the K^* and ω contributions tend to cancel each other. Actually, our sum rule obtained is Eq. (23), in the derivation of which we did not use the PCAC hypothesis (nor did we make the pion soft). Putting in numerical values for the VVP and $VP\gamma$ couplings [see Eq. (24)], we get

$$(f_1F_K/g_Q)=0.02+f_+(0)+f_-(0)$$
$$=0.97\pm0.17.$$

Thus,

$$f_1/g_Q=(1/F_K)(0.97\pm0.17). \tag{34}$$

We hope that with more available data for the Q meson,[18] it will be possible to test the sum rule [Eq. (34)] directly, without having to use the PCAC hypothesis.

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[18] Spectral-function analysis gives $g_Q|M_Q=g_{K^*}|M_{K^*}$. Then, assuming a smooth extrapolation and taking K^*-pole dominance for the K_{l3} form factor f_+, one can evaluate g_{K^*} and hence g_Q (see e.g., Das, Mathur, and Okubo in Ref. 5). However, $g_{QK^*\pi}$ still remains undetermined.

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Pomeranchukon Exchange in Inelastic Two-Body Reactions*

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Inelastic two-body and quasi-two-body reactions are classified phenomenologically. A class of events which could be interpreted as exhibiting Pomeranchukon exchange is identified. The conditions for such Pomeranchukon exchange are studied and in the production of a resonance from an incident particle, the change in spin ΔJ, and the change in parity ΔP, are found empirically to obey the relation $\Delta P=(-1)^{\Delta J}$.

TWO-BODY and quasi-two-body reactions at high energy offer the simplest means of studying reaction mechanisms. In this paper, attempts are made to classify the reactions phenomenologically.

We first consider the variation of cross section σ with incident laboratory momentum $p_{\rm in}$. Excluding threshold effects, it has been shown previously[1] that the cross section may be expressed as a power of $p_{\rm in}$ and this may be written

$$\sigma=K(p_{\rm in}/p_0)^{-n}, \tag{1}$$

where n is the exponent, K is a constant, and p_0 is a dimensional constant taken as 1 GeV/c. It is interesting to note that the constant K has about the same value for similar reactions, e.g., $\pi^\pm p\rightarrow p\rho^\pm$ and $K^\pm p\rightarrow pK^{*\pm}$, also for $K^-p\rightarrow\Lambda\pi^0$, $K^-p\rightarrow\Lambda\omega$, $K^-p\rightarrow\Lambda\rho$, $K^-p\rightarrow\Lambda f^0$, $K^-p\rightarrow\Sigma^+\pi^-$, $K^-p\rightarrow Y^{*+}(1385)\pi^-$.

It is found, as shown in Fig. 36 of Ref. 1, that the values of the exponent n, for the various two-body reactions, lead to their classification into four categories, namely (A) "quasi-elastic", (B) non-strange-meson exchange, (C) strange-meson exchange, and (D) baryon exchange, with average values of n of 0.2, 1.6, 2.0, and 3.7, respectively. Categories (B), (C), and (D) mean simply that the two-body reaction is classified in terms of the type of particle assumed to be exchanged. Category (A), however, requires some explanation; it is defined phenomenologically as the group of two-body reactions which have almost constant cross sections, and the best known example of this is elastic scattering.

In one-particle-exchange (O.P.E.) calculations, the exponent n is predicted to vary with the mass and spin of the exchanged particle, but this is not found to be so experimentally.[1] However, the Regge-pole theory offers an explanation of the four groups of n-values. Here $d\sigma/dt$ is proportional to $s^{2\alpha(t)-2}$, and as most of the two-body cross sections are concentrated near $t=0$, we may, as a first approximation, take the exponent n to be proportional to $|2\alpha(0)-2|$, The comparison between the experimental and calculated values is shown in Table I. As the cross section is actually observed at

TABLE I. Average values of the exponent n in the relation $\sigma=K(p_{\rm in})/p_0)^{-n}$ for different types of particle exchange. These n values are compared with the values of the corresponding exponent of s at $t=0$ from the Regge-Pole theory (see text).

