$SU(6)_W$ analysis of the electroproduction of pseudoscalar mesons in the second resonance region*

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Recent data on the photoproduction and electroproduction of π and η mesons in the second resonance region are analyzed assuming that the electromagnetic current transforms on the W spin as a mixture of $W=0$ and $W=1$, $W_z=0,\pm 1$. The data favor the presence of a term transforming as $W=1$, $W_z=0$, with the $W=0$ and $W=1$, $W_z=0$ matrix elements showing similar q^2 dependence, q^2 being the square of the mass of the virtual photon. The ratio between the two helicity cross sections $\sigma_{1/2}/\sigma_{3/2}$ is found to be small for $0<-q^2<1.5$ GeV^2.

I. INTRODUCTION

One of the most remarkable features of the experimental data in particle physics during the last two years is how they more and more agree with an underlying quark dynamics in a, so far, quarkless world. Evidence for that comes not only from hadron spectroscopy, but also from deep-inelastic lepton-induced reactions. In particular, the interactions of real and virtual photons with hadrons both in the deep-inelastic regime and in the resonance region have given very interesting information. Rather complete experimental information on single-pion photoproduction in the resonance region has been obtained.[1] The analysis of this experiment leads to resonant phases (and approximate magnitudes) which agree with quark-model predictions.[2]

Within the frame of the Melosh transformation[3] the data have been also analyzed, assuming that the operator which induces the electromagnetic transitions transforms[4,5] under $SU(6)_W$ as a sum of

$$\{\underline{35},\ (8,3)_{W_z=\pm 1},\ \Delta L_z=0\}+\{\underline{35},\ (8,3)_{W_z=0},\ \Delta L_z=\pm 1\}+\{\underline{35},\ (8,3)_{W_z=\mp 1},\ \Delta L_z=\pm 2\}+\{\underline{35},\ (8,1)_{W_z=0},\ \Delta L_z=\pm 1\}, \quad (1.1)$$

where W is the W spin and L_z is the projection of the internal orbital angular momentum along the direction of motion. (As has been remarked by Lipkin,[6] this structure for the electromagnetic transition operator follows from rather general assumptions shared by most of the quark models.) The last term contributes only to transitions with orbital angular momentum equal or larger than 2, and the analysis of Gilman and Karliner[6] suggests that it is negligible. The third term is required in the $^3P_0$ spurion model of Petersen and Rosner.[7]

Although not as complete as in the case of real photons, some information exists on the electroproduction of pions in the resonance region.[8] Also some preliminary data exist on the reaction $ep \to ep\eta$ in the second resonance region.[9] This reaction is very interesting as only the $S_{11}(1535)$ resonance has ηp as the most important decay mode. We will show in this paper that when we take together both the photoproduction and electroproduction experimental information we seem to need the presence of the term $\underline{35}$, $(8,3)_{W_z=0}$, $\Delta L_z=1$, with the matrix elements of both this term and the last one in (1.1) showing similar q^2 dependence for $0<Q^2\equiv -q^2<1.5$ GeV^2, q^2 being the square mass of the virtual photon.

Another related topic is the value of the two helicity amplitudes $A_{1/2}$ and $A_{3/2}$ for the photoproduction of $D_{13}(1520)$ and $F_{15}(1688)$. For real photons $|A_{1/2}|^2 \ll |A_{3/2}|^2$, and as a matter of fact $A_{1/2}$ is consistent with zero.[1] For $Q^2\neq 0$ the situation is unclear. As was pointed by Gilman and Close,[10] although the symmetric quark model with harmonic forces predicts low values for $\sigma_{1/2}/\sigma_{3/2}$ at $Q^2=0$, when Q^2 increases this ratio changes drastically, and at $Q^2=0.6$ GeV^2, $\sigma_{1/2}/\sigma_{3/2}\approx 3$. In their analysis Gilman and Close[10] show that at $Q^2=0.6$ GeV^2 the data suggest $\sigma_{1/2}/\sigma_{3/2}$ to be small. However, in a recent experiment on the reaction[11] $ep\to en\pi$ at $Q^2=0.4$ GeV^2, it was shown that these new data might also be consistent with $\sigma_{1/2}/\sigma_{3/2}$ large (~3) at $Q^2=0.4$ GeV^2. In this paper we will show, taking into account the data on electroproduction of η mesons, that for $D_{13}(1520)$, $\sigma_{1/2}/\sigma_{3/2}<1$ if $0<Q^2<1.5$ GeV^2.

