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ELECTROPRODUCTION FINAL STATES AS $\omega \to 1$

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ABSTRACT

The successful model of Barbour and Moorhouse for pion photoproduction is extended to electroproduction and combined with recent ideas on configuration mixing or SU(6) breaking in deep inelastic electroproduction as $\omega \to 1$. We find that two consequences obtain in the current fragmentation region as $\omega \to 1$:

(a) the missing mass spectrum in $ep \to e\pi^- X$ and $en \to e\pi^+ X$ will be featureless (phase space) ;

(b) in $ep \to eM^{+,0}X$ and $en \to eM^{0,-}X$ for <u>any</u> non-strange meson M the missing hadron system will contain only octets. Hence, in particular $ep \to e\pi\Delta$ will vanish relative to $ep \to e\pi^+ n$ as $\omega \to 1$. For K production only Λ and no Σ final states will be produced.

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It is well known that in a parton model when the partons have the quantum numbers of Gell-Mann and Zweig quarks then the total cross-sections, or inelastic structure functions νW_2, for virtual photo-absorption on neutrons and protons are bounded by [1])

$$\frac{1}{4} \leq \sigma^{\gamma n}/\sigma^{\gamma p} \leq 4 \tag{1}$$

If the nucleon were in a $\underset{\sim}{56}$-plet representation of SU(6) in this (current) quark basis then [2]) $\sigma^{\gamma n}/\sigma^{\gamma p} = 2/3$; to obtain the suggested empirical trend [*]) of 1/4 for this ratio as $\omega\ (= 2M\nu/q^2) \rightarrow 1$ it has been suggested that in this limit the nucleon is in a mixture of $\underset{\sim}{56}$ and $\underset{\sim}{70}$-plet current quark basis representations [3]),[4]).

A different, but intimately related, approach is to consider the constituent quark basis [5]) where it is accepted that the nucleon is in a $\underset{\sim}{56}$-plet representation of SU(6). Here, however, one does not know what is the form of the electromagnetic interaction of the constituent quarks other than that the photon is assumed to be in a $\underset{\sim}{35}$-plet representation of SU(6). Given that assumption one can write down the most general form for the electromagnetic interaction consistent with the assumption of single quark operators, and compute [6]) the excitation amplitudes to $\underset{\sim}{56}$ and $\underset{\sim}{70}$ representations (the non-diffractive s channel component in $\gamma N \rightarrow \gamma N$) and if one demands that only non-exotic $\underset{\sim}{1}$ and $\underset{\sim}{35}$ representations are exchanged in the t channel of the virtual forward Compton amplitude then this constrains the relative importance of $\underset{\sim}{56}$ and $\underset{\sim}{70}$ in the s channel. On summing over all states in the s channel one again finds that [7])

$$\sigma^{\gamma n}/\sigma^{\gamma p} = 2/3 . \tag{2}$$

To obtain a ratio less than 2/3 one must introduce t channel exotics, allow for non $\underset{\sim}{35}$ pieces in the electromagnetic interaction or break the SU(6) [8]). There is evidence that suggests that SU(6) is indeed broken in nature ; in particular the observation of Shaw [9]) that the magnetic transition form factor $\gamma p \rightarrow \Delta(1236)$ appears to fall

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[*]) We shall assume here that this is indeed the case. However, one should bear in mind that there is no a priori reason for the neutron-proton ratio to be monotonically decreasing with ω and other values, e.g., 4/9 could obtain as $\omega \rightarrow 1$.

faster with increasing photon mass than does the elastic $G_M^P(q^2)$ of the proton, cannot be accommodated in unbroken SU(6). It is our purpose here to propose some new tests of the SU(6) breaking or configuration mixing mechanisms that have been put forward 3),4),10),11) as possible causes of the trend $\sigma^{\gamma n}/\sigma^{\gamma p} \to 1/4$ as $\omega \to 1$ and do not consider here further the t channel exotic or non-$\underset{\sim}{35}$-plet photon possibilities as, to the best of our knowledge, no systematic examinations of these mechanisms have been made to date.

First we shall briefly review the mechanisms discussed in Refs. 3),4),10),11).