Category	Assumed particle exchange	n experimental	Regge-pole theory $\|2\alpha(0)-2\|$
A	Pomeranchukon (+mesons)	0.2	0
B	$S=0$ meson	1.6	1.0
C	$S=1$ meson	2.0	1.4
D	Baryon	3.7	2.7

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† On leave of absence from CERN, Geneva.

[1] D. R. O. Morrison, Phys. Letters 22, 528 (1966); also, in Proceedings of the Stony Brook Conference on High-Energy Two-Body Reactions, 1966 (unpublished).

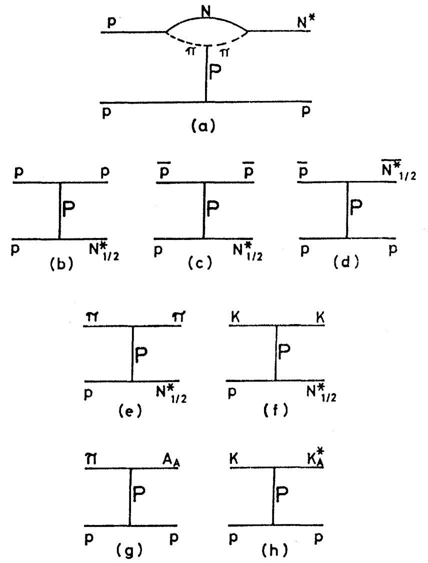

FIG. 1. Feynman diagrams where Pomeranchukon exchange is possible. A_A means a non-strange resonance of negative G parity and $J^P=0^-, 1^+, 2^-, \cdots$ $K_A{}^*$ means a strange meson with $J^P=0^-, 1^+, 2^-, \cdots$.

values of $|t|\geqslant 0$, n may be expected to be somewhat larger than $|2\alpha(0)-2|$. For the quasi-elastic category, it is assumed that Pomeranchukon exchange is possible and that its trajectory has $\alpha(0)=1$. We now assume that the quasi-elastic events of category (A) can be produced both by Pomeranchukon exchange and by non-strange-meson exchange. Thus we might expect that at low incident momenta, meson exchange may be the more important, while at high energies it will have decreased appreciably and Pomeranchukon exchange will dominate. While this evidence favors the Regge-pole theory, we will use the word "Pomeranchukon" in inelastic reactions only as a name to relate certain phenomena.

The first examples of quasi-elastic reactions were found by Cocconi *et al.*[2] in studies of the reations

$$pp\rightarrow pN^*. \tag{2}$$

Anderson *et al.*[3] have studied the same reactions, where they found that the cross sections for the production of the 1400-, 1520-, 1690-, and 2190-MeV isobars were almost constant ($n\approx 0.2$), while the cross section for 1236-MeV isobar production decreased quickly with increasing incident momentum. It has been pointed out[4] that the reaction mechanism involved could be the dissociation of a proton into a baryon and a virtual pion which then scatters off the other proton, following which it recombines with the baryon to produce the N^* isobar. This mechanism can be described as in Fig. 1 (a), where we have represented the elastic scattering as proceeding by normal "elastic Pomeranchukon" exchange. Such a mechanism requires that no isospin be exchanged so that the 1236-MeV isobar $N_{3/2}$ cannot be formed by this mechanism, which explains its nonobservation at high momenta. It has also been shown[5] that this mechanism gives a constant cross section for the production of isospin $-\frac{1}{2}$ isobars, $N_{1/2}{}^*$.

Reactions (2) can also be represented by the Feynman diagram of Fig. 1(b), where "inelastic Pomeranchukon" P exchange takes place. Figure 1(b) may be considered as the most general form of the reaction mechanism and Fig. 1(a) as a contributing diagram, though probably it is the more important one.[6]

We would now like to propose empirically that for Pomeranchukon exchange, the change in spin ΔJ is related to the change in parity ΔP between the incident particle and the outgoing resonance at the same vertex of the Feynman diagram, and is given by

$$\Delta P=(-1)^{\Delta J}. \tag{3}$$

The $N_{1/2}{}^*$ isobars of 1400, 1520, 1690, and 2190 MeV, with constant cross sections have $J^P=\frac{1}{2}^+$, $\frac{3}{2}^-(\frac{5}{2})^\pm$, and $\frac{7}{2}^-$, respectively, and so obey[7] relation (3). The $N_{1/2}{}^*$ isobar of mass 1570 MeV and $J^P=\frac{1}{2}^-$, which does not satisfy Eq. (3), is not observed by Anderson *et al.*[3] nor by Foley *et al.*,[8] though an alternative explanation could be that its cross section is an order of magnitude smaller than those of the other $T=\frac{1}{2}$ isobars, and hence is too small to be observed.

