QUARK MODEL PREDICTIONS FOR ELECTROPRODUCTION OF $\frac{3}{2}^+$ ISOBARS

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The excited quark model and the additive quark model constraints on the angular decay distributions of B^* produced by virtual photons in the process $\gamma_{\text{virt}} B \to PB^*$ are obtained. Some of the quark model relations are compared with the experimental data to check the quark model, others are used to obtain for Δ^{++} the ratio of the cross-sections for production by longitudinal and transverse photons on protons $R = \sigma_L/\sigma_T$. The agreement of the quark model predictions with experiment is found to be good.

1. *Introduction*

The quark model constraints on angular decay distributions have been successfully checked experimentally for many quasi two-body hadron-hadron [1] and also for photoproduction processes [2–4]. Thus it is worthwhile to see whether they are also confirmed by experimental tests in electroproduction processes. Quite recently electroproduction data have become available for angular decay distributions of Δ^{++} from the DESY streamer chamber group [5–6].

In this paper we give the quark model relations on the angular decay distributions for the electroproduction of a single resonance B^*

$$eB \to ePB^*, \tag{1}$$

where e, P, B and B^* respectively stand for an electron, a pseudoscalar meson, a baryon from the $1/2^+$ octet and an isobar from the $3/2^+$ decuplet. Assuming that the process (1) goes through one photon exchange we consider the process

$$\gamma_{\text{virt}} B \to PB^*, \tag{2}$$

in the framework of the quark model. The constraints on angular decay distributions which we present in this paper follow from the assumptions of models 1 and 2, which can be characterized as follows:

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1) In model 1 the process is viewed to proceed according to the graph of Fig. 1. Quark structure is thus not assumed for the meson and for the virtual photon, but is assumed for the baryon only. Model 1 is a simple generalization of the quark model for photoproduction considered in Refs [7–9]. In Ref. [10] such a model has also been used to obtain relations between cross sections for electroproduction of pseudoscalar mesons. We call this model the excited quark model.

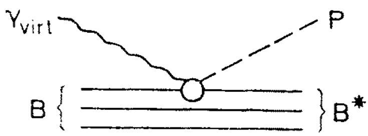

Fig. 1. The excited quark model

2) Model 2 is a trivial generalization of the additive quark model of photoproduction [11]. This model includes vector meson dominance for the initial virtual photon in a very weak sense together with the additivity assumption for hadron-hadron scattering. Thus, the amplitudes for high-energy electroproduction are calculated as sums of quark--quark scattering amplitudes (see Fig. 2). We call this model, for shortness, the additive quark model. We need vector meson dominance in a very weak sense, as the predictions following from the additive quark model on the angular decay distributions do not change

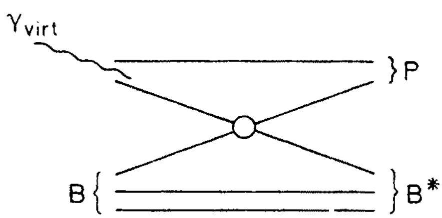

Fig. 2. The additive quark model

whether or not we include higher mass vector mesons besides ϱ^0, ω, φ, as we need not know the coupling constants of the different vector mesons to the virtual photon. We only need the quark structure of the isoscalar and isovector part of the object through which the photon interacts with the baryon target.

As the assumptions of model 2 are more specific than those of model 1, all the results obtained from model 1 can also be derived from model 2.

The predictions of the quark model on the angular decay distributions of single resonance have been divided [12] into three classes (a), (a′) and (c), depending on how much is assumed about the quark-quark interaction. We recall that the relations of classes (a) and (a′) are derived from the additivity assumption and parity conservation only. Relations of class (a′) only exist for electro-(photo) production of vector mesons and have no covariance properties in contrast to the regular class (a) relations. The relations of class (c) need additional assumptions about the quark-quark amplitudes. From the excited quark model we will obtain relations of class (a) and from the additive quark model we will obtain relations of class (c) for the process (2).

