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HADRON SCATTERING AND QUARK MODELS

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Recently a number of rather successful relations among hadron cross-sections have been derived from the simple quark model by applying the additivity assumption to the two-body quark-quark and quark-antiquark scattering amplitudes ¹⁾⁻³⁾. In this note we point out that there is a somewhat different, although equally simple, quark model of hadron scattering which also yields several relations among cross-sections that are in remarkable agreement with the data over the entire energy range 6-20 GeV/c where they can be checked.

The model is based on the hypothesis that the only significant net interaction among systems of quarks occurs when their total charge is integral. This assumption is motivated not only by the fact that no other systems have been found to date, but also by the well-known argument ⁴⁾ that it is difficult to understand the symmetry of the baryon wave function if it is the ground state of an interaction involving only ordinary two-body forces between fermion quarks ⁵⁾. To put it more graphically, in a meson-baryon collision, for example, the antiquark in the meson sees the individual quarks of the baryon, but the quark in the meson sees the quarks of the baryon only in pairs in this model. Therefore, in analyzing hadron scattering, we apply the additivity assumption to the quark-antiquark and three-quark interactions.

This model immediately leads to the following relations among measured total cross-sections :

$$\sigma(\pi^-p) + \sigma(\pi^+p) = \frac{1}{3} [\sigma(\bar{p}p) + \sigma(\bar{p}N)] + \frac{1}{6} [\sigma(pp) + \sigma(pN)] \quad (1)$$

$$\sigma(\pi^-p) - \sigma(\pi^+p) = \sigma(K^-p) - \sigma(K^+p) - \sigma(K^-N) + \sigma(K^+N) \quad (2)$$

$$\sigma(K^+p) - \sigma(K^+N) = \frac{1}{2} [\sigma(pp) - \sigma(pN)] \quad (3)$$

$$\sigma(K^-p) - \sigma(K^-N) = \sigma(\bar{p}p) - \sigma(\bar{p}N) \quad (4)$$

In obtaining Eqs. (1)-(4) we have used the optical theorem, but we have not assumed any symmetry higher than isospin. Additional assumptions, of course, will give stronger results as in the usual quark model. For example, neglecting charge exchange among the quarks leads to

$$\sigma(K^{\pm}P) = \sigma(K^{\pm}N) \quad (5)$$

while neglecting strangeness exchange among the quarks gives

$$\sigma(K^{+}P) = \sigma(K^{-}P) \quad (6)$$

in addition to Eqs. (1)-(4).

Comparing Eqs. (1)-(4) with the experimental data ⁶⁾ shows that there is complete agreement over the entire energy range 6-20 GeV/c. The agreement is particularly remarkable for the relation involving sums of cross-sections [Eq. (1)] where the right and left sides vary appreciably with energy but remain equal within the experimental uncertainty. Should this empirical agreement persist in the asymptotic limit where the Pommeranchuk theorem applies, one would find

$$\sigma(\pi N) = \frac{1}{2} \sigma(NN) \quad (7)$$

rather than the celebrated $2/3$ of the usual quark model.

In the original quark model ¹⁾⁻³⁾ in place of Eq. (1) one has the relation

$$\sigma(\pi^{-}P) + \sigma(\pi^{+}P) = \frac{1}{3} [\sigma(\bar{P}P) + \sigma(\bar{P}N) + \sigma(PP) + \sigma(PN)] \quad (8)$$

which does not agree so well with the data ⁷⁾. Equation (2) is the so-called "good" Johnson-Treiman ⁸⁾ relation and is also a consequence of the usual quark model. Rather than Eq. (3) one found previously the relation ¹⁾⁻³⁾

$$\sigma(K^{+}P) - \sigma(K^{+}N) = \sigma(PP) - \sigma(PN) \quad (9)$$

Unfortunately, one cannot choose between Eq. (3) and Eq. (9) since they are both satisfied experimentally by virtue of each side being consistent with zero. Finally, we note that Eq. (4) is common to both models.

In spite of the empirical success of the results [Eqs. (1)-(4)] it is difficult to take such an oversimplified model very seriously. Besides sharing several of the mysteries of the usual quark model (not the least of which is the existence of quarks), the present model has other puzzling features. For example, while a three-body force might help one to understand the $SU(6)$ assignment of the baryons to the $\underline{56}$, such a force strong enough to bind three massive quarks into a nucleon would very likely lead to embarrassing four- and five-quark bound states⁹⁾ unless some kind of selection rule operates. It is also difficult to understand the similarity of the forward peaking in nucleon-nucleon and nucleon-antinucleon elastic scattering in the model without simply assigning the appropriate properties to the quark interactions, ad hoc¹⁰⁾. Even the empirical agreement becomes only approximate when one tries to include the corrections for the kinematics and the annihilation processes which have been used to greatly improve the agreement of the original quark model⁷⁾. It remains to be seen at higher energies where these corrections become negligible whether the present model or the original model (or neither) will succeed.

In any event it should be emphasized that the above relations [Eqs. (1)-(4)] agree remarkably well with the data over a wide range of energy and are therefore interesting even though they might prove to have little to do with quarks.

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