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ELECTROMAGNETIC COUPLINGS OF HIGHER-MASS N* RESONANCES†

G. Knies‡
Lawrence Berkeley Laboratory, University of California

R. G. Moorhouse
Department of Natural Philosophy, Glasgow University

H. Oberlack**
Lawrence Berkeley Laboratory, University of California

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ABSTRACT

The previous partial-wave analysis of $\gamma N \to N\pi$ by Moorhouse, Oberlack, and Rosenfeld has been extended to 2000 MeV.

We have previously reported[1,2] partial-wave analyses of pion photoproduction data up to center-of-mass energy 1780 MeV which yielded photoproduction amplitudes and electromagnetic couplings of the N^* resonances[3] in the 1st, 2nd, and 3rd N^* resonance regions. We have now extended our energy region and analyzed data up to center-of-mass energy 1995 MeV, obtaining electromagnetic couplings, in the 4th resonance region, of P_{13} (1800), P_{31} (1860), P_{33} (2000), F_{35}(1860), F_{37} (1930). Previously, in analyzing to 1780 MeV we had only been able to obtain, in the 4th resonance region, indications on the couplings of the prominent F_{37}(1930) through the low-energy tail of its real part; similarly we now obtain some preliminary and tentative indications on the couplings of the relatively prominent $H_{3,11}$(2400).

Our method is the same as before,[1,2] with some trivial modifications: we have extended the region where we fit data up to 1995 MeV center-of-mass energy, and we have increased the upper limit of the fixed -t dispersion integration to 2440 MeV center-of-mass energy; we have incorporated additional high-energy resonances in the region between 1995 and 2500 MeV and we have refined the integration treatment of these resonances outside our data region.[4] To our data set we have added 391 data points between 1780 and 1995 MeV—essentially all data available to us in that energy region. We have also added about 100 recent data points of the reaction $\gamma p \to \pi^0 p$ with a polarized target.[5] Simply for reasons of computer memory space we have had to take out about 600 lower-energy data points, so that our total data set now comprises 3806 data points on $\gamma p \to \pi^+ n$, $\gamma p \to \pi^0 p$, and $\gamma n \to \pi^- p$ from threshold to 1995 MeV center-of-mass energy. As before, our data set contains inconsistencies which we are unable to resolve.

Our four best fits have a χ^2/data-point equal to 4.66, 4.56, 3.88 and 3.48; in the latter case we varied 98 electromagnetic couplings[6] of resonances and background and in the other cases somewhat fewer. A more detailed beakdown of the χ^2 is given in Table I.

With our increased data range we now have numbers for the electromagnetic couplings of all those resonances that have been assigned to the $\{56\}_2$ $L = 2^+$ multiplet of the quark model, albeit that the couplings of the smaller angular momentum resonances have very large errors. We show these couplings from our present solutions, labeled "KMO" in Table II, where we also display the electromagnetic couplings of the resonances belonging to $\{70\}_1$ $L = 1^-$ multiplet; also shown for comparison are our previous solutions.[1,2] The extension to higher energy of our fitted data, and of our knowledge of the amplitudes, is also very relevant to our fits in the lower-energy region of the $\{70\}_1$ $L = 1^-$ multiplet. This is because the real-part tails of the high-energy features (such as resonances) are important in the low-energy region: in our method these real-part tails enter through the fixed -t dispersion relation. Consequently we would expect a better determination of $\{70\}_1$ $L = 1^-$ couplings with our present program than previously.[1,2]

The couplings of the most prominent resonance of the $\{70\}_1$ $L = 1^-$, the $D_{13}(1512)$, are nearly the same as for our previous fits;[1,2] in particular, the helicity 3/2 couplings are not pure isovector (if pure, they would be equal and opposite) but have a small though non-negligible isoscalar component. Without further discussing the detailed comparison of the couplings of the $\{70\}_1$ $L = 1^-$ with our previous results[1,2] we may say that the overall picture is one of agreement, with no marked disagreements.