Other reactions which could proceed by Pomeranchukon exchange are shown in Figs. 1(c) to 1(h). In particular, the reactions

$$\pi^\pm p\rightarrow \pi^\pm N^* \tag{4}$$

have recently been studied by Foley *et al.*,[8] who find that the $N_{1/2}{}^*$ isobars of mass 1400 and 1690 MeV and J^P of $\frac{1}{2}^+$ and $(\frac{5}{2})^\pm$ have constant production cross sections and can satisfy[7] relation (3).

It will be assumed that the inelastic Pomeranchukon has strangeness and baryon number zero, but we now wish to test whether it has positive, negative, or no G parity and whether spin and parity changes are allowed according to Eq. (3). To do this we consider the production of mesonic resonances in quasi-two-body

[2] G. Cocconi, A. N. Diddens, E. Lillethun, G. Manning, A. E. Taylor, T. G. Walker, and A. M. Wetherell, Phys. Rev. Letters **7**, 450 (1961).

[3] E. W. Anderson, E. J. Bleser, G. B. Collins, T. Fujii, J. Menes, F. Turkot, R. A. Carrigan, Jr., R. M. Edelstein, N. C. Hien, T. J. McHahon, and I. Nadelhaft, Phys. Rev. Letters **16**, 855 (1966); and (private communication).

[4] D. Amati, J. Prentki, and L. van Hove (private communications); S. D. Drell and K. Hiida, Phys. Rev. Letters **7**, 199 (1961). The idea of diffraction dissociation on nuclei first suggested by M. L. Good and W. D. Walker [Phys. Rev. **120**, 1857 (1960)] is equivalent.

[5] Discussed further in D. R. O. Morrison, Phys. Letters **22**, 226 (1966).

[6] Another contributing diagram might be, for example, the dissociation of one proton into a hyperon and a kaon followed by the elastic scattering of the kaon on the other proton.

[7] The N^* isobar of mass 1690 MeV observed could be $\frac{5}{2}^+$ or $\frac{5}{2}^-$.

[8] K. J. Foley, R. S. Jones, S. J. Lindenbaum, W. A. Love, S. Ozaki, E. D. Platner, C. A. Quarles, and E. H. Willen, Phys. Rev. Letters **19**, 397 (1967); and (private communication).

TABLE II. Classification of reactions with incident pions and kaons which produce a mesonic resonance and a baryon, in terms of the G parity, spin J, and parity P, of the resonance and in terms of the charge of the exchanged particle. The experimental value of the exponent n, in the relation $\sigma = K(p_{in}/p_0)^{-n}$, is given for each reaction.

Resonance G	Resonance J^P	Charge of exch. particle	Reaction	n experimental	Comments	Class
Negative or none	$0^-, 1^+, 2^-, \cdots$	Zero	$\pi^\pm p \to pA_1^\pm$	0.1 ± 0.2	Constant σ	1
			$K^\pm p \to pK^{*\pm}(1320)$	≈ 0	Constant σ	
			$K^\pm p \to pK^{*\pm}(1790)$	$\cdots$		
		Nonzero	$\pi^+ n \to pA_1^0$		Not seen	2
			$\pi^+ p \to N^{*++}A_1^0$		Not seen	
			$K^- p \to nK^{*0}(1320)$		Not seen	
			$K^- p \to nK^{*0}(1790)$		Not seen	
	$0^+, 1^-, 2^+, \cdots$	Zero	$K^\pm p \to pK^{*\pm}(890)$	1.8 ± 0.1		3
			$K^\pm p \to pK^{*\pm}(1420)$	2.2 ± 0.3		
		Nonzero	$K^- p \to nK^{*0}(890)$	≈ 2		4
			$K^- p \to nK^{*0}(1420)$	≈ 2		
			$\pi^- p \to nA_2^0 \to nK_1^0K_1^0$	1.65 ± 0.35		
Positive	$0^-, 1^+, 2^-, \cdots$	Zero	$\pi^\pm p \to pB^\pm$	≈ 1.5		5
		Nonzero	$\pi^- p \to n\eta$	1.5 ± 0.1		6
			$\pi^+ n \to p\eta$	1.5 ± 0.1		
			$\pi^+ p \to N^{*++}\eta$	1.8 ± 0.3		
	$0^+, 1^-, 2^+, \cdots$	Zero	$\pi^\pm p \to p\rho^\pm$	1.8 ± 0.2		7
		Nonzero	$\pi^- p \to n\rho^0$	1.7 ± 0.2		8
			$\pi^- p \to n\omega$	$\cdots$		
			$\pi^- p \to nf^0$	1.2 ± 0.2		
			$\pi^+ n \to p\omega$	$\cdots$		
			$\pi^+ p \to N^{*++}\omega$	1.7 ± 0.4		
			$\pi^+ n \to pf^0$	$\cdots$		

