lyth, talk at parallel session B7, this conference.
119. Mandelstam [1970]: S. Mandelstam, Phys. Rev. D1(1970)1734.

120. Mandula et al. [1970]: J. Mandula, J. Weyers, and G. Zweig, Ann. Rev. Nucl. Sci 20(1970)289.
121. Mandula et al. [1974]: J. E. Mandula, J. Weyers, and G. Zweig, Nucl. Phys. B71(1974)365.
122. Melosh [1973]: H. J. Melosh, IV, Thesis, California Institute of Technology, 1973 (unpublished).
123. Melosh [1974]: H. J. Melosh, IV; Phys. Rev. D9(1974)1095.
124. Metcalf and Walker [1974]: W. J. Metcalf and R. L. Walker, "A phenomenological analysis of pion photoproduction," California Institute of Technology report CALT-68-425, February 1974, (unpublished).
125. Micu [1969]: L. Micu, Nucl. Phys. B10(1969)521.
126. Mitra [1974]: A. N. Mitra, paper no. 284, session C5, this conference.
127. Mitra and Ross [1967]: A. N. Mitra and M. Ross, Phys. Rev. 158(1967)1630.
128. Moorhouse and Parsons [1973]: R. G. Moorhouse and N. Parsons, Nucl. Phys. B62(1973)109; Phys. Letters 47B(1973)24.
129. Morgan [1974a]: D. Morgan, talk at parallel session C2, this conference. ©
130. Morgan [1974b]: D. Morgan, "Is the O^+ nonet respectable?," Rutherford Laboratory report RL-74-063 (1974), submitted (together with postscript) to this conference.
131. Morpurgo [1968]: G. Morpurgo, in "Theory and phenomenology in particle physics," Proceedings of the International School of Physics "Ettore Majorana," Erice, Sicily, 13-28 July, 1968, edited by A. Zichichi, New York and London, Academic Press, 1969, p.84. See also Okubo [1954]; Ohnuki and Toyoda [1965].
132. Nambu and Jona-Lasinio [1961]: Y. Nambu and G. Jona-Lasinio, Phys. Rev. 122(1961)345; Ibid., 124(1961)246.
133. Ohnuki and Toyoda [1965]: Y. Ohnuki and A. Toyoda, Nuovo Cimento 36(1965)1405.
134. Okubo [1954]: S. Okubo, Prog.Theor. Phys. 12 (1954)603.
135. Olsson [1974]: M. G. Olsson, paper no. 270, session C4, this conference.
136. Oneda and Takasugi [1974]: S. Oneda and E. Takasugi, paper no. 759, session C5, this conference.
137. Osborn [1974a]: H. Osborn, "Angular constraints and the Melosh transformation," Caltech report CALT-68-435, 1974 (unpublished).
138. Osborn [1974b]: H. Osborn, talk at parallel session B7, this conference.
139. Petersen [1974]: W. P. Petersen, " 3P_0 model and helicity structure of photoproduction couplings," Daresbury Nuclear Physics Laboratory report DL/P201, March 1974, submitted to Nuclear Physics B.
140. Petersen and Rosner [1972]: W. Petersen and J. Rosner, Phys. Rev. D6(1972)820. See also W. P. Petersen, Thesis, University of Minnesota, 1973 (unpublished).
141. Petersen and Rosner [1973]: W. Petersen and J. Rosner, Phys. Rev. D7(1973)147.
142. Pilkuhn et al. [1973]: H. Pilkuhn et al., Nucl. Phys. B65(1973)460.
143. Prevost et al. [1974]: J. Prevost et al., Nucl. Phys. B69(1974)246.
144. Pryce [1948]: M. H. L. Pryce, Proc. Roy. Soc. 195A(1948)62.
145. Rey et al. [1974]: paper no. 689, session C4, this conference. See also von Schlippe [1972]; Donnachie and Hamilton [1965].
146. Rosenfeld et al. [1974]: A. H. Rosenfeld et al., paper no. 465, sessions C4, C5, this conference.
147. Rosner [1973]: J. Rosner, Phys. Rev. D7(1973)172.
148. Rosner [1974]: J. Rosner, Physics Reports, to be published.

150. Ross et al. [1974]: R. T. Ross et al., paper no. 349, sessions C4 and C5, this conference.
151. de Rujula [1974]: A. de Rujula, talk at parallel session B5, this conference.
152. von Schlippe [1972]: W. von Schlippe, Lett. al Nuovo Cimento 4(1972)767.
153. Sehgal [1974]: L. M. Sehgal, paper no. 361, session C5, this conference.
154. Snow [1973]: G. Snow, Nucl. Phys. B55(1973)445.
155. Tani [1951]: S. Tani, Prog. Theor. Phys. 6(1951)267.
156. Wagner [1974]: F. Wagner, rapporteur's talk on meson spectroscopy, this conference.
157. Walker [1969]: R. Walker, Phys. Rev. 182(1969)1729. See also Proceedings of the 4th International Symposium on Electron and Photon Interactions at High Energies, Liverpool, Sept. 14-20, 1969, edited by D. W. Braben and R. E. Rand, Daresbury (England), Daresbury Nuclear Physics Laboratory, 1969.
158. Weinberg [1969]: S. Weinberg, Phys. Rev. 177(1969)2604.
159. Weisberger [1965]: W. Weisberger, Phys. Rev. Letters 14(1965)1047; Phys. Rev. 143(1966)1302.
160. Weyers [1973]: J. Weyers, "Constituent quarks and current quarks," CERN report TH.1743, September 1973, lectures given at the International Summer School on Particle Interactions at Very High Energies, Louvain, Belgium, 1973.
161. Weyers [1974]: J. Weyers, "Possible representations of local current algebra," CERN report TH.1833, March 1974 (unpublished).
162. Yaffe et al. [1973]: D. Yaffe et al., in "Baryon Resonances-1973", West Lafayette, Indiana, Purdue University, 1973, p.85.
163. Zweig [1964]: G. Zweig, CERN reports TH.401 and TH.412, 1964 (unpublished).