In Sec. II, we carry out an analysis of the photoproduction data of Moorhouse *et al.*[1] and Devenish *et al.*[1]. We include in the current a term transforming as $W=1$, $W_z=0$ [second term in (1.1)] and compute the helicity amplitudes for different values of this term. We find that the data suggest that the contribution of such a term is important. In Sec. III, we analyze the electroproduction data and assuming that the current operator transforms as (1.1), we find again the need of the $W=1$, $W_z=0$ term, with the matrix elements for both $W=1$, $W_z=0$ and $W=0$ showing similar Q^2 dependence. We also find $\sigma_{1/2}/\sigma_{3/2}<1$ if $0<Q^2<1.5$ GeV^2. We close the paper with a few final remarks.

II. SU(6)$_W$ ANALYSIS OF PHOTOPRODUCTION DATA

A rather complete analysis of the photoproduction of pions on nucleons has been carried out recently, by Moorhouse *et al.*[1] and Devenish *et al.*,[1] in order to understand the characteristics of the transition of the photon-nucleon system to different baryonic resonances. This analysis improves the previous one by Walker.[12]

As has been discussed by many authors, and in particular by Faiman and Plane,[13] the spectrum and decays of the hadronic resonances are well classified by SU(6)$_W$, with the baryons being in the $\underline{56}$ and $\underline{70}$ representations of that group. Within the frame of the symmetric quark model with harmonic forces, in both nonrelativistic[14] and relativistic versions,[15] different authors have studied the photoproduction of baryonic resonances. In that frame two parameters eventually appear, the oscillator frequency (in the relativistic versions this may be related to the slope of the Regge trajectories) and the baryon magnetic moment, which may be related to the magnetic moment of the quark. A reasonable fit to the data is obtained, assuming that the "effective mass" of the quark is about 300 MeV. One finds the correct sign for almost all the transition amplitudes, that $\sigma_{1/2}/\sigma_{3/2}$ is small for $D_{13}(1520)$ and $F_{15}(1688)$, and that the amplitudes have the right order of magnitude although the s-wave resonances are too low by a factor 2 or 3.

As was mentioned in the Introduction, the problem has been discussed recently within the somewhat more general frame suggested by the Melosh transformations.[4,5] In particular, it is assumed that the dipole operator transforms under SU(6)$_W$ as the sum[4,5]

$$\begin{aligned}E\{\underline{35},\ (8,1)_{W_z=0},\ \Delta L_z=\pm1\}\\ +M\{\underline{35},\ (8,3)_{W_z=\pm1},\ \Delta L_z=0\}\\ +C\{\underline{35},\ (8,3)_{W_z=0},\ \Delta L_z=\pm1\}\\ +D\{\underline{35},\ (8,3)_{W_z=\mp1},\ \Delta L_z=\pm2\}.\quad(2.1)\end{aligned}$$

The last term does not contribute to the $L=0\to L=1$ transitions. For the ordinary quark model $C=D=0$, and for the $^3P_0$ spurion model[7] $E=C$ and $D=0$.

Very recently, an analysis of the photoproduction of baryonic resonances in the resonance region has been carried out in the frame of the Melosh transformation by Gilman and Karliner.[5] They consider two fits in the second resonance region, one with $C/E=0$ and the other with $C/E\approx1$. Although all the signs of the amplitudes are in agreement with experiment, the magnitudes of a number of the predicted amplitudes are not in such good agreement. In particular, for $C/E=0$ they predict values which are too large for $S_{11}(1535)$, S_{31}, and D_{33} as well as for the $\gamma n\to D^0_{13}(1520)$, $\lambda=\frac{3}{2}$ amplitude. On the other hand, for $C/E=1$, the $\lambda=\frac{1}{2}$, $\gamma n\to D^0_{13}$, and $\gamma p\to S^+_{11}(1535)$ are found to be too small. The S_{31} is again too large. Taking into account the mixing angle suggested by strong interactions (small mixing angle for the two D_{13} states, large mixing angle for the two S_{11} states), the change in the predictions is not enough to get a good agreement with the experimental data.

In this section we fit the second resonance photoproduction data, considering several values for the ratio $C/E\equiv r$ ($r=0, \frac{1}{3}, \frac{2}{3}, 1$).