We will give the quark model constraints on the angular decay distributions of B^* in terms of statistical tensors in the transversity frame, in which the quantization axis is perpendicular to the reaction plane [13]. To write them we will use the formalism proposed in Refs [14–15], according to which the spin density matrix of B^* can be decomposed into nine (independently measureable) matrices ϱ^i, $i = 0, \ldots, 8$. The ϱ^0, ϱ^1, ϱ^2 and ϱ^3 matrices have the same definitions as in photoproduction, so they are connected with transverse photons. ϱ^4 describes the contribution from longitudinal photons. ϱ^5 and ϱ^6 measure the transverse-longitudinal photon interference, and ϱ^7 and ϱ^8 are connected with circularly polarized (virtual) photons (*i.e.* longitudinally polarized leptons). The definitions of the statistical tensors to be used subsequently ${}^{(0)}T$, ${}^{(1)}T$, ${}^{(2)}T$, and ${}^{(3)}T$ can be found in Ref. [3], while the definitions and the properties of the other statistical tensors are the following ones: ${}^{(4)}T$ is identical to ${}^{(0)}T$, ${}^{(5)}T$ and ${}^{(8)}T$ are identical to ${}^{(1)}T$, and ${}^{(6)}T$ and ${}^{(7)}T$ are identical to ${}^{(2)}T$. The prescription for how to obtain the statistical tensors from the experimental data are given in the Appendix.

Some of the relations, which we shall obtain for angular decay distributions of resonances produced by virtual photons, will be compared with recent DESY experimental data [5–6] to check the quark model of electroproduction; other relations we shall use to calculate (for Δ^{++}) the ratio $R = \sigma_L/\sigma_T$ of the cross-sections for production by longitudinal and transverse photons on protons.

The predictions for the density matrices ϱ^0, ϱ^1, ϱ^2 and ϱ^3 ought to be satisfied also in photoproduction ($Q^2 = 0$). We know [2–4] that the comparison with the experimental data has shown a good agreement for photoproduction processes.

2. *Quark model predictions for the process* $\gamma_{\text{virt}} B \to PB^*$

Relations of class (a)

It is easy to check that if the scattering proceeds *via* direct absorption of a virtual photon and emission of a meson by one single quark (excited quark model of Fig. 1), it implies the following relations on the angular decay distributions of the electroproduced isobar:

$$ {}^{(0)}T_2^2 = -{}^{(1)}T_2^2, \tag{3} $$

$$ {}^{(0)}T_0^2 = -\tfrac{1}{8} - \tfrac{3}{4}\,{}^{(1)}T_0^0, \tag{4} $$

$$ {}^{(1)}T_0^2 = -\tfrac{3}{8} - \tfrac{1}{4}\,{}^{(1)}T_0^0, \tag{5} $$

$$ {}^{(4)}T_0^2 = \tfrac{1}{4}, \tag{6} $$

$$ {}^{(5)}T_0^2 = \tfrac{1}{2}\,{}^{(5)}T_0^0, \tag{7} $$

$$ {}^{(8)}T_0^2 = \tfrac{1}{2}\,{}^{(8)}T_0^0. \tag{8} $$

All relations (3)–(8) are expressed in terms of statistical tensor in the transversity frame.

At present only relation (7) can be compared with the experimental data for electroproduced Δ^{++}, because only the data for ϱ^5 are available. Thus, instead of checking the quark model relations we use relation (4) together with (6) and next relation (5) to calculate the value of

$$R = \frac{\sigma_L(ep \to e\pi^- \Delta^{++})}{\sigma_T(ep \to e\pi^- \Delta^{++})}, \tag{9}$$

which is the ratio of the cross-sections for production of Δ^{++} by longitudinal and transverse photons on protons. The quark model relations for εR (ε is the polarization parameter of the virtual photon) are then the following ones:

$$\varepsilon R = \frac{1+6^{(1)}\overline{T}_0^0+8^{(04)}T_0^2}{2-6^{(1)}\overline{T}_0^0-8^{(04)}T_0^2}, \tag{10}$$

$$\varepsilon R = \frac{-3-2^{(1)}\overline{T}_0^0-8^{(1)}\overline{T}_0^2}{2^{(1)}\overline{T}_0^0+8^{(1)}\overline{T}_0^2}, \tag{11}$$

where

$$^{(1)}\overline{T}_M^J = \frac{1}{1+\varepsilon R}\,^{(1)}T_M^J, \quad \text{and} \quad ^{(04)}T_M^J = \frac{1}{1+\varepsilon R}(^{(0)}T_M^J+\varepsilon R^{(4)}T_M^J).$$

Relations of class (c)