If we think of the nucleon as built from a quark (which has $I = S = \frac{1}{2}$ and which interacts with the external electromagnetic field) and a shell then since the nucleon has $I = \frac{1}{2}$ the shell can have $I = 0$("β") or $I = 1$("α") only. In a constituent basis where the nucleon is a member of the $(\underset{\sim}{8},\underset{\sim}{2})$ representation of the SU(3) × SU(2) subgroup of SU(6) then the shell can only have spin $S = 0$("β") or 1("α") it being traditionally assumed that no angular momentum is present in the quark shell system. If one now demands that the nucleon is a member of the 56 dimensional representation of SU(6) then the nucleon wave function in isospin-spin space reads

$$\frac{1}{\sqrt{2}}\left(\alpha\alpha + \beta\beta\right) \tag{3}$$

and the above-mentioned problems with $\sigma^{\gamma n}/\sigma^{\gamma p}$ [Eq. (2)] and with the $\gamma p \to \Delta$ / $\gamma p \to p$ behaviour at large q^2 arise. However, if one had only demanded that the nucleon belong to $(\underset{\sim}{8},\underset{\sim}{2})$ representations of SU(3) × SU(2) then the allowed configurations would be

$$\alpha\alpha\ ,\ \alpha\beta\ ,\ \beta\alpha\ ,\ \beta\beta \tag{4}$$

and the nucleon could be in an arbitrary combination of these states. If as $q^2 \to \infty$ or $\omega \to 1$ the nucleon is dominantly in only $\beta\alpha$ or $\beta\beta$ configurations then the $\sigma^{\gamma n}/\sigma^{\gamma p}$ of 1/4 immediately obtains since the only configurations are now those involving the isoscalar shell in which cases the quark must have the same isospin quantum numbers as the target, hence having charge 2/3, -1/3 in proton and neutron, respectively. We shall call this model 1. The vanishing of $\gamma p \to \Delta$ relative to $\gamma p \to p$ also obtains since the absence of the $I = 1$ shell prevents the $I = \frac{3}{2}$ Δ production.

A stronger assumption was made in Ref. 11), namely that as $q^2 \to \infty$ the differing spin dynamics in the vector, as against scalar core configurations in Eq. (3) [treating the nucleon as a quasi-two-body system, cf. Blankenbecler et al., Ref. 12)], were responsible for suppression of the $\alpha\alpha$ mode and so <u>only</u> the $\beta\beta$ configuration contributes (model 2). This naturally contains model 1 predictions but further predicts that as $\omega \to 1$ the spin dependence of the total photo-absorption will be entirely in $J_z = \frac{1}{2}$ as against $\frac{3}{2}$ (the latter requiring α configuration to be present in spin space). This will hopefully soon be tested in the forthcoming polarized beam-target experiments at SLAC 13).

In the <u>current</u> quark basis we can again think of the nucleon as quark plus shell and, as before in the constituent basis, the nucleon's isospin constrains the shell to have only $I = 0(B)$ or $I = 1(A)$ *). There is, however, no a priori reason in this basis to ignore internal angular momentum in the quark-shell system and so the nucleon can exist in any arbitrary combination of $(\underset{\sim}{8},\underset{\sim}{2})$, $(\underset{\sim}{8},\underset{\sim}{4})$, etc., current basis representations of $SU(3) \times SU(2)$. To obtain 1/4 for $\sigma^{\gamma n}/\sigma^{\gamma p}$ the configurations in the $\omega \to 1$ limit are restricted to the set $(\underset{\sim}{8}^B, \underset{\sim}{2S+1})$ 10) with S half-integral. This is the analogue in the current basis of model 1 above. In Refs. 3), 4), configuration mixing schemes have been proposed where as $\omega \to 1$ the nucleon is supposed to be in a linear combination of $\underset{\sim}{56}$ and $\underset{\sim}{70}$ representations of $SU(6)$ which corresponds to retaining as dominant only the (BB) configuration analogous to model 2 in the constituent basis. In Ref. 3), it again follows that the spin dependence is totally in the $J_z = \frac{1}{2}$ mode, but in Ref. 4) the presence of orbital angular momentum in the system allows the possibility of $J_z = \frac{3}{2}$.

