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ELASTIC SCATTERING OF VECTOR MESONS BY PROTONS
FROM PHOTOPRODUCTION

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ABSTRACT

Using the vector dominance model we infer the momentum transfer dependence of the scattering of vector mesons by nucleons from photoproduction data. It is shown that this scattering agrees with that deduced from a broken SU_3 quark model. The small slope of φ photoproduction at incident momenta of a few GeV/c is accounted for. The analysis indicates a size for the ρ^0 meson similar to that of the pion.

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We examine here in a quark model with broken SU_3 symmetry ^{1),2)} the momentum transfer behaviour of the scattering of vector mesons from nucleons. The SU_3 symmetry is broken in such a way as to make the K^+p and K^+n total cross-sections equal. Lipkin ¹⁾ introduces three independent amplitudes for quark-quark and quark-antiquark scattering, P , S and A where

$$\begin{aligned} P &= (\bar{P}N) = (N\bar{P}) = (\bar{P}N) = (\bar{N}P) = (P\bar{P}) = (N\bar{N}) \\ P-S &= (\lambda\bar{P}) = (\lambda\bar{N}) = (\bar{\lambda}P) = (\bar{\lambda}N) \\ P+A &= (P\bar{P}) = (N\bar{N}) \end{aligned} \quad (1)$$

Here P and N are the non-strange quarks and λ the strange quark. Bars denote antiquarks. One has then under the additivity assumption ³⁾ for quark amplitudes

$$\begin{aligned} f(\pi^-p) &= 6P + 2A \\ f(\pi^+p) &= 6P + A \\ f(K^+p) &= 6P - 3S \end{aligned} \quad \begin{aligned} f(\rho^0p) &= f(\omega p) = 6P + \frac{3}{2}A \\ f(\phi p) &= 6P - 6S \end{aligned} \quad (2)$$

It follows that

$$f(\rho^0p) = f(\omega p) = \frac{1}{2} [f(\pi^-p) + f(\pi^+p)] \quad (3)$$

$$f(\phi p) = 2f(K^+p) + f(\pi^-p) - 2f(\pi^+p) \quad (4)$$

In the above $f(xp)$ is the amplitude for elastic scattering of particle x from a proton at momentum transfer $\sqrt{-t}$.

In order to get experimental information for the left-hand side of Eqs. (3) and (4), we assume the validity of the vector dominance model ^{4),2)}. According to this model, photoproduction of a vector meson is related to scattering through :

2.

$$\frac{d\sigma}{dt}(\gamma+p \rightarrow V+p) \cong \frac{\alpha}{4} \left(\frac{\gamma_V^2}{4\pi} \right)^{-1} \frac{d\sigma}{dt}(V+p \rightarrow V+p) \quad (5)$$

The particle V can be any of the vector mesons ρ^0 , ω or φ . The values of γ_V are given in Ref. 2) and do not concern us in this discussion. (We note, however, that the ratio of values found experimentally are consistent with those deduced ²⁾ from the quark model used here.) α is the fine structure constant.

Using the optical theorem

$$\text{Im } f(0) = k \sigma_{\text{tot}} / 4\pi \quad (6)$$

and relations (3) and (4) in the forward direction, one finds that for lab. momenta around 5 GeV/c, $\sigma_{\text{tot}}(\omega p) = \sigma_{\text{tot}}(\rho^0 p) = 28 \pm 1$ mb and $\sigma_{\text{tot}}(\varphi p) = 11 \pm 2$ mb. Recent analyses ^{5),6)} of data for photoproduction of ρ^0 mesons in nuclei yield results in good agreement with the values deduced using Eqs. (3) and (6). Preliminary analysis ⁷⁾ of similar data for photoproduction of φ mesons is in agreement with the quark model prediction for the φ nucleon total cross-section using Eqs. (4) and (6). The total cross-section values for ρ^0 and φ mesons on nucleons inferred from nuclear photoproduction experiments are listed in the Table.

We now examine the t dependence of the scattering of vector mesons from nucleons using Eqs. (3), (4) and (5). We ignore any possible phase difference between amplitudes in the momentum transfer region under consideration. Because differences are involved in Eq. (4), we feel this is safe for φ scattering only for $|t| \lesssim 0.5$ (GeV/c)². For ρ^0 and ω scattering, we comment on the range of t values further on in this paper.

We have then

$$\frac{d\sigma(\rho^0 p)}{dt} = \frac{d\sigma(\omega p)}{dt} = \frac{1}{4} \left\{ \left[\frac{d\sigma(\pi^- p)}{dt} \right]^{1/2} + \left[\frac{d\sigma(\pi^+ p)}{dt} \right]^{1/2} \right\}^2 \quad (7)$$

$$\frac{d\sigma(\varphi p)}{dt} = \left\{ 2 \left[\frac{d\sigma(K^+ p)}{dt} \right]^{\frac{1}{2}} + \left[\frac{d\sigma(\pi^+ p)}{dt} \right]^{\frac{1}{2}} - 2 \left[\frac{d\sigma(\pi^+ p)}{dt} \right]^{\frac{1}{2}} \right\}^2 \quad (8)$$

For small enough $|t|$ we can write the various scattering cross-sections in the form $(d\sigma/dt) = ae^{bt}$. The values of b are listed in the Table. For the vector mesons we have used Eq. (5) and photoproduction data ⁸⁾. For K^+ mesons and π mesons ^{9),10),11)} we of course get b directly from scattering data. We will attempt to use Eq. (7) for values of t which go slightly beyond where the simple exponential form e^{bt} describes the momentum transfer dependence of the scattering cross-sections.