To obtain more predictions than the relations (3)–(8), we must use the additive quark model (Fig. 2) and the assumptions about quark-quark scattering amplitudes necessary to obtain class (c) relations. Thus from the additive quark model we have the following relations:

$$\begin{aligned}\operatorname{Im}{}^{(0)}T_2^2 &= \operatorname{Im}{}^{(1)}T_2^2 = \operatorname{Im}{}^{(2)}T_1^2 = \operatorname{Im}{}^{(3)}T_1^2 = \operatorname{Im}{}^{(4)}T_2^2 = \\ &= \operatorname{Re}{}^{(5)}T_2^2 = \operatorname{Re}{}^{(6)}T_1^2 = \operatorname{Re}{}^{(7)}T_1^2 = \operatorname{Re}{}^{(8)}T_2^2 = 0,\end{aligned} \tag{12}$$

$$\operatorname{Re}{}^{(0)}T_2^2 = -\frac{\sqrt{6}}{12}-\frac{1}{\sqrt{6}}\,^{(0)}T_0^2, \tag{13}$$

$$\operatorname{Re}{}^{(1)}T_2^2 = -\frac{1}{\sqrt{6}}\,^{(1)}T_0^0-\frac{1}{\sqrt{6}}\,^{(1)}T_0^2, \tag{14}$$

$$\operatorname{Re}{}^{(4)}T_2^2 = \frac{\sqrt{6}}{8}, \tag{15}$$

$$^{(5)}T_0^0 = {}^{(5)}T_0^2 = 0, \tag{16}$$

$$^{(8)}T_0^0 = {}^{(8)}T_0^2 = 0. \tag{17}$$

All relations (12)–(17) are expressed in terms of statistical tensors in the transversity frame. Relations (12) coincide with the definition of the Donohue-Høgaasen frame [16], [13] for the electroproduced isobar, and imply that all relations (13)–(15) can be valid only in the Donohue-Hogaasen frame. Relations (16) and (17), however, hold with respect to any frame, as they are invariant with respect to a rotation of the B^* spin reference frame around the normal to the production plane.

We will compare relations (14) and (16) with the DESY experimental data for Δ^{++}. Again, similarly to the case of class (a) relations, from Equations (13) and (15) we obtain for εR the following prediction:

$$\varepsilon R = \frac{1+2\sqrt{6}\,\mathrm{Re}\,{}^{(04)}_{\mathrm{DH}}T^2_2+2\,{}^{(04)}T^2_0}{2-2\sqrt{6}\,\mathrm{Re}\,{}^{(04)}_{\mathrm{DH}}T^2_2-2\,{}^{(04)}T^2_0}. \tag{18}$$

Thus three relations, namely (10), (11) and (18), give a prediction of the same quantity εR and allow us to check the consistency of the quark model. We would like to point out that in the case of photoproduction (with $R = 0$) ${}^{(04)}T^J_M$ becomes ${}^{(0)}T^J_M$, while ${}^{(1)}\overline{T}^J_M$ becomes ${}^{(1)}T^J_M$ and relation (10) reproduces relation (4), relation (11) relation (5), and relation (18) relation (13).

3. *Comparison with experiment of the quark model relations for the process* $\gamma_{\mathrm{virt}}\, \mathrm{p} \to \pi^-\Delta^{++}$

At present experimental data are available only for the following quantities [5]:

$$r^{04}_{ik} = \frac{\varrho^0_{ik}+\varepsilon R\,\varrho^4_{ik}}{1+\varepsilon R}, \tag{19}$$

$$r^{\beta}_{ik} = \frac{\varrho^{\beta}_{ik}}{1+\varepsilon R}, \qquad \beta = 1, 2, \tag{20}$$

$$r^{\gamma}_{ik} = \sqrt{R}\,\frac{\varrho^{\gamma}_{ik}}{1+\varepsilon R}, \qquad \gamma = 5, 6. \tag{21}$$

So immediately we can check the excited quark model relation (7) and next the additive quark model relations (14) and (16) in terms of r^5 and r^1. Relations (7) and (16) are equally simple if we write them instead of in terms of statistical tensors in the transversity frame in terms of density matrix elements with the spin quantization axis of B^* in the scattering plane. Rewriting relation (7) in terms of density matrix elements with the spin quantization axis in the scattering plane, we see that

$$r^5_{33} = -\sqrt{3}\,\mathrm{Re}\,r^5_{3-1}, \tag{22}$$

and the next relation, (16), is equivalent to

$$r^5_{11} = -r^5_{33}. \tag{23}$$

TABLE I

Experimental check of the quark model relations (22), (23), and (14) for $\gamma_{\text{virt}} p \to \pi^- \Delta^{++}$ at $0.3 < Q^2 < 1.5$ GeV^2 and $1.3 < W < 2.0$ GeV