It is our intention here to point out the testable consequences that these proposed dynamics have for the constitution of the final state hadrons as $\omega \to 1$ in (quasi-two-body) $eN \to eMX$ with M any meson and X a baryon system and when the momentum transfer between photon and meson is $|t| \lesssim 1$ $(\mathrm{GeV}/c)^2$. The four schemes (models 1 and 2 in constituent and in current bases) in general yield different

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*) We use A, B to denote the scalar or vector representations in the current basis to distinguish from the constituent basis where we use α, β .

predictions but there is one case where their predictions coincide and this is also the most readily accessible to experimental test. We shall work from here on in the constituent basis, and discuss the implications of models 1 and 2 in that basis. The consequences of the analogous models in the current basis can be similarly worked out and we shall just state the results where necessary.

It was noted by Barbour and Moorhouse 14) that away from the pion pole and for $|t| \lesssim 1$ $(GeV/c)^2$ the charged pion photoproduction cross-section ratios in $\gamma N \rightarrow \pi^{\pm}N, \pi^{\pm}\Delta$ could be understood in a simple quark model where a single quark is photo-excited and subsequently emits the pion. We have checked 15) that these ratios do not depend upon quarks per se but obtain solely from SU(6) s channel couplings, the assumption that SU(6) symmetry is true in nature and the absence of t channel exotics (similarly to the Compton case discussed above) *). Furthermore we have found that these ratios obtain when the most general form of electromagnetic interaction is employed for both scalar and transverse photons in $\underset{\sim}{35}$-plets (i.e., we work consistently in the constituent basis and Melosh transform the photon and pion - via PCAC - vertices). The results therefore go over into electroproduction ; indeed as noted by Clegg 16) these predictions for $\pi N, \pi\Delta$ electroproduction ratios are in reasonable accord with the data 17).

Now, as noted above, these results implicitly depend upon the assumption of exact SU(6) symmetry (on extending the calculation to arbitrary meson-baryon final stades 15) and then summing over all the states one again finds the familiar 2/3 ratio appearing for the inclusive cross-sections on neutron and proton). We have also noted that the relative importance of $\alpha\alpha$ and $\beta\beta$ constituent quark configurations in nucleon photo-absorption matrix elements are q^2 dependent whereas they should be independent of q^2 if SU(6) is a good symmetry at all q^2 (model 2). Hence we would expect to find that the cross-section ratios for $\pi N, \pi\Delta$ production at small t will have q^2 dependence due to the same SU(6) breaking that was hypothesized to be responsible for the $\sigma^{\gamma n}/\sigma^{\gamma p}$ ratio being q^2 dependent at fixed s. Similarly one would expect to find ratios for the $\pi N, \pi\Delta$ production differing from those of Ref. 14) if instead of the exact SU(6) one employed the SU(3) × SU(2) approach (model 1). Indeed when we make the s channel sum in either model 1 or 2 then instead of the Barbour-Moorhouse results, we find that

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*) Our results are strictly true only for the imaginary parts of the amplitudes. For the justification for claiming that these results obtain to good approximation for the observed cross-sections and for the neglect of the diagrams where the meson is emitted before the photon is absorbed, see Ref. 14).

(i) the only final states X produced in $ep \rightarrow eM^{+,o}X$ and $en \rightarrow eM^{o,-}X$ for any non-strange meson M will be entirely octets while for K production X will be entirely Λ and not Σ.

(ii) as a direct consequence the missing mass spectrum in $ep \rightarrow eM^{-}X$ and $en \rightarrow eM^{+}X$ will be smooth, i.e., there will be no quasi-two-body channels in these states.

Identical results obtain in both the analogue models 1 and 2 of Refs. 3), 4) in the current basis. Furthermore on summing over all the states M, X we obtain 1/4 for the inclusive cross-sections on neutron and proton.