In Table I, we present our results. In the first two columns of the table we show the resonances and their classification in SU(6)$_W$. The pairs of resonances $S_{11}(1535)$, $S_{11}(1700)$ and $D_{13}(1520)$, $D_{13}(1700)$ are taken as configuration mixtures of W doublets and W quadruplets. The values for the mixing angles $\theta_s=45°$ and $\theta_d=15°$ are taken from the analysis of strong decays by Faiman and Plane.[13] In the next two columns of the table we label the matrix elements of the current given by (2.1) for helicities $\frac{1}{2}$ and $\frac{3}{2}$, when the target is proton or neutron and the incoming photon has helicity 1.

In the next four columns, we show the predictions for $r=0$, $\frac{1}{3}$, $\frac{2}{3}$, and 1. In the last column of Table I, we show the experimental values of Knies, Moorhouse, and Oberlack. We observe that the data favor $r\neq0$. In particular, the fit with $r=\frac{2}{3}$ is better than the fits with the other values of r.

We have normalized M such that the $D^+_{13}(1520)$, $\lambda=\frac{1}{2}$ matrix element is given by $[E(1-r)-3M]/\sqrt{3}$. We require this matrix element to be zero (which is consistent with the experimental data). This implies the relation $M/E=(1-r)/3$, which allows one to write all the matrix elements as functions of r with E as a common factor.

It is worthwhile to remark that although the values of the mixing angles depend on the treatment of the phase space in the strong decays, our results depend on the order of magnitude and not on the specific values of the mixing angles. For $35°<\theta_s<55°$ and $5°<\theta_d<20°$ our results remain practically unchanged.

Note that the restriction $M=\frac{1}{3}E(1-r)$ implies that

TABLE I. Comparison of photon amplitudes for $\underline{70}\,L=1 \to \underline{56}\,L=0$ with experiment.

State	Multiplet [a]	J_z	I_z	A_{th} (GeV^{-1}) $r=0$	$r=\frac{1}{3}$	$r=\frac{2}{3}$	$r=1$	A_{exp} (GeV^{-1})
$S_{11}(1535)$	$\cos\theta_s\,(^2 8_{1/2}) - \sin\theta_s\,(^4 8_{1/2})$	$\frac{1}{2}$	p	+0.816	0.406	0.162	0	0.30 ± 0.10
		$\frac{1}{2}$	n	+0.726	+0.406	+0.217	+0.090	0.27 ± 0.03
$D_{13}(1520)$	$\cos\theta_d\,(^2 8_{3/2}) - \sin\theta_d\,(^4 8_{3/2})$	$\frac{3}{2}$	p	0.91	0.91	0.91	0.91	+0.91 ± 0.06
		$\frac{1}{2}$	p	0	0	0	0	−0.10 ± 0.04
		$\frac{3}{2}$	n	+0.83	+0.770	+0.640	+0.551	+0.64 ± 0.05
		$\frac{1}{2}$	n	+0.335	+0.285	+0.254	+0.234	+0.41 ± 0.03
$S_{31}(1620)$	$^2 10_{1/2}$	$\frac{1}{2}$	p	0.641	0.577	0.538	0.513	0.16 ± 0.07
$D_{33}(1670)$	$^2 10_{3/2}$	$\frac{3}{2}$	p	0.942	0.628	0.44	0.314	0.32 ± 0.04
		$\frac{1}{2}$	p	0.725	0.544	0.44	0.363	0.36 ± 0.04
$S_{11}(1700)$	$\sin\theta_s\,(^2 8_{1/2}) + \cos\theta_s\,(^4 8_{1/2})$	$\frac{1}{2}$	p	0.816	0.407	0.162	0	0.26 ± 0.08
		$\frac{1}{2}$	n	+0.543	+0.407	+0.325	+0.271	0.07 ± 0.16
$D_{13}(1700)$	$\sin\theta_d\,(^2 8_{3/2}) + \cos\theta_d\,(^4 8_{3/2})$	$\frac{3}{2}$	p	0.243	0.244	0.243	0.243	0.14 ± 0.18
		$\frac{1}{2}$	p	0	0	0	0	0.07 ± 0.18
		$\frac{3}{2}$	n	+0.532	+0.251	+0.082	−0.029	−0.11 ± 0.11
		$\frac{1}{2}$	n	+0.149	+0.012	−0.109	−0.174	0.16 ± 0.18
$D_{15}(1670)$	$^4 8_{5/2}$	$\frac{3}{2}$	p	0	0	0	0	0.07 ± 0.04
		$\frac{1}{2}$	p	0	0	0	0	0.06 ± 0.07
		$\frac{3}{2}$	n	+0.243	+0.243	+0.243	+0.243	0.33 ± 0.14
		$\frac{1}{2}$	n	+0.172	+0.171	+0.171	+0.172	0.20 ± 0.03