It is to be noted in the Table that the slopes b for ρ^0 , ω and $\pi^\pm$ mesons are rather similar. The φ -p scattering slope inferred from photoproduction data ⁸⁾ using the vector dominance model is $b \sim 3.4 (\text{GeV}/c)^{-2}$ which appears anomalously small. This is explained by Eq. (8) and follows mainly from the small slope of K^+p scattering. This, in turn, probably relates to the difficulty K^+ mesons have in producing reactions at a few GeV/c because of their strangeness quantum number. It is to be noted that the slope of a diffraction pattern depends both on size and the absorptive characteristics of the target projectile system.

Figure 1 shows a comparison of the left and right-hand sides of Eq. (7) using experimental data for both sides ^{8),10),11)}. Figure 2a shows the same comparison as for Fig. 1, except that the vector meson is the ω . Figure 2b compares φ production data ⁸⁾ with pseudoscalar meson scattering data ^{9),10)} according to Eqs. (5) and (8). We see in detail here that the small K^+p scattering slope is reflected in the φ photoproduction slope. This is another indication that the φ meson is indeed associated with the strange mesons.

It is seen in Fig. 1 that both sides of Eq. (7) agree beyond the region of simple exponential behaviour of π -p scattering. There is a break in slope in π -p scattering as a function of t for values of $|t| \simeq 0.7 \text{ (GeV/c)}^2$. This is probably a diffraction effect relating to particle size and interaction strength similar to that discussed recently for proton-proton scattering^{12),13),14)}. It is reasonable to deduce then that the break in slope of the ρ^0 photoproduction angular distributions at similar values of t along with their similar b values is an indication that the ρ^0 meson has a size much like that of the pion. This is implicit of course in the quark model used here. In the case of ω photoproduction, the slope b is again similar to that of pion scattering but larger t values data are lacking. Again the photoproduction cross-section shows an energy dependence⁸⁾ which indicates appreciable contribution from one-pion exchange.

We have analyzed the vector meson data described above using equations (7) and (8). The additivity assumption used to obtain these equations corresponds to single quark-quark or antiquark-quark scattering. There will be multi-scattering corrections^{14),15)} which can be large at the larger momentum transfers and, in fact, probably produce the diffraction minima. It might be expected, however, that Eq. (7) will be somewhat more generally valid in an approximate way at least for the ρ^0 meson (and the ω meson at higher energies) since the ρ , ω and π mesons are all made of non-strange quarks in the quark model. In this connection we call to attention the similarity between ρ^0 , ω , π^+ and π^- scattering in formulae (2).

We note finally that the small slope for ϕ photoproduction (or elastic scattering) on protons at a few GeV energies must be taken into account in comparing total photoproduction cross-sections with quark model predictions²⁾. Since the data still have considerable experimental uncertainty, we do not undertake such an analysis here.

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Particle	π^+	π^-	K^+	K^+	K^+	θ°	ω	φ
Momentum range (GeV/c)	2.3 - 4.0	2.5 - 4.0	3.5	5.0	5.0	2.5 - 5.8	2.5 - 5.8	2.5 - 5.8
$ t $ range (GeV/c) ²	0.05 - 0.6	0.05 - 0.6	0.04 - 0.65	0.04 - 0.65	0.04 - 0.65	0.05 - 0.5	0.02 - 0.5	0.015 - 1.0
b (GeV/c) ²	6.7 $\pm$ 0.2	7.4 $\pm$ 0.2	3.85 $\pm$ 0.12	4.70 $\pm$ 0.21	4.70 $\pm$ 0.21	7.6 $\pm$ 0.5	7.5 $\pm$ 0.9	3.35 $\pm$ 0.7
σ_{tot} (mb); $p_{\text{lab}} \approx 5$ GeV/c	26.5	29.1	17.5	~ 17.7	~ 17.7	26 ± 3 31.2 ± 2.3	---	13.3 ± 2.7

TABLE : Data from Refs. 5), 6), 8), 9), 10), 11) and 16).

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FIGURE CAPTIONS

Figure 1 : Differential cross-section given by right-hand side of Eq. (7) for different incident pion momenta ^{10),11)} as a function of t (full lines). Data for photoproduction of ρ^0 mesons on nucleons ⁸⁾ as a function of t (normalized arbitrarily) is indicated by the crosses. Energies and momenta in lab system.

Figure 2 : a) Same as Fig. 1, except that photoproduction data are for the ω meson.

b) Differential cross-section given by right side of Eq. (8) for incident lab. momentum of 5 GeV/c using data from Refs. 10) and 11) (full line). The data have been smoothed somewhat to get this curve. Experimental points are data for photoproduction of φ mesons on protons ⁸⁾. We have used scattering data at 5 GeV/c lab. momentum, and not a lower value, because of the relatively large mass differences of the mesons involved and since we are dealing with differences in Eq. (8). At momenta around 3 GeV/c the right side of (8) is even flatter as a function of t and non-exponential in t . The photoproduction data are normalized arbitrarily.

FIG 1

FIG. 2