PHOTOPRODUCTION OF SCALAR AND VECTOR MESONS IN THE REGION OF THE SECOND MAXIMUM IN ANGULAR DISTRIBUTION AND THE QUARK MODEL

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The assumption of antiquark-quark scattering dominance in the formation of the secondary maximum in angular distribution is applied to photoproduction processes. The SU(6) quark model is used to obtain simple relations between the differential cross-sections for scalar and vector meson photoproduction in the momentum transfer region in which the secondary maximum appears. A qualitative explanation of the difference between the angular distributions of π^0 and η photoproduction on protons is presented.

1. The absence of secondary maximum in angular distribution at $-t \approx 1(\mathrm{GeV}/c)^2$ in proton-proton elastic scattering and its appearance in antiproton-proton and pion-proton scattering has led to a tempting assumption that the presence of the secondary maximum is a characteristic feature of antiquark-quark scattering [1]. In the framework of the additive quark model some useful relations between the differential cross-sections have been obtained for the secondary maxima in hadron-nucleon processes under the assumption that the formation of the secondary maximum is dominated by antiquark-quark scattering amplitudes [1], [2]. Some of these relations have been compared with experimental data and, in general, a rather good agreement has been found.

This paper is a continuation of the work done in reference [2].

We apply here the assumption of antiquark-quark scattering dominance in the region of the secondary maximum to photoproduction processes. We follow the idea of *cf.* Joos *et al.* [3]–[5] which has been found rather successful in explaining some of the experimental features of photoproduction processes:

According to the vector dominance hypothesis the photon is a linear combination of the neutral vector mesons

$$\gamma = \frac{1}{2\sqrt{3}}(3\varrho^0 + \omega - \sqrt{2}\,\Phi).$$

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Using this relation one can describe the photoproduction processes in terms of vector meson-baryon scattering amplitudes. On the other hand, in the quark model these amplitudes are decomposed into quark-quark scattering amplitudes. In our case the particular assumption is that only antiquark-quark amplitudes contribute to the formation of the secondary maximum and the quark-quark contributions can be neglected.

As in reference [2], we use in this paper the SU(6) wave functions of hadrons [6] and the additive quark model [7] to obtain relations between the differential cross-sections in the region of the secondary maximum.

We restrict our attention to those results from which all helicity amplitudes have been eliminated.

In the next Section we present a list of the relations obtained and a discussion of the results. In Section 3 the experimental data on photoproduction at momentum transfer $-t > 0.5$ (GeV/c)^2 are briefly reviewed.

2. The following relations between the differential cross-sections in the region of the secondary maximum in angular distribution have been obtained under the assumptions described in Section 1:

$$[\sigma(\gamma p \to X^0 \Delta^+) + \sigma(\gamma p \to \eta \Delta^+)] : \sigma(\gamma p \to \pi^+ \Delta^0) : \sigma(\gamma p \to \pi^- \Delta^{++}) : \sigma(\gamma p \to \pi^0 \Delta^+) = 9:8:6:1 \tag{1}$$

$$\sigma(\gamma p \to \omega \Delta^+) : \sigma(\gamma p \to \varrho^+ \Delta^0) : \sigma(\gamma p \to \varrho^- \Delta^{++}) : \sigma(\gamma p \to \varrho^0 \Delta^+) = 9:8:6:1 \tag{2}$$

$$\sigma(\gamma p \to \pi^+ n) = 4\sigma(\gamma n \to \pi^- p) \tag{3}$$

$$\sigma(\gamma p \to \pi^+ \Delta^0) = 4\sigma(\gamma n \to \pi^- \Delta^+) \tag{4}$$

$$4\sigma(\gamma p \to \pi^- \Delta^{++}) = \sigma(\gamma n \to \pi^+ \Delta^-) \tag{5}$$

$$4\sigma(\gamma p \to \varrho^+ n) = \sigma(\gamma n \to \varrho^- p) \tag{6}$$

$$4\sigma(\gamma p \to \varrho^- \Delta^{++}) = \sigma(\gamma n \to \varrho^+ \Delta^-) \tag{7}$$

$$\sigma(\gamma p \to \varrho^+ \Delta^\circ) = 4\sigma(\gamma n \to \varrho^- \Delta^+) \tag{8}$$

$$\sigma(\gamma p \to K^+ \Sigma^0) = 2\sigma(\gamma p \to K^0 \Sigma^+) \tag{9}$$

$$\sigma(\gamma p \to K^{*+} \Sigma^0) = 2\sigma(\gamma p \to K^{*0} \Sigma^+) \tag{10}$$

$$\sigma(\gamma p \to K^+ Y^{*0}) = 2\sigma(\gamma p \to K^0 Y^{*\circ}) \tag{11}$$

$$\sigma(\gamma p \to K^{*+} Y^{*0}) = 2\sigma(\gamma p \to K^{*0} Y^{*+}) \tag{12}$$

In deriving Eq. (2) the $\omega - \Phi$ mixing angle has been chosen in such a way that the Φ meson would consist of strange quarks only.