Excited quark model relation	LHS in the Gottfried-Jackson system [6] at $\langle Q^2 \rangle = 0.535$ GeV^2 and $\langle W \rangle = 1.633$ GeV	RHS
$r^5_{33} = -\sqrt{3}\,\text{Re}\, r^5_{3-1}$	-0.022 ± 0.015	-0.059 ± 0.023
Additive quark model relation	LHS in the Gottfried-Jackson system [6] at $\langle Q^2 \rangle = 0.535$ GeV^2 and $\langle W \rangle = 1.633$ GeV	RHS
$r^5_{11} = -r^5_{33}$	-0.008 ± 0.014	0.022 ± 0.015
Additive quark model relation	LHS in the transverse Donohue-Høgaasen system [6] at $\langle Q^2 \rangle = 0.535$ GeV^2 and $\langle W \rangle = 1.633$ GeV	RHS
$\text{Re}\, {}^{(1)}\bar{T}^2_2 = -\frac{1}{\sqrt{6}}\,({}^{(1)}\bar{T}^0_0 + {}^{(1)}\bar{T}^2_0)$	0.075 ± 0.036	0.021 ± 0.023

In Table I one can see how relations (22), (23) and (14) are satisfied by the preliminary data for electro-produced Δ^{++} [6] for all events averaged over Q^2 and W. The boundaries of Q^2 are 0.3 and 1.5 GeV^2, and for W are 1.3 GeV and 2.0 GeV. The agreement is good within rather large experimental errors.

TABLE II

Experimental check of the quark model relations (22), (23) and (14) for $\gamma_{\text{virt}} p \to \pi^- \Delta^{++}$ at $0.3 < Q^2 < 1.5$ GeV^2 and $1.3 < W < 1.5$ GeV

Excited quark model relation	LHS in the Gottfried-Jackson system [6] at $\langle Q^2 \rangle = 0.526$ GeV^2 and $\langle W \rangle = 1.432$ GeV	RHS
$r^5_{33} = -\sqrt{3}\,\text{Re}\, r^5_{3-1}$	-0.079 ± 0.032	-0.107 ± 0.048
Additive quark model relation	LHS in the Gottfried-Jackson system [6] at $\langle Q^2 \rangle = 0.526$ GeV^2 and $\langle W \rangle = 1.432$ GeV	RHS
$r^5_{11} = -r^5_{33}$	0.046 ± 0.029	0.079 ± 0.032
Additive quark model relation	LHS in transverse Donohue-Høgaasen system [6] at $\langle Q^2 \rangle = 0.526$ GeV^2 and $\langle W \rangle = 1.432$ GeV	RHS
$\text{Re}\, {}^{(1)}\bar{T}^2_2 = -\frac{1}{\sqrt{6}}\,({}^{(1)}\bar{T}^0_0 + {}^{(1)}\bar{T}^2_0)$	0.114 ± 0.074	0.065 ± 0.048

In Table II we also compare relations (22), (23) and (14) with the experimental data, but we chose only that part of the data which have the lowest value of W, because background contamination is smallest for this part [5]. We see that the quark model relations are then really well confirmed by the data.

TABLE III

Predictions for $R = \sigma_L(e\,p \to e\,\pi^-\Delta^{++})/\sigma_T(e\,p \to e\,\pi^-\Delta^{++})$, at different values of Q^2 and W from quark model relations (10) and (18)

Quark model predictions for

$R = \sigma_L\,(e\,p \to e\,\pi^-\Delta^{++})/\sigma_T\,(e\,p \to e\,\pi^-\Delta^{++})$

$\langle Q^2 \rangle$ (GeV^2)	$\langle W \rangle$ (GeV)	Relation (10)	Relation (18)
0.396 $0.3 < Q^2 < 0.5$	1.433 $1.3 < W < 1.5$	0.457 ± 0.583	0.037 ± 0.158
0.600 $0.5 < Q^2 < 0.8$	1.427 $1.3 < W < 1.5$	0.485 ± 0.431	0.064 ± 0.198
1.049 $0.8 < Q^2 < 1.5$	1.453 $1.3 < W < 1.5$	0.30 ± 1.05	0.042 ± 0.398
0.526 $0.3 < Q^2 < 1.5$	1.432 $1.3 < W < 1.5$	0.274 ± 0.344	0.080 ± 0.125
0.535 $0.3 < Q^2 < 1.5$	1.633 $1.3 < W < 2.0$	0.365 ± 0.195	0.256 ± 0.078

In Table III we give quark model predictions for $R(\Delta^{++})$ for different ranges of Q^2 and for the lowest value of W and next for all events averaged over Q^2 and W. We do not quote the value obtained for R from relation (11), as the errors are extremely large. The values for R obtained from relations (10) and (18) show the consistency of the quark model.