The comparison of the electromagnetic couplings with the unmixed quark model (evaluated as previously[1,2] in the 4-dimensional oscillator version of Feynman, Kislinger, and Ravndal[7]) is also given in Table II. For the $\{70\}_1$ $L = 1^-$ the striking agreements in sign have been commented on previously.[1,2] If we were to explain some discrepancies in magnitude by mixing, we would discern large mixing between the two S_{11} states and small mixing between the two D_{13} states. The S_{31} (1630) and the D_{33} (1685), which have no obvious mixing partners, have become satisfactorily close to the quark model predicted values. The $D_{15}(1660)$ has also no evident mixing partners, and the smallness of the positive charge couplings tends to verify the selection rule[8] on the vanishing of couplings of positive charge resonances belonging to [8,4] submultiplets of {70} multiplets.

Turning now to the $\{56\}_2$ $L = 2^+$ multiplet, we see that the F_{15} (1680) couplings like the D_{13} (1512) are satisfactory in sign and relative magnitude but, also like the $D_{13}(1512)$ and the $P_{33}(1232)$, those couplings that are predicted to be large are even larger than the prediction. There is consistency with the selection rule[9] on the vanishing of the helicity 3/2 couplings of charge zero resonances of [8,2] submultiplets of {56} multiplets.

For the first time[10] we publish a close determination of the couplings of the $F_{37}(1930)$ and we see a good agreement with the quark model. On the other hand, there is a disagreement for the F_{35} (1860). The quark model suggests a possible mixing partner for the $F_{35}(1860)$ (though <u>not</u> for the F_{37}) in the F_{35} member of the $\{70\}_2$ $L = 2^+$ multiplet. The existence of this multiplet is not only an <u>a priori</u> theoretical suggestion of the symmetric quark model, but is also additionally suggested, on the basis of that model, by the probable existence of an $F_{17}(2000)$.[11] And of course,

if such an F_{35} resonance exists, say at a mass of around 2000 MeV,[11] then its presence, unallowed for in our analysis, could markedly affect the value we obtain for the couplings of the $F_{35}(1860)$, since those couplings would be doing double duty. Such problems could arise for all members of the $\{56\}_2$ $L = 2^+$ except the F_{37}.

The selection rule[12] on the vanishing of the E2 (E_{1+}) transition on the $P_{33}(1232)$ can be extended to the E4 (E_{3+}) transition of the F_{37} (1930) and the E_6 (E_{5+}) transition of the $H_{3,11}(2400)$. We display the comparison in Table III, and we see good agreement for P_{33} (1232), as is well-known, and the agreement is almost as good for the $F_{37}(1930)$. The comparison for the $H_{3,11}$ is highly tentative since that resonance is well outside our data region and is only observed through the contribution to the fixed -t dispersion relation (that is, essentially the low-energy tail of the real part of the resonance). In our previous work[1,2] we gave similar tentative numbers for the F_{37} which, though of the correct sign, were of larger magnitude than our present numbers (similarly our numbers for the $H_{3,11}$ have now the quark model sign, but are much too large in magnitude); so we present these $H_{3,11}$ ratios more in the spirit of a challenge to experiment and to partial-wave analysis.

In a recent paper, Devenish, Rankin, and Lyth[13] also used a method of fixed -t dispersion relations to fit 2913 data points over an energy range through the third resonance region, comparable with our previous fits.[1,2] If we compare our present values for resonances within their range, we see a fair agreement, though the errors they quote are generally much bigger than the spread of our present four solutions.

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FOOTNOTES AND REFERENCES

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‡On leave of absence from DESY, Hamburg, Germany.

**Present address: Max-Planck-Institut für Physik and Astrophysik, Munich, Germany.

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3. We include both $N_{1/2}$ resonances and $N_{3/2}$ (Δ) resonances under the general term N^* resonances.
4. Previously the fixed -t dispersion integrand whose energy was above the data region was approximated by a δ-function representation of the imaginary parts of the high-energy resonances. We now take an exact treatment of these resonances in the integrand.
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10. The only other fit over the energy range of the f_{37} that we know of is from a private communication of a preliminary fit by W. J. Metcalf and R. L. Walker (Jan. 1973); they give -59 and -89 for $A_{1/2}$ and $A_{3/2}$ respectively.
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TABLE I. The χ^2/(data point). Overall χ^2/(data-point) for our different solutions are given in the last column. In the first 12 columns we show the χ^2/(data point) separately for each type of reaction and observable quantity: σ denotes differential cross-section, P denotes polarization of the recoil nucleon, Σ the asymmetry produced by linearly polarized photons and T the asymmetry produced by polarization of the nucleon target.