reactions by incident pions and kaons which have negative or no G parity, respectively, and both of which have $J^P = 0^-$. The eight possible classes of reactions are listed in Table II. It may be seen that the cross section is constant (i.e., $n \approx 0$) only for class 1 reactions, showing that (a) the inelastic Pomeranchukon has positive G parity, (b) spin and parity changes can occur, but only when Eq. (3) is satisfied, and (c) the inelastic Pomeranchukon must be neutral (as expected since the isospin was taken as zero). It is concluded that the inelastic Pomeranchukon, which was introduced to account for the approximately constant cross sections of quasi-elastic events, has the same properties as the Pomeranchukon observed in elastic scattering, with the condition that Eq. (3) be obeyed.

A surprising result is that when the resonances that can be produced by Pomeranchukon exchange are produced in a reaction requiring the exchange particle to have nonzero charge, i.e., class 2 reactions, then these reactions have *not* been observed, although one might expect meson exchange to occur. This phenomenon is shown in Fig. 2 for the reactions

$$K^- p \to p(K\pi\pi)^-, \tag{5}$$

$$K^- p \to n(K\pi\pi)^\circ, \tag{6}$$

studied by the Aachen-Berlin-CERN-London (I. C.)-Vienna Collaboration with 10-GeV/c incident K^- mesons. It can be seen that the $K^*(1320)$ and the L meson of mass 1790 MeV, which are clearly observed in reaction (5) where Pomeranchukon exchange can occur, are not observed in reaction (6). This reduction in cross section between the two reactions is about a factor of 50 times. It should, however, be noted that Crennell *et al.*[9] have observed $K^*(1320)$ production in the strangeness-exchanging reaction

$$\pi^- p \to \Lambda K^*(1320).$$

As there appears to be some doubt about the J^P assignment of the A_2 when it decays in $(\pi\rho)$, reactions producing it have not been included in Table II. The reaction

$$\pi^\pm p \to pA_2 \tag{7}$$

has an exponent n of 0.55 ± 0.2 taken over the range $4 \leqslant p_{in} \leqslant 25$ GeV/c, which is significantly different from the value of about 1.6 that could be expected from a class 3 reaction, assuming that $J^P = 2^+$ for the A_2

[9] D. J. Crennell, G. R. Kalbfleisch, K. W. Lai, J. M. Scarr, and T. G. Schumann, Phys. Rev. Letters 19, 44 (1967).

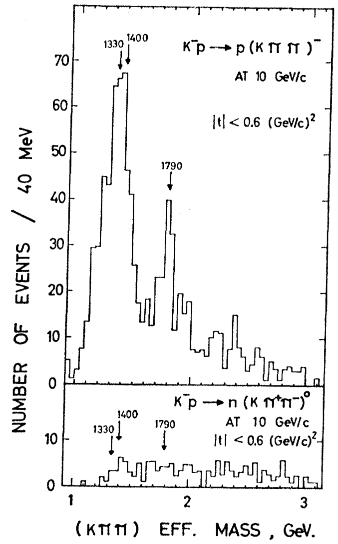

FIG. 2. $(K\pi\pi)$ effective-mass distribution with $|t|<0.6$ $(\mathrm{GeV}/c)^2$ for the reactions at 10 GeV/c. (a) $K^-p\rightarrow pK^\circ\pi^-\pi^\circ$ and $K^-p\rightarrow pK^-\pi^+\pi^-$; (b) $K^-p\rightarrow nK^\circ\pi^+\pi^-$.