4. *Conclusions*

We have obtained the excited quark model and the additive quark model constraints on the angular decay distributions of B^* produced by virtual photons in the process $\gamma_{\text{virt}}B \to PB^*$, and next compared with the experimental data on Δ^{++} electroproduction which became recently available from the DESY streamer chamber. Some of the relations derived for virtual spacelike photons are obviously identical to relations previously given for real photons. However, now these relations can be tested experimentally also for spacelike four momenta of the photon, and in addition we have relations for longitudinal photons. Thus relations on decay angular distributions of electroproduced resonances enlarge the possibilities of testing the underlying assumed quark structure of the corresponding production amplitudes. More specifically, we can draw the following conclusions from the analysis of this paper:

1. Quark model relations are confirmed by the experimental data for angular decay distributions of electroproduced Δ^{++}.

2. The quark model predicts the ratio $R(\Delta^{++})$ of the cross-sections for production of Δ^{++} by longitudinal and transverse photons on protons from the knowledge of angular decay distributions. The values of $R(\Delta^{++})$ obtained for $\langle Q^2 \rangle = 0.535$ GeV^2 and $\langle W \rangle =$

$= 1.633$ GeV from two independent relations are $R(\Delta^{++}) = 0.365 \pm 0.195$ and 0.256 ± 0.078. The agreement of the two ratios shows the consistency of the underlying quark model assumptions.

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APPENDIX

From the present experimental data [5–6] for the angular decay distribution of electroproduced resonances $W(\cos\theta, \varphi, \Phi)$ the following statistical tensors can be measured:

$$F(J)^{(04)}T^J_M = \frac{1}{2\sqrt{\pi}} \frac{1}{\langle Y^0_0 \rangle} \langle Y^J_M(\theta, \varphi) \rangle, \tag{A1}$$

$$F(J)\varepsilon^{(1)}\bar{T}^J_M = -\frac{1}{\sqrt{\pi}} \frac{1}{\langle Y^0_0 \rangle} \langle \cos 2\Phi\, Y^J_M(\theta, \varphi) \rangle, \tag{A2}$$

$$F(J)\varepsilon^{(2)}\bar{T}^J_M = -\frac{1}{\sqrt{\pi}} \frac{1}{\langle Y^0_0 \rangle} \langle \sin 2\Phi\, Y^J_M(\theta, \varphi) \rangle, \tag{A3}$$

$$F(J)\sqrt{2\varepsilon(\varepsilon+1)}\,{}^{(5)}\bar{T}^J_M = \frac{1}{\sqrt{\pi}} \frac{1}{\langle Y^0_0 \rangle} \langle \cos \Phi\, Y^J_M(\theta, \varphi) \rangle, \tag{A4}$$

$$F(J)\sqrt{2\varepsilon(\varepsilon+1)}\,{}^{(6)}\bar{T}^J_M = \frac{1}{\sqrt{\pi}} \frac{1}{\langle Y^0_0 \rangle} \langle \sin \Phi\, Y^J_M(\theta, \varphi) \rangle, \tag{A5}$$

where

$${}^{(04)}T^J_M = \frac{1}{1+\varepsilon R}\left({}^{(0)}T^J_M + \varepsilon R\,{}^{(4)}T^J_M\right),$$

$${}^{(\alpha)}\bar{T}^J_M = \frac{1}{1+\varepsilon R}\,{}^{(\alpha)}T^J_M, \quad \text{for} \quad \alpha = 1, 2,$$

$${}^{(\alpha)}\bar{T}^J_M = \frac{\sqrt{R}}{1+\varepsilon R}\,{}^{(\alpha)}T^J_M, \quad \text{for} \quad \alpha = 5, 6.$$

The sign $\langle\ \rangle$ means the average over the decay distribution $W(\cos\theta, \varphi, \Phi)$. In all formulae (A1)–(A5) $F(0) = 1/\sqrt{\pi}$ and $F(2) = -1/\sqrt{5\pi}$. θ and φ are the decay angles in the resonance rest frame.

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