Reaction	π^+n				π^0p				π^-p				All
Quantity	σ	P	Σ	T	σ	P	Σ	T	σ	P	Σ	T	All Data
Number of data points (d. p.)	1614	12	91	24	1209	139	38	98	526	1	54	0	3806
χ^2/d. p. Solution 1	3.34	5.51	2.62	1.89	6.91	3.95	3.09	1.98	4.89	0.64	3.64	-	4.66
Solution 2	4.66	5.45	3.18	2.28	5.01	3.57	3.03	3.27	4.32	0.00	3.25	-	4.56
Solution 3	3.46	5.05	2.64	3.46	5.06	3.58	3.25	1.44	3.48	2.54	3.25	-	3.88
Solution 4	3.40	6.07	2.18	4.22	4.13	3.25	4.03	1.42	2.85	0.02	2.76	-	3.48

TABLE II. Resonance couplings $A(\gamma NN^*)$. The result from the present partial-wave analysis (labeled KMO) is an average over four fits, and the error is the spread over the four fits. For comparison we show the results from previous fits (labeled MOR[2] and MO[1]), and also the quark-model result for the usual assignment of the resonance to an $\{SU6\}_n\ L^P;\ [SU3, 2S+1]\ J^P$ multiplet, where the subscript n denotes harmonic oscillator excitation number. The superscripts on the resonance couplings A refer to the isospin; for isospin I = 3/2 N^* resonances, there is only one γN coupling, denoted by A^{V3}. For I = 1/2 N^* resonances, we use the two independent γp and γn couplings, denoted by A^P and A^N. The subscripts 1/2 and 3/2 denote the total γ-nucleon helicity. Units of the couplings are $GeV^{-1/2} \cdot 10^{-3}$. An asterisk on a quark model prediction denotes that the result does not involve a difference of two terms. The resonance masses shown are averages over the 4 KMO fits (they are varied within a small range of about 5 MeV from our πN elastic scattering input values).

TABLE II.

$\{SU6\}$ L	N*(mass)	I = 3/2:	$A^{V3}_{1/2}$	$A^{V3}_{3/2}$		
	$[SU3, 2S_q+1]\,J^P$	I = 1/2:	$A^{P}_{1/2}$	$A^{P}_{3/2}$	$A^{N}_{1/2}$	$A^{N}_{3/2}$
$\{56\}_0$ L = 0^+	$P_{33}(1232)$	KMO	-138±4	-253±2		
		MOR	-142 ± 1	-261 ± 1		
		MO	-142 ± 6	-259 ± 16		
	[10,4] $3/2^+$	Quarks	-108*	-187*		
$\{70\}_1$ L = 1^-	$S_{11}(1535)$	KMO	56±20		-52±5	
		MOR	36 ± 2		-27 ± 9	
		MO	53 ± 20		-48 ± 21	
	[8,2] $1/2^-$	Quarks	156		-108	
	$D_{13}(1508)$	KMO	-19±8	169±12	-77±5	-120±10
		MOR	0 ±6	174± 6	-88 ± 7	-119 ± 25
		MO	-26±15	194± 31	-85 ± 14	-124 ± 13
	[8,2] $3/2^-$	Quarks	-34	109*	-31	-109*
	$S_{31}(1630)$	KMO	33±15			
		MOR	78 ± 6			
		MO	90 ± 76			
	[10,2] $1/2^-$	Quarks	47			
	$D_{33}(1685)$	KMO	78±9	70±9		
		MOR	41 ± 28	21 ± 20		
		MO	68 ± 42	22 ± 52		
	[10,2] $3/2^-$	Quarks	88	84*		
	$S_{11}(1705)$	KMO	58±18		-15±35	
		MOR	54 ± 5		-82 ± 19	
		MO	66 ± 42		-72 ± 66	
	[8,4] $1/2^-$	Quarks	0		30	
	$D_{13}(1690)$	KMO	-15±40	30±40(1)	-36±40	24±24
		MOR	23 ± ?	35 ± ?	-15± ?	28 ± ?
		MO	3± ?	20 ± ?	-28± ?	27 ± ?
	[8,4] $3/2^-$	Quarks	0*	0*	-10*	-40*
	$D_{15}(1660)$	KMO	13±14	14±8	-43±6	-71±30
		MOR	19 ± 7	16± 2	-17± 4	-49± 4
		MO	11 ± 12	21 ± 20	10 ± 40	-35 ± 14
	[8,4] $5/2^-$	Quarks	0*	0*	-38*	-53*

