THE QUARK DISSOCIATION MODEL OF PHOTOPRODUCTION

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A B S T R A C T

The quark model for photoproduction which has recently been proposed to explain the suppression of ϕ production is investigated in more detail. A number of clean tests of the model are suggested. Comparison is made with available data.

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I. - It has recently been proposed ^{1),2)} that a quark dissociation model gives a successful explanation of the observed vector meson photoproduction cross-sections, and, in particular, resolves the problem of the suppression of the ϕ meson photoproduction which has puzzled theorists for so long. In this note, we investigate the consequences of this model for other photoproduction processes, and give a series of tests of the model. We restrict our attention to those results from which all quark amplitudes have been eliminated, so that the results presented are clean, exact tests of the quark dissociation model, and no further adjusting of parameters is possible. We have also attempted to find results which can be experimentally tested in the near future.

The model of the photoproduction process which we want to test is illustrated in Fig. 1, where M is any meson, B and B' are any baryons. The basic tenets of the model are that: 1) the photon can be thought of as consisting of a linear combination of the ρ , ω , and ϕ mesons, given by

$$\gamma = \frac{1}{2\sqrt{3}} (3 \rho^0 + \omega - \sqrt{2} \phi) \quad (1)$$

and, 2) the meson-baryon scattering amplitude can be described by the quark model for inelastic processes ^{3),4)}.

The major difficulty in handling the results of the quark dissociation model, as in handling other inelastic processes, is simply to reduce as much as possible the number of quark amplitudes which can appear in an expression for a cross-section. The best way to do this is to find reactions where as many quantum numbers as possible are exchanged. This means that the reaction cross-sections are sometimes rather small, but we hope that the results will stimulate our experimental colleagues to find ways of measuring them.

II. - Consider reactions of the type

$$\gamma p \rightarrow V^0 \Delta^+$$

where V^0 is a neutral vector meson and Δ is the $N_{\frac{3}{2}}^*(1236)$.

To analyze these reactions in the quark dissociation model we need the nine amplitudes $A(V^0 p \rightarrow V^0 \Delta^+)$, $V^0 = \rho^0, \omega, \phi$. Of these the following four vanish directly because of isospin conservation :

$$\begin{aligned} A(\omega p \rightarrow \omega \Delta^+) &= A(\phi p \rightarrow \phi \Delta^+) = A(\omega p \rightarrow \phi \Delta^+) \\ &= A(\phi p \rightarrow \omega \Delta^+) = 0 \end{aligned}$$

The amplitude $A(\rho^0 p \rightarrow \rho^0 \Delta^+)$ vanishes under the following assumptions : a) isospin conservation, b) isospin $T = 2$ exchange in the t channel is forbidden. The assumption b) is very well established experimentally for high s and, in particular, is true in the quark model. This leaves us with a $T = 1$ exchange in the t channel, but a vertex connecting a $T = 1$ state to two ϕ 's vanishes because of isospin conservation. Finally, we have in the quark model

$$A(\phi p \rightarrow \rho^0 \Delta^+) = A(\rho^0 p \rightarrow \phi \Delta^+) \quad (2)$$

since in the quark model ϕ contains only strange and ρ^0 only non-strange quarks and this reaction thus involves double scattering, which is zero by definition. The Eq. (2) is also justified experimentally, since ϕ is known to couple weakly to non-strange hadrons. Of the nine amplitudes thus only two remain : $A(\rho^0 p \rightarrow \omega \Delta^+)$ and $A(\omega p \rightarrow \rho^0 \Delta^+)$. But these are, in fact, equal if we assume that the reactions proceed by an exchange mechanism and that the factorization theorem is valid. In particular, they are equal in the quark model. Eliminating the single remaining amplitude we obtain the following relations :

$$\frac{\bar{\sigma}(\gamma p \rightarrow \rho^0 \Delta^+)}{\bar{\sigma}(\gamma p \rightarrow \omega^0 \Delta^+)} = \frac{\bar{\sigma}(\gamma n \rightarrow \rho^0 \Delta^0)}{\bar{\sigma}(\gamma n \rightarrow \omega^0 \Delta^0)} = \frac{1}{9}$$

$$\bar{\sigma}(\gamma p \rightarrow \phi \Delta^+) = \bar{\sigma}(\gamma n \rightarrow \phi \Delta^0) = 0$$

(3)

where $\bar{\sigma}$ represents either: 1) $d\sigma/dt$ at any s and t (within the domain of validity of the quark model, i.e., s large), or 2) the reaction cross-section corrected for phase space.