Relations obtained in the same way in the usual version of the quark model are obviously also valid under the particular assumption used in deriving equations (1)–(12). Other relations can be obtained by combining equations quoted above with those of references [5] and [8].

Out of our relations, the equation

$$\frac{\sigma(\gamma p \to \omega \Delta^+)}{\sigma(\gamma p \to \varrho^0 \Delta^+)} = 9 \tag{2}$$

follows from more general assumptions which depend on the quark model rather weakly [5]. Also the relation

$$\frac{\sigma(\gamma p \to X^0 \Delta^+) + \sigma(\gamma p \to \eta \Delta^+)}{\sigma(\gamma p \to \pi^0 \Delta^+)} = 9, \tag{1}$$

does not require neglecting quark-quark amplitudes and has been obtained already in reference [5]. We quote them for completeness.

The remaining relations can be used to test the specific assumption of antiquark-quark scattering dominance in the secondary maximum region.

We would like to point out that other models give predictions that differ from ours. For example, in reference [5] the high-energy limit relation [9] between quark-quark and antiquark-quark scattering amplitudes

$$A(qq) = \beta A(\bar{q}q) \tag{13}$$

with $|\beta| = 1$ has been used to obtain the relations:

$$\frac{\sigma(\gamma p \to \varrho^+ \Delta^0)}{\sigma(\gamma p \to \varrho^- \Delta^{++})} = \frac{1}{3} \tag{14}$$

$$\frac{\sigma(\gamma p \to \pi^+ \Delta^0)}{\sigma(\gamma p \to \pi^- \Delta^{++})} = \frac{1}{3}. \tag{15}$$

In contrast with this result our prediction is 4/3.

The value 1/3 is predicted for these ratios also by the one-pion-exchange model (OPE) as a result of isospin conservation in the $p\pi\Delta$ vertex. The photoexcitation mechanism which correctly describes the data on photoproduction on hydrogen at the photon energy $E_\gamma < 1.8$ GeV [10] gives the value 1/3 if the isospin of the intermediate isobar is $T = 1/2$ and 4/3 if $T = 3/2$.

The experimental data available at present do not allow these relations to be tested at $-t \approx 1 (\text{GeV}/c)^2$. The data on the total cross-sections favour rather the value 1/3 [11] for the ratio (15). However, in the forward diffraction peak, which gives essential contribution to the total cross-sections, both quark-quark and antiquark-quark amplitudes contribute.

3. In this part we briefly summarize the experimental data on photoproduction processes on hydrogen at momentum transfers $-t > 0.5$ $(\text{GeV}/c)^2$. First we would like to point out that according to the hypothesis stated in reference [1] the secondary structure should be observed for all photoproduction processes, as they always involve antiquark — a constituent of the vector meson — scattering.

Actually, this structure is observed in experiments at photon energies of a few GeV and disappears as the photon energy is increased.

A pronounced dip at $-t \approx 0.5$ $(\text{GeV}/c)^2$ and a subsequent maximum is observed for single neutral pion photoproduction on hydrogen up to $E_\gamma \approx 6$ GeV [12]-[14]. At higher energies (9–16 GeV) this structure is smoothed down, the more the higher photon energy [13], [14].

The data on ϱ^0 photoproduction on protons suggest the appearance of a secondary structure at $-t \approx 0.6-1.2$ $(\mathrm{GeV}/c)^2$ in the photon energy intervals: $1.8\ \mathrm{GeV} > E_\gamma > 1.4\ \mathrm{GeV}$ and $2.5\ \mathrm{GeV} > E_\gamma > 1.8\ \mathrm{GeV}$ [11]. This structure vanishes rapidly with increasing energy and a smooth fall off of the differential cross-section with increasing $|t|$ is observed for $E_\gamma > 2.5$ GeV [11], [14]–[16]. There is also some indication for a similar structure in ω photoproduction in the energy interval $1.8\ \mathrm{GeV} > E_\gamma > 1.4\ \mathrm{GeV}$ [11]. However, better data are required to make the situation more clear.