meson. This has led to the suggestion[10] that there may be two $(\pi\rho)$ mesons near 1300 MeV, one with $J^P=1^+$ or 2^-, which we may call A_{2A}, and the other with $J^P=2^+$, this latter also decaying into $K\bar{K}$. Then in reaction (7) A_{2A} production would predominate, accounting for the value $n=0.55$ and for the fact that several spin-parity analyses of the $(\pi\rho)$ decay give 1^+ or 2^-. In the reactions

$$\pi^+n\rightarrow pA_2^0, \quad (8)$$

$$\pi^+p\rightarrow N^{*++}A_2^0, \quad (9)$$

the A_{2A} would not be observed as it is a class 2 reaction, and indeed J^P analyses yield 2^+ for these two reactions; and also the exponent n, for the reaction

$$\pi^-p\rightarrow nA_2^0\rightarrow nK_1^0K_1^0, \quad (10)$$

has a value of 1.65 ± 0.35 as would be expected for a class 4 reaction.

[10] D. R. O. Morrison, Phys. Letters **25B**, 238 (1967).

Although the exponent n is about the same in Pomeranchukon exchange reactions whether or not the spin of the resonance produced is different from that of the incident particle, it may be that the slope of the differential cross section $d\sigma/dt$ is different. In reactions (2) and (4), Anderson *et al.*[3] and Foley *et al.*[8] have found that the slope for production of $N^*(1400)$, which has the same $J^P=\frac{1}{2}^+$ as the incident proton, is about 18 $(\mathrm{GeV}/c)^{-2}$, whereas for production of other isobars with different J^P assignments the slope is much less, ≈ 5 $(\mathrm{GeV}/c)^{-2}$.

Although the relation $\Delta P=(-1)^{\Delta J}$ has been introduced empirically, it may be justified theoretically, as the problem is similar to that of the production of a resonance by Pomeranchukon exchange where both the incident particles are spinless.[11] Here the differential cross section $d\sigma/dt$ is required to vanish in the forward direction ($t=0$) when Eq. (3) is not satisfied. Leader[12] has shown that for the case where the incident particle has spin zero and the target particle any spin, Eq. (3) is satisfied. In this case the suppression factor for Pomeranchukon exchange will be given[13,14] by $(\sin\frac{1}{2}\theta)^2$, where θ is the scattering angle in the t channel. This suppression factor will apply to class 3 reactions where the resonance produced has $J^P=0^+, 1^-, 2^+, \cdots$, and therefore does not satisfy Eq. (3).

It is a pleasure to acknowledge helpful discussions with Dr. E. Leader, Dr. R. F. Peierls, and Dr. T. L. Trueman. The author is grateful to the Brookhaven National Laboratory for their hospitality.

[11] A. S. Goldhaber and M. Goldhaber, *Preclудes in Theoretical Physics*, edited by A. de-Shalit, H. Feshbach, and L. van Hove (John Wiley & Sons, Inc., New York, 1966), p. 313; see, also, L. Wang, Phys. Rev. **153**, 1664 (1967); V. N. Gribov, in *Proceedings of the Thirteenth Annual International Conference on High-Energy Physics, Berkeley, Calif., 1966* (University of California Press, Berkeley, Calif., 1967), paper 12b. 16. (The author is indebted to Dr. H. Lubatti and Professor L. van Hove for drawing these papers to his attention.) G. C. Fox and E. Leader, Phys. Rev. Letters **18**, 626 (1967); E. Squires (private communication).

[12] E. Leader, Cavendish Laboratory, Cambridge, Report No. HEP 67-6, see Eq. (117) (unpublished).

[13] M. Gell-Mann, M. L. Goldberger, F. E. Low, E. Marx, and F. Zachariasen, Phys. Rev. **133**, B145 (1964).

[14] T. L. Trueman, Phys. Rev. Letters **17**, 1198 (1966).