The result of Eq. (3) is of great interest because it follows from rather general assumptions, and depends on the quark model only in the rather weak sense of Eq. (2). Thus the measurement of the associated resonance production would allow us to test the assumption of dissociation independently of the quark model. Such a test is also critical for other types of dissociation models which have been proposed ⁵⁾.

Notice, in particular, that the predicted ratio of ϕ and ω production rates in $\gamma N \rightarrow V^0 \Delta(1:9)$ is the inverse of the same quantity in $\gamma N \rightarrow V^0 N(9:1)$. The ϕ production rate was in Ref. ²⁾ predicted to be small but non-vanishing also for $\gamma N \rightarrow V^0 N$.

In addition, if we work out helicity amplitudes for photo-production as in Ref. ³⁾, we find the following results for cross-sections

$$\begin{aligned}\bar{\sigma}(\gamma p \rightarrow K \Lambda) &= 3 \bar{\sigma}(\gamma p \rightarrow K^+ Z^0) + 3 \bar{\sigma}(\gamma p \rightarrow K^+ \gamma^{*0}) \\ \bar{\sigma}(\gamma p \rightarrow K^* \Lambda) &= 3 \bar{\sigma}(\gamma p \rightarrow K^{*+} Z^0) + 3 \bar{\sigma}(\gamma p \rightarrow K^{*+} \gamma^{*0})\end{aligned}$$

$$\begin{aligned}\bar{\sigma}(\gamma p \rightarrow X^0 \Delta^+) + \bar{\sigma}(\gamma p \rightarrow \gamma^0 \Delta^+) &= 9 \bar{\sigma}(\gamma p \rightarrow \pi^0 \Delta^+) \\ \bar{\sigma}(\gamma n \rightarrow X^0 \Delta^0) + \bar{\sigma}(\gamma p \rightarrow \gamma^0 \Delta^0) &= 9 \bar{\sigma}(\gamma n \rightarrow \pi^0 \Delta^0)\end{aligned}\quad (4)$$

where $\overline{\sigma}$ is defined as above. Off the forward direction these relations assume the equality of the quark-quark scattering form factors. There are two points to be made about these relations. First, they are valid at all s and t (s large), so that they offer a very detailed test of the model. Second, there are no adjustable parameters, for, although the assignment of the η and the X_0 in the quark model is not certain ^{3),6)}, the angle α which is used in writing the η and X_0 wave functions has been eliminated from the results, so that Eq. (4) is completely independent of α . In terms of α we find that

$$\frac{\overline{\sigma}(\gamma_p \rightarrow \eta^0 \Delta^+)}{\overline{\sigma}(\gamma_p \rightarrow X^0 \Delta^+)} = \cot^2 \alpha = \left[\frac{\cos \theta_p + \sqrt{2} \sin \theta_p}{\sin \theta_p - \sqrt{2} \cos \theta_p} \right]^2 \quad (5)$$

where θ_p is the 0^- nonet mixing angle.

So far the results have been perfectly general. If we restrict our attention to forward scattering, we find in addition that

$$\begin{aligned} \sigma(\gamma_p \rightarrow \begin{pmatrix} K^{*+} \\ K^+ \end{pmatrix} \Lambda) : \sigma(\gamma_p \rightarrow \begin{pmatrix} K^{*+} \\ K^+ \end{pmatrix} \Sigma^0) : \sigma(\gamma_p \rightarrow \begin{pmatrix} K^{*+} \\ K^+ \end{pmatrix} \gamma^{*0}) \\ = 27 : 1 : 8 \end{aligned} \quad (6)$$

where $\sigma \equiv (d\overline{\sigma}/dt)|_{\theta=0}$.