In model 2 one has the further prediction that the only octets will be those in the $(\underset{\sim}{8},\underset{\sim}{2})$ constituent basis representations of $SU(3) \times SU(2)$, e.g., nucleon, $D_{13}(1520)$ but not $D_{15}(1690)$. In the analogue of model 2 in the current basis one would predict that only $(\underset{\sim}{8},\underset{\sim}{2})$ current basis representations will be produced.

The derivation of these results in the s channel approach and a discussion of the final states in deep inelastic lepton-production at small ω ($\lesssim 5$, say) will be given elsewhere 15). The origin of these results is most easily seen by considering the effect of the $SU(6)$ breaking (model 2) upon the original explicit mechanism of Ref. 14). Diagrammatically their model is shown in Fig. 1. The $SU(6)$ breaking corresponds to neglecting at large q^2, fixed s, the diagram 1a involving the $I = S = 1$ shell. Clearly the only states X that can then be produced are those containing an $I = S = 0$ shell viz. $I = \frac{1}{2}$ $(\underset{\sim}{8})$ $S = \frac{1}{2}$ states if M has strangeness zero. Similarly if M is a kaon then the $I = 0$ shell prevents Σ states being produced. The origin of the predictions in the other models can be seen similarly.

Therefore we advocate that the q^2 dependence of four-point form factors be measured to supplement previous measurements of their three-point counterparts (Fig. 2) [where by three-point we mean the familiar q^2 dependence of the baryon resonance bump in $\gamma N \rightarrow N^*$ for fixed $s = m_{N^*}^2$ whereas by four-point we mean the q^2 dependence of the baryon resonance bumps in $\gamma N \rightarrow \pi N^*$ at fixed s, fixed m_{N^*} and fixed $t_{\gamma\pi} \lesssim 1\ (\mathrm{GeV}/c)^2$]. In any event this knowledge and comparison of the q^2 dependences of bump heights in inclusive as against semi-inclusive final states will be useful in increasing our understanding of deep inelastic phenomena and the dynamics operating there. If any of the cited mechanisms are indeed responsible for the observed behaviour of $\sigma^{\gamma n}/\sigma^{\gamma p}$ as $\omega \rightarrow 1$ then we predict that the four-point form factor ratios will be like the three point, viz.

$$\frac{\frac{d\sigma}{dt}(\gamma_V p \to \pi\Delta)}{\frac{d\sigma}{dt}(\gamma_V p \to \pi N)}\left(q^2, s_{fix}, t_{fix} \lesssim 1(\mathrm{GeV}/c)^2\right) \sim \frac{\sigma(\gamma p \to \Delta)}{\sigma(\gamma p \to p)}(q^2) \sim \left(\frac{F_2^V(q^2)}{G_M(q^2)}\right)^2 \overset{q^2\to\infty}{\sim} \frac{1}{q^4}$$

where the empirical observation of Shaw 9) for the three-point ratio has been used in the third relation with F_2^V, G_M the Dirac isovector and magnetic elastic form factors of the proton.

Note that this relation between the four-point and three-point N and Δ form factors is non-trivial. It would only be trivial if it were the case that only $I = \frac{1}{2}$ N^* states yielded πN and only $I = \frac{3}{2}$ states yielded $\pi\Delta$ in which case a direct connection would result. In nature it is of course not the case that the above takes place, e.g., $\Delta \to N\pi$, and the fact that the identification obtains is a consequence of SU(6) phases plus the specific breaking mechanisms. As such this is a new test of the dynamics proposed in Refs. 3), 4), 10), 11) to explain the $\omega \to 1$ behaviour of the total inclusive photo-absorption cross-sections. If the predicted Δ suppression is observed then one might hope to proceed further to distinguish between the various proposed mechanisms, in particular the $\omega \to 1$ behaviour of the polarized electroproduction data will be of interest in this regard 3),11).

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4) G. Altarelli, N. Cabibbo, L. Maiani and R. Petronzio - CERN Preprint TH. 1727 (1973).

5) For the reader not familiar with the distinction between current and constituent quarks we recommend the lectures of J. Weyers, International Summer School on Particle Interactions at Very High Energies, Louvain ; CERN Preprint TH. 1743 (1973), where earlier literature may be found.