(1) Solutions 1, 3, and 4 yield 57±11, while solution 2 gives -9.

TABLE II (Cont.)

$\{SU6\}$ L	N*(mass)	I = 3/2:	$A^{V3}_{1/2}$	$A^{V3}_{3/2}$		
	$[SU3,2S_q+1]\,J^P$	I = 1/2	$A^{P}_{1/2}$	$A^{P}_{3/2}$	$A^{N}_{1/2}$	$A^{N}_{3/2}$
$\{56\}_2$ L = 2^+	$P_{13}(1770)$	KMO	−4±32	−6±30	14±14	−8±25
		MOR				
		MO				
	$[8,2]\,3/2^+$	Quarks	−11	30	30	0*
	$F_{15}(1680)$	KMO	−16±14	97±7	23±5	1±18
		MOR	−14±3	147±6	23 ±3	−41 ±4
		MO	−8±4	100±12	17 ±14	−5 ±18
	$[8,2]\,5/2^+$	Quarks	−10	60*	30*	0*
	$P_{31}(1860)$	KMO	10 ±12			
		MOR				
		MO				
	$[10,4]\,1/2^+$	Quarks	−30			
	$P_{33}(2000)$	KMO	−32 ± 20	13 ± 8		
		MOR				
		MO				
	$[10,4]\,3/2^+$	Quarks	−30	50		
	$F_{35}(1860)$	KMO	42 ± 16	−22 ± 20		
		MOR	?[b]	?[b]		
		MO	−60 ±?	−100±?		
	$[10,4]\,5/2^+$	Quarks	−20	−90		
	$F_{37}(1920)$	KMO	−70 ± 12	−78 ±10		
		MOR	−80[c]	−180[c]		
		MO	−133 ±46	−100 ±41		
	$[10,4]\,7/2^+$	Quarks	−50*	−70*		
$\{56\}_2$ L = 0^+	$P_{11}(1470)$	KMO	−66 ± 13		0 ± 13	
		MOR	−87 ± 2		33 ±13	
		MO	−55 ±28		2 ±25	
	$[8,2]\,1/2^+$	Quarks	27*		−18*	
	$P_{33}(1718)$	KMO	3 ± 15	−34 ± 22		
		MOR				
		MO				
	$[10,4]\,3/2^+$	Quarks	34*	20*		
$\{70\}_2$ L=0^+	$P_{11}(1800)$	KMO	22 ± 15		27 ± 15	
		MOR	16 ±25		57 ±22	
		MO	26 ±28		27 ±22	
	$[8,2]\,1/2^+$	Quarks	−40*		10*	

TABLE III. The ratio $R = A_{3/2}/A_{1/2}$, from the Becchi-Morpurgo selection rule[12] $E_{\ell+} = 0$, is compared with R from our four partial-wave solutions.

Resonance	R(Selection Rule)	R from Solutions:-			
		I	II	III	IV
P_{33} (1232)	+1.73	+1.86	+1.83	+1.87	+1.78
F_{37} (1930)	+1.29	+1.23	+1.14	+1.10	+1.00
$H_{3,11}$ (2400)[a]	+1.18	+0.562	+0.75	+0.79	+1.52

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