[a] $\theta_d \simeq 15°$; $\theta_s \simeq 45°$.

for $r=\frac{2}{3}$, M is about three times smaller than the value obtained by FKR[2] (Feynman, Kislinger, and Ravndal) from the relation with the magnetic moment of the nucleon. For transitions to $L=0$ baryons [as the nucleon and $P_{33}(1236)$] we would like to have the magnetic moment unchanged, which suggests the presence in M of components depending on L and being zero for $L=0$. In particular, for transitions to $L=1$, a term with the structure $(\vec{\epsilon}\times\vec{\eta})\cdot\vec{\sigma}$, with $\vec{\epsilon}$ the photon polarization vector and $\vec{\eta}$ the polarization vector of the orbital angular momentum, will give a contribution not only to the C term in (2.1) but also to M.

III. ELECTROPRODUCTION OF MESONS IN THE SECOND RESONANCE REGION

In the previous section, we have analyzed the π photoproduction data and shown that they favor $r=C/E\neq 0$. In particular, a value of $r=\frac{2}{3}$ is in good agreement with the data. In this section, we will take into account the data of electroproduction of η and π mesons in the second resonance region where only the $S_{11}(1535)$ and $D_{13}(1520)$ resonances play a dominant role. As of these two resonances only $S_{11}(1535)$ decay via $\eta+N$, one should expect the relation $\gamma^*N\to\eta N$ to reflect the Q^2 behavior of the vertex $g_{\gamma^*NN^*(1535)}$. Both resonances will contribute to the electroproduction of pions.

An experimental analysis of η electroproduction at a center-of-mass energy of the order of 1530 MeV has been performed by Kummer *et al.*[9] (see our Fig. 1). They also compare the data with the predictions of some relativistic quark models which include only E and M contributions for the transverse part of the electromagnetic current. Even after including the longitudinal contributions predicted by the models, the predictions are inconsistent with experimental data. It is possible to get a good fit by including an *ad hoc* longitudinal contribution; however, the ratio between this longitudinal part and the transverse one turns out to be much larger than the theoretical prediction of the usual quark models and the observed values for this ratio in almost all the electroproduction experiments.[16]

In this section we assume that the longitudinal contribution is small indeed, while for the transverse components we assume the algebraic structure given by (2.1) (including the term transforming as $W=1$, $W_z=0$), as is suggested by the analysis of the previous section.

In Fig. 1 we plot the experimental data in the second resonance region. The cross sections are normalized to 1 in $Q^2=0$. The η data are taken from the work of Kummer *et al.*[9] The pion data are taken from Shuttleworth *et al.*[8] and Bloom and Gilman.[17]

The smooth lines are eye-guide fits to the data.

From the assumed transformation properties of the current, we may write for the cross section the expressions

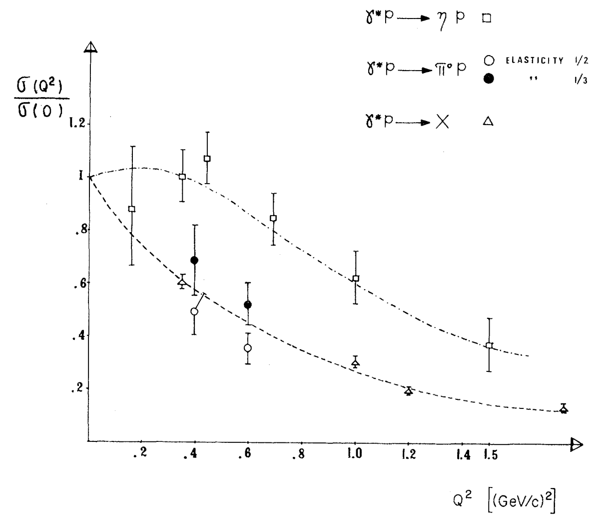

FIG. 1. The cross section for electroproduction of mesons off nucleons, normalized to 1 at $Q^2=0$, in the second resonance region.