Relations of this type have been given by Kupsch ⁷⁾ using a different model. The present model reproduces those of the results in Ref. ⁷⁾ which are valid for $\theta = 0$ and where only isospin and not SU_3 invariance is assumed for quarks. In particular we do not reproduce the result of Ref. ⁷⁾ that

$$\sigma(\gamma_p \rightarrow \pi^+ n) = 50 \sigma(\gamma_p \rightarrow K^+ \Sigma^0)$$

Equation (6) is, in fact, valid even for a wider class of processes, namely for all those in which the helicity state of the nucleon is changed, while a sum rule analogous to Eq. (4) is valid for helicity non-flip cross-sections. If the observed ratio of, e.g., Λ and Σ^0 production is closer to 3 than 27, the processes must be dominated by helicity non-flip transitions.

III. - Another set of reactions which can be calculated in the model, and which is of experimental interest is the "charge inversion" type of reaction, where one compares, for example, the reaction

$$\gamma p \rightarrow \pi^+ n$$

with the reaction

$$\gamma n \rightarrow \pi^- p$$

or where one has different charge configurations in the final state.

Unfortunately, there are no clean relations which can be obtained for these reactions unless we pass to the high-energy limit ^{4),8)}, in which case (β is a phase factor)

$$A_q = \beta \bar{A}_q$$

where A_q is any quark helicity amplitude, and $\bar{A}_q$ is the corresponding quark-antiquark amplitude. We then find that we can derive the following results independent of β :

$$\frac{\bar{\sigma}(\gamma p \rightarrow \rho^+ \Delta^0)}{\bar{\sigma}(\gamma p \rightarrow \rho^- \Delta^{++})} = \frac{1}{3}$$

$$\frac{\bar{\sigma}(\gamma p \rightarrow \pi^+ \Delta^{++})}{\bar{\sigma}(\gamma p \rightarrow \pi^- \Delta^0)} = \frac{1}{3}$$

$$\frac{\bar{\sigma}(\gamma p \rightarrow \pi^+ n)}{\bar{\sigma}(\gamma n \rightarrow \pi^- p)} = 1 \quad (7)$$

The last expression has also been derived in a Regge pole model ⁹⁾.

IV. - It was pointed out in Ref. ³⁾ that in some cases it is possible to obtain expressions for density matrix elements from which all quark amplitudes have been cancelled, and which are therefore extremely good tests of any quark model. The same situation is found to hold in photo-production processes. For the sake of simplicity, we restrict our attention for the moment to the case of forward scattering ($\theta = 0$). In this case, simple angular momentum conservation leads to the result that

$$\rho_{mm'}^A(\gamma N \rightarrow A+B) = \rho_{mm'}^B(\gamma N \rightarrow A+B) = 0 \quad m \neq m' \quad (8)$$

where $\rho_{mm'}^A(\gamma N \rightarrow A+B)$ is the density matrix element for particle A in the reaction indicated, evaluated at $\theta = 0$.

The only clear numerical prediction which we have found is that

$$\begin{aligned} \rho^{\Delta}(\gamma p \rightarrow \pi^- \Delta^{++}) &= \rho^{\gamma^*}(\gamma p \rightarrow K^+ \gamma^*) \\ &= \frac{1}{8} \begin{pmatrix} 3 & & \\ & 1 & 0 \\ 0 & & 3 \end{pmatrix} \end{aligned} \quad (9)$$

which corresponds to a decay angular distribution of the B^* of the form $w(\theta, \phi) \sim \frac{5}{3} - \cos^2 \theta$.

A comparison of the first result to experiment ¹⁰⁾ is given in Fig. 2. We see that the agreement is reasonably good. More important, however, we note that there is a clean distinction between the quark dissociation model and the strong absorption model predictions for the angular distribution of the decay products of the Δ . Further measurements of these quantities, then, would enable us to make a choice between these two models. Data on the second reaction is expected shortly ¹¹⁾, and it will be interesting to see if the agreement continues there.