A bump in angular distribution at $-t = 0.8–1.6$ $(\mathrm{GeV}/c)^2$ is also observed in single positive pion photoproduction on hydrogen at photon energies 1.1 GeV and 1.2 GeV [17]. This bump is smoothed down into a shoulder at $E_\gamma = 3.4–4.0$ GeV [18] and is absent in higher energy data ($E_\gamma = 5–16$ GeV) of reference [19].

Similarily, the data of the same group on $\gamma p \to \pi^- \Delta^{++}$ [20] and on $\gamma p \to K^+ \Lambda(\Sigma^0)$ [21] at the energies 5–16 GeV show no structure in this angular region.

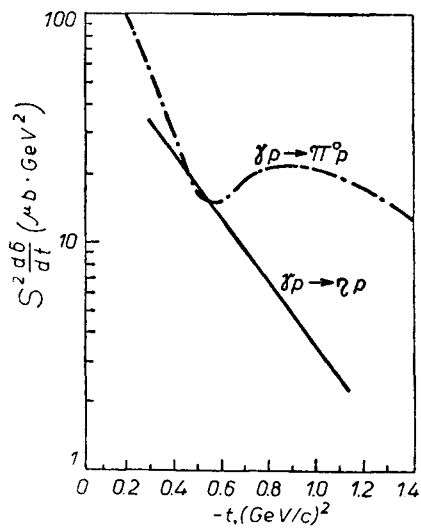

Fig. 1. The shapes of the differential cross-sections for $\gamma p \to \pi^0 p$ and $\gamma p \to \eta p$ at photon energy $E_\gamma \approx 6$ GeV. The figure is based on Fig. 11 of reference [14]. The cross-section for $\gamma p \to \eta p$ is represented by a hand-drawn line through experimental points plotted there

Also in the processes: $\gamma p \to \Phi p$ — in the energy interval $5.8\ \mathrm{GeV} > E_\gamma > 2.5\ \mathrm{GeV}$ [11] and at $E_\gamma = 6–17.8$ GeV [14], [16] — and $\gamma p \to \eta p$ at $4.0-9.0$ GeV [13], [14], [22] no evidence for a secondary maximum has been found[1].

It would be interesting to see whether there is any structure at lower energies in these reactions. Here, we would like to point out that the K^+p elastic scattering data [23] indicate

[1] We recall, that this situation is familiar from pion-proton and antiproton-proton elastic scattering, where the secondary maxima, which are pronounced in a few GeV region, vanish as the incident energy increases [24].

that there is no secondary maximum in $\bar{q}_\lambda q_p(q_n) \rightarrow \bar{q}_\lambda q_p(q_n)$ amplitudes. If this is the case for all helicity amplitudes, the secondary maximum should not appear also in the angular distribution of the process $\gamma p \rightarrow \Phi p$, provided the Φ meson consists of strange quarks only.

This feature of $\bar{q}_\lambda q_p(q_n)$ scattering amplitudes should be reflected also in the photoproduction of η mesons on protons. The value of the mixing angle between η_1 and η_8 [25] implies a contribution of the $\bar{q}_\lambda q_p(q_n)$ scattering amplitudes to the cross-section for this process. This may result in a flattening of the dip produced by non-strange antiquark scattering amplitudes.

If the model were generally successful this would provide a simple qualitative explanation of the observed difference between the angular distributions of π^0 and η pnotoproduction on protons [13], [14] (see Fig. 1). This difference is somewhat puzzling on the grounds of the Regge-pole theory, in which the exchange of vector meson trajectories implies a dip around $-t \approx 0.5$ $(\mathrm{GeV}/c)^2$ for both reactions[2].

TABLE I

Process	E_γ / prediction	1–2 GeV	2–5 GeV	5–10 GeV	10–16 GeV
$\gamma p \rightarrow \pi^+ n$	yes	yes	shoulder	no	no
$\gamma p \rightarrow \pi^0 p$	yes	?	shoulder	yes	shoulder
$\gamma p \rightarrow \eta p$	weak	?	?	no	?
$\gamma p \rightarrow \pi^- \Delta^{++}$	yes	?	?	no	no
$\gamma p \rightarrow \varrho^0 p$	yes	shoulder	no	no	no
$\gamma p \rightarrow \omega p$	yes	shoulder	no	?	?
$\gamma p \rightarrow \Phi p$	no	no?	no	no	no
$\gamma p \rightarrow K^+ \Lambda(\Sigma^0)$	yes	?	?	no	no

For the sake of clarity we present in Table I the evidence for the secondary maxima in photoproduction processes on hydrogen together with our predictions.

The data on the formation of the secondary maximum in photoproduction processes do not allow our relations to be tested at present. To performe a comparison with experiment more data on secondary maximum cross-sections are necessary.

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