$$\left.\frac{\sigma(Q^2)}{\sigma(0)}\right|_{S_{11}(1535)} = \frac{M^2(Q^2)}{M^2(0)}\,\frac{1}{9}\left(1+2\,\frac{x-rz}{1-r}\right)^2, \tag{3.1}$$

$$\left.\frac{\sigma(Q^2)}{\sigma(0)}\right|_{S_{11}(1535)+D_{13}(1520)} = \frac{M^2(Q^2)}{M^2(0)}\;\frac{\left\{\frac{3}{2}\left(\frac{\cos\theta_s}{\cos\theta_d}\right)^2\left(1+2\,\frac{x-rz}{1-r}\right)^2+3\left(1-\frac{x-rz}{1-r}\right)^2+9\left(\frac{x+rz}{1-r}\right)^2\right\}}{\frac{27}{2}\left(\frac{\cos\theta_s}{\cos\theta_d}\right)^2+9\left(\frac{1+r}{1-r}\right)^2}, \tag{3.2}$$

where

$$x=\frac{E(Q^2)M(0)}{E(0)M(Q^2)},\quad z=\frac{C(Q^2)M(0)}{C(0)M(Q^2)}, \tag{3.3}$$

and, as in Sec. II, $r=C(0)/E(0)$.

We may define

$$f=\left.\frac{\sigma(Q^2)}{\sigma(0)}\right|_{S_{11}(1535)+D_{13}(1520)}\Bigg/\left.\frac{\sigma(Q^2)}{\sigma(0)}\right|_{S_{11}(1535)}, \tag{3.4}$$

which depends on r, x, and z but not explicitly on $M(Q^2)$.

For $D_{13}(1520)$ we obtain for the ratio between the two helicity cross sections

$$\frac{\sigma_{1/2}}{\sigma_{3/2}}=\frac{1}{3}\,\frac{\left(1-\frac{x-rz}{1-r}\right)^2}{\left(\frac{x+rz}{1-r}\right)^2}. \tag{3.5}$$

From Fig. 1 we see that $f<1$ for $0<Q^2<1.5$, and in particular for the ratio between the σ_π and σ_η eye-guide fits, $f=0.53$ at $Q^2=0.5$ and $f=0.44$ at $Q^2=1.0$.

In Fig. 2(a) we plot f [Eq. (3.4)] as a function of x, when $r=0$. For any x, $f>0.85$. This is in contradiction with the values for f quoted in the preceding paragraph. Therefore, even if we must be careful because of the background and errors, it seems that the value $r=0$ is not likely. In Fig. 2(b), we plot the ratio between the two helicity cross sections $\sigma_{1/2}/\sigma_{3/2}$ as a function of x. For $x=0.5$ (the value of x which implies the lowest values of f in Fig. 1) we have $\sigma_{1/2}/\sigma_{3/2}=\frac{1}{3}$.

In Figs. 3(a) and 3(b) we plot z and $\sigma_{1/2}/\sigma_{3/2}$ as functions of x, for different values of f and with $r=\frac{1}{3}$. In Figs. 4(a) and 4(b) we have similar plots for a value $r=\frac{2}{3}$. In both cases we have that if $x>0.1$, then $\sigma_{1/2}/\sigma_{3/2}<1$. The value $r=1$ implies that $f=9x^2/(1+2x)^2$, $z=x$, and $\sigma_{1/2}/\sigma_{3/2}=0$.

In Fig. 5 we plot, as a function of Q^2, the f obtained as the ratio of the two eye-guide fits of Fig. 1. We also plot the functional form for x given by the model of FKR,[15] i.e.,

$$x\equiv x_R=\frac{[(M+m)^2+Q^2](M-m)^2}{(M^2-m^2-Q^2)^2+4M^2Q^2}.$$

We also plot $x=x_R/(3-2x_R)$. This value may be obtained by substracting from the M given by FKR a constant term such that for $Q^2=0$, M is reduced