6) A.J.G. Hey and J. Weyers - CERN Preprint TH. 1718 (1973).
In a specific approach [the Melosh transformation, see Ref. 5)] which starts from the "known" interaction in a current quark basis and transforms to the constituent basis, the resulting form of the interaction also contains the four terms that arise on general grounds. Compare also F.J. Gilman and I. Karliner - Phys.Letters 46B, 426 (1973), where one of these terms is omitted and also H.J. Lipkin - NAL-PUB-THY 73/62, where the significance of single quark operators is also discussed.

7) This was first shown using the magnetic interaction [the term B in Ref. 6)] by :
F.E. Close, F.J. Gilman and I. Karliner - Phys.Rev. D6, 2533 (1972) ;
F.E. Close and F.J. Gilman - Phys.Rev. D7, 2258 (1973).
For inclusion of the orbital term [term A in Ref. 6)] and discussion in an explicit quark model, see :
H. Osborn and G. Woo - Cambridge preprint DAMTP 73/18 (1973).
That this result also obtains when the most general form of electromagnetic interaction is used for 35-plet photons and single quark operators will be shown in Ref. 15). For transverse photons this result has also been obtained by F.J. Gilman (unpublished).

8) In the weaker case of SU(3) with no t channel exotics the bound of 1/4 arises when, among other constraints, the decuplet s channel contributions vanish. See :

S. Pallua and B. Renner - Phys.Letters 38B, 105 (1972).

A similar approach in SU(3) has been applied to semi-inclusive processes :

M. Chaichian and S. Kitakado - Nuovo Cimento Letters 7, 331 (1973).

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W. Bartel et al. - Phys.Letters 28B, 148 (1968) ;

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15) These and various related questions have been investigated by the author in collaboration with A.J.G. Hey, H. Osborn and A.M. Thomson.

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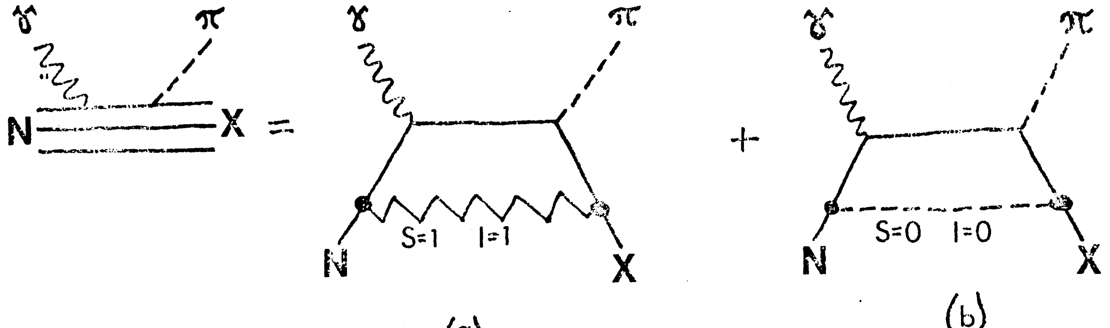
FIGURE CAPTIONS

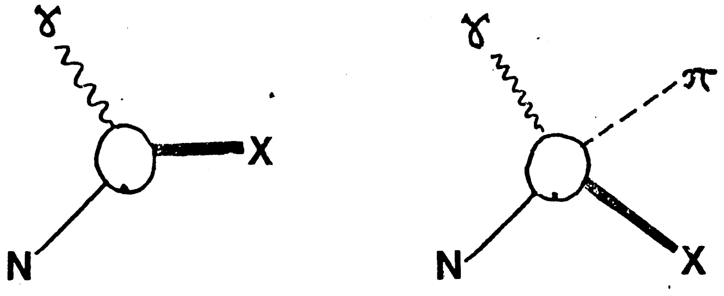
Figure 1 The single quark excitation de-excitation model of pion photoproduction of Ref. 14). The separation of quark and "shell" spin-isospin configuration is also shown, (a) and (b).

Figure 2 (a) Three-point transition form factor to state X.
(b) Four-point transition form factor to state X.



(a) (b)

Fig. 1



(a) (b)

Fig. 2