Further results for forward scattering are

$$\rho_{00}^{\rho}(\gamma p \rightarrow \rho^0 \Delta^+) = \frac{4}{3} \rho_{\frac{3}{2} \frac{3}{2}}^{\Delta}(\gamma p \rightarrow \rho^0 \Delta^+)$$

$$\rho_{00}^{\rho}(\gamma n \rightarrow \rho^0 \Delta^0) = \frac{4}{3} \rho_{\frac{3}{2} \frac{3}{2}}^{\Delta}(\gamma p \rightarrow \rho^0 \Delta^0)$$

$$\rho_{00}^{K^*}(\gamma p \rightarrow K^{*+} \gamma^*) = \frac{8}{3} \rho_{\frac{3}{2} \frac{3}{2}}^{\gamma^*}(\gamma p \rightarrow K^{*+} \gamma^*)$$

$$\begin{aligned} 9 \frac{\rho_{11}^{K^*}(\gamma p \rightarrow K^* \Lambda)}{\rho_{00}^{K^*}(\gamma p \rightarrow K^* \Lambda)} &= 4 \frac{\rho_{11}^{K^*}(\gamma p \rightarrow K^{*+} \gamma^*)}{\rho_{00}^{K^*}(\gamma p \rightarrow K^{*+} \gamma^*)} \\ &+ \frac{\rho_{11}^{K^*}(\gamma p \rightarrow K^* \Sigma^0)}{\rho_{00}^{K^*}(\gamma p \rightarrow K^* \Sigma^0)} \quad (10) \end{aligned}$$

In addition, it is possible in a few cases to make statements about density matrices which must be true at all angles and all energies. We find

$$\begin{aligned} D(\gamma N \rightarrow \rho^0 B) &= D(\gamma N \rightarrow \omega^0 B) \\ D(\gamma N \rightarrow \pi^0 B) &= D(\gamma N \rightarrow \eta^0 B) \\ &= D(\gamma N \rightarrow \eta'^0 B) \quad (11) \end{aligned}$$

where $D(\gamma N \rightarrow A + B)$ represents any density matrix elements for the reaction in question, and N represents a proton (neutron) when B represents a $\Delta^+(\Delta^0)$, and D is evaluated at arbitrary θ .

V. - Finally, we note that in the next few years, experimental results will become available for photoproduction processes in which both the photon and the target proton are polarized ¹²⁾. It is easy to make predictions for such experiments in the quark dissociation model. Again restricting our attention to the $\theta = 0$ case, we find that angular momentum conservation immediately gives the results of the table.

From the quark model, we can derive, in addition, the following predictions : for the reaction

$$\gamma p \rightarrow \pi^- \Delta^{++}$$

we find

$$\left. \frac{d\sigma^A}{dt} \right]_{\theta=0} / \left. \frac{d\sigma^P}{dt} \right]_{\theta=0} = 3$$

while for the reaction

$$\gamma p \rightarrow \rho^- \Delta^{++}$$

we find

$$\rho_{00}^P = \frac{3}{7 - 2\rho_{00}^A} = \frac{3(1-x)}{4(3-2x)}$$

where

$$x = \left. \frac{d\sigma^P}{dt} (\gamma p \rightarrow \rho^- \Delta^{++}) \right]_{\theta=0} / \left. \frac{d\sigma^A}{dt} (\gamma p \rightarrow \rho^- \Delta^{++}) \right]_{\theta=0}$$

and where the superscript P or A tells whether the spins of the photon and nucleon in the initial state are parallel or antiparallel.

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- T A B L E -

Reaction	Spins aligned	Spins anti-aligned
$\gamma p \rightarrow \pi^- \Delta^{++}$	$\rho_{\frac{1}{2}\frac{1}{2}} = \frac{1}{2}$ $\rho_{\frac{3}{2}\frac{3}{2}} = 0$	$\rho_{\frac{1}{2}\frac{1}{2}} = 0$ $\rho_{\frac{3}{2}\frac{3}{2}} = \frac{1}{2}$
$\gamma p \rightarrow V^- \Delta^{++}$	$\rho_{00} = \rho_{\frac{3}{2}\frac{3}{2}}$ $\rho_{11} = \rho_{\frac{1}{2}\frac{1}{2}}$	$\rho_{\frac{3}{2}\frac{3}{2}} = 0$ $\rho_{\frac{1}{2}\frac{1}{2}} = \frac{1}{2}$

Density matrix elements for
forward production from pola-
rized beams and targets.
 V^- represents any negative
vector meson.

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Figure 1

Figure 2