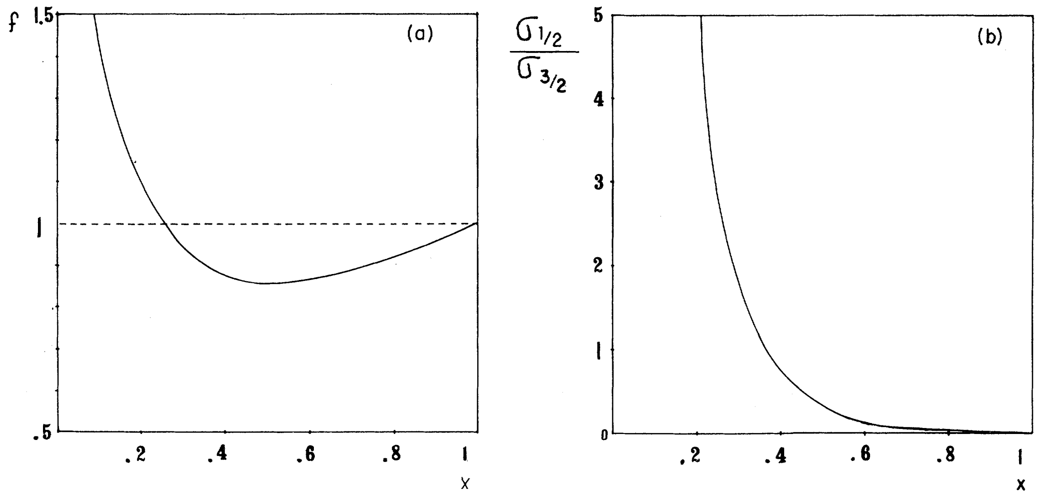

FIG. 2. (a) The ratio

$$f=\frac{\sigma(Q^2)}{\sigma(0)}\bigg|_{S_{11}(1535)+D_{13}(1520)}\bigg/\frac{\sigma(Q^2)}{\sigma(0)}\bigg|_{S_{11}(1535)}$$

as a function of $x=E(Q^2)M(0)/E(0)M(Q^2)$ for $r=0$. (b) The ratio between the two helicity cross sections $\sigma_{1/2}/\sigma_{3/2}$ as a function of x for $r=0$.

by a factor $1-r$, with $r=\frac{2}{3}$.

From the data of Figs. 3(a), 3(b), 4(a), and 4(b) we see that at $Q^2=0.5$ we have $\sigma_{1/2}/\sigma_{3/2}<0.6$. Therefore a small value for $\sigma_{1/2}/\sigma_{3/2}$, as suggested by the analysis of Close and Gilman,[10] is strongly favored.

In Fig. 6 we plot in the x, z plane the points implied by the curves of Fig. 5. For the cases we have considered $x=x_R$, $r=\frac{1}{3}$, $\frac{2}{3}$, and $x=x_R/(3-2x_R)$, $r=\frac{2}{3}$, the points follow almost straight lines in the x, z plane, and cross near the origin.

Therefore, the preceding analysis suggests that in the second resonance region, and in the range $0<Q^2<1.5$, the form factors associated with the $W=0$ and $W=1$, $W_z=0$ terms of the currents have similar Q^2 dependence.

Note that if $r=1$, we have that $f<0.5$ for $x<0.44$, in contradiction with the plots of Fig. 5.

One may wonder about other values of r, in particular $r>1$. We have seen in Fig. 6 that the electroproduction data suggest $x\simeq z$. Equations (3.1)–(3.4) with $x=z$ give the same value of f for r and its inverse $1/r$. On the other hand, the photoproduction fit becomes worse if $r>1$. Consequently,

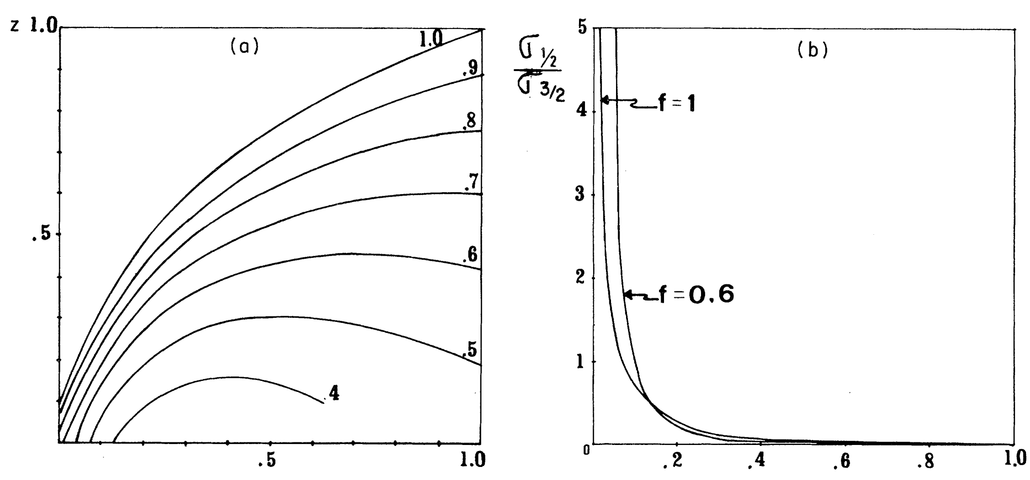

FIG. 3. (a) $z=C(Q^2)M(0)/C(0)M(Q^2)$ as a function of x for $0.4<f<1.0$ and $r=\frac{1}{3}$. (b) $\sigma_{1/2}/\sigma_{3/2}$ as a function of x for $r=\frac{1}{3}$.

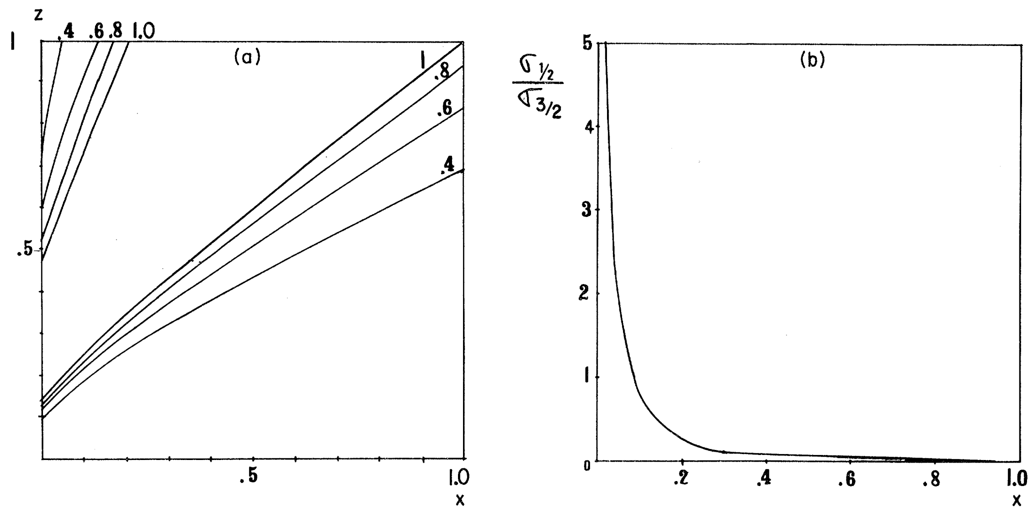

FIG. 4. (a) z vs x for $0.4<f<1.0$ and $r=\frac{2}{3}$. (b) $\sigma_{1/2}/\sigma_{3/2}$ vs x for $r=\frac{2}{3}$. The curves are practically independent of f for $0.4<f<1$.

only for values of $r<1$ is one able to obtain a good fit of both photoproduction and electroproduction data.

IV. FINAL REMARKS

We have shown that when one takes into account both the photoproduction and electroproduction data in the second resonance region, there appears a consistent picture which suggests (a) the presence of a term transforming as $W=1$, $W_z=0$; (b) the form factors associated to the $W=0$ and $W=1$, $W_z=0$ pieces of the electromagnetic current show similar Q^2 dependence; (c) $\sigma_{1/2}/\sigma_{3/2}|_{D_{13}(1520)}$ is small in the range $0<Q^2<1.5$ in agreement with the analysis of Close and Gilman.[10]

It is worthwhile to remark that the $^3P_0$ spurion model of Peterson and Rosner[7] for $N^*\to N+V$, with V a vector meson, suggests the presence of a C term with $r=1$. However, if we take $A_{1/2}(D_{13}(1520))\simeq 0$ this implies $A_{1/2}(1535)\approx 0$. Even if this amplitude is small, it seems to be different from zero. One might think, that at $Q^2=0$, an important vector-meson dominance (VMD) contribution is present, but that is not the whole story (as $r\neq 1$). As Q^2 increases, the VMD contribution would be less and less important and the M piece of the current would dominate. This is consistent with the picture suggested by both inclusive and exclusive electroproduction where the diffractive component is found to disappear rather quickly[18] when Q^2 becomes larger than zero. However, it is worthwhile to remark again that one of the fundamental ingre-

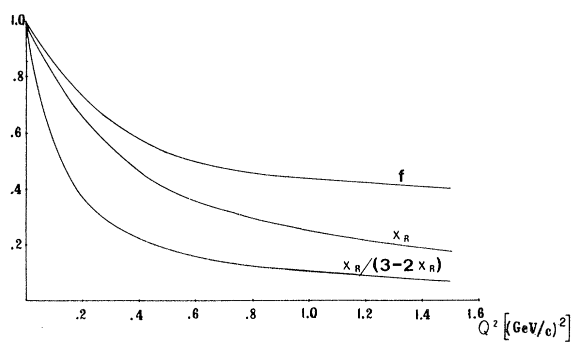

FIG. 5. The f obtained from the eye-guide fit of Fig. 1 is plotted as a function of Q^2. Two functional forms for x (see text) are also plotted.

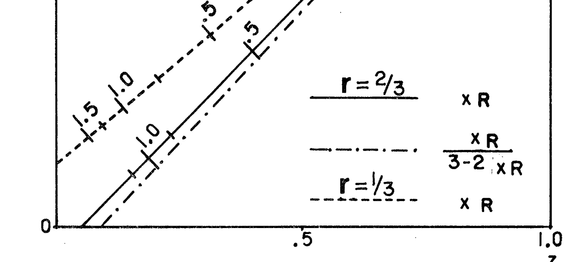

FIG. 6. Points of the x, z plane allowed by the fits of Fig. 5. The numbers on the lines are the Q^2 values for the given (x,z) pairs.

dients of the analysis of this work is the data on the electroproduction of η mesons, where, in addition to the errors, we have the uncertainty due to the background. In our analysis, we have assumed that the background has similar Q^2 dependence as the $S_{11}(1535)$ resonance. Although, as was pointed out by Bloom *et al.*,[19] the inclusive electroproduction data suggest similar Q^2 behavior for both prominent resonances and background, a detailed analysis of the η data must be carried out. However, if $r=\frac{2}{3}$, f may vary between 0.4 and 1.2 without changing our conclusions.

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[1]R. G. Moorhouse and H. Oberlack, Phys. Lett. 43B, 44 (1973); R. G. Moorhouse, H. Oberlack, and A. H. Rosenfeld, Phys. Rev. D 9, 1 (1974); G. Knies, R. G. Moorhouse, and H. Oberlack, *ibid.* 9, 2680 (1974); R. C. E. Devenish *et al.*, Univ. of Lancaster report, 1973 (unpublished).

[2]R. P. Feynman, M. Kislinger, and F. Ravndal, Phys. Rev. D 3, 2706 (1971); R. G. Moorhouse *et al.*, Ref. 1.

[3]H. J. Melosh, Phys. Rev. D 9, 1095 (1974).

[4]A. J. G. Hey and J. Weyers, Phys. Lett. 48B, 69 (1974); A. Love and D. V. Nanopoulos, *ibid.* 45B, 507 (1973).

[5]F. J. Gilman and I. Karliner, Phys. Lett. 46B, 426 (1973); Phys. Rev. D 10, 2194 (1974).

[6]H. J. Lipkin, Phys. Rev. D 9, 1579 (1974).

[7]W. P. Peterson and J. L. Rosner, Phys. Rev. D 7, 747 (1973).

[8]W. J. Shuttleworth *et al.*, Nucl. Phys. B45, 428 (1972); C. Driver *et al.*, *ibid.* B33, 84 (1971); R. Meaburn *et al.*, Daresbury Report No. DNPL/P163, 1973 (unpublished).

[9]P. S. Kummer *et al.*, Phys. Rev. Lett. 30, 873 (1973).

[10]F. E. Close and F. J. Gilman, Phys. Lett. 38B, 541 (1972).

[11]R. Meaburn *et al.*, Ref. 8.

[12]R. L. Walker, Phys. Rev. 182, 1729 (1969).

[13]D. Faiman and P. E. Plane, Nucl. Phys. B50, 379 (1972).

[14]D. Faiman and A. Hendry, Phys. Rev. 173, 1720 (1968); 180, 1572 (1969); L. A. Copley, G. Karl, and E. Obryk, Phys. Lett. 29B, 117 (1969); Nucl. Phys. B13, 303 (1969).

[15]R. P. Feynman, M. Kislinger, and F. Ravndal, Phys. Rev. D 3, 2706 (1971).

[16]J. C. Alder *et al.*, Nucl. Phys. B48, 487 (1972).

[17]E. D. Bloom and F. J. Gilman, Phys. Rev. D 4, 2901 (1971).

[18]G. Cocho *et al.*, Nucl. Phys. B78, 269 (1974).

[19]E. D. Bloom *et al.*, MIT-SLAC Report No. SLAC-PUB-796, 1970 (unpublished), presented at the Fifteenth International Conference on High Energy Physics, Kiev, U.S.S.R., 1970.