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[2]It is a consequence of the TCP theorem that the g factors of particle and antiparticle are equal. Thus our result should be checked against the theoretical and experimental values of the electron anomaly. The coefficient of α^3 used here is a preliminary number from a new perturbation theory calculation by J. A. Campbell, University of Texas (private communication). His result is about ten times greater than previous dispersion-theory estimates, but it is still too small to affect our results. The value of α^{-1} used is based on non-quantum-electrodynamic data. See B. N. Taylor, W. H. Parker, and D. N. Langenberg, Rev. Mod. Phys. 41, 375 (1969).

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SELECTION RULES FOR DIFFRACTION DISSOCIATION*

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(Received 2 September 1969)

The concept that internal quantum numbers do not change in diffractive production is extended to the quantum numbers of the quark model. The resulting approximate selection rules are discussed and compared with the predictions of other models.

Diffraction-dissociation reactions are processes having approximately constant cross sections like elastic scattering. In Regge theory, they are the reactions which go by Pomeranchukon exchange. While we know that for a reaction such as $a+b \to c+b$ the internal quantum numbers B, S, I, G, etc., do not change from a to c, there has been some controversy about selection rules for changes of spin and parity. For example, Morrison[1] has given an empirical rule, $\Delta P = (-1)^{\Delta J}$, while Chou and Yang[2] have suggested that the production cross section vanishes in the forward direction unless the product of the intrinsic parities of all particles is positive. In the present paper we extend the idea that internal quantum numbers are conserved in diffraction dissociation and arrive at new rules for allowed production which agree with Morrison or Chou and Yang in some, but not all, cases. Corresponding with which these additional quantum numbers may be specified, we predict a hierarchy in strengths of diffraction production processes.

The rule that there is no change of B, S, I, and G is clearly indicated by experimental evidence[3] that cross sections for reactions involving the exchange of any of these quantum numbers fall rapidly at high energies. The preservation of internal quantum numbers also follows from popular theoretical picutres of diffraction dissociation: (i) If diffraction dissociation of a compound state results from elastic scattering of its components, then no internal quantum number changes. (ii) If the diffraction-dissociation amplitude is built up by unitarity from a coherent sum over intermediate states,

$$\operatorname{Im} A(ab \to cb) = \sum_n A^*(ab \to n)\rho_n A(n \to cb),$$

maximum coherence occurs when the quantum numbers of the final state are as close as possible to the quantum numbers of the initial state.

In specific models, states are characterized by further internal quantum numbers. Since internal quantum numbers should not change in diffraction dissociation, these models give rise to additional selection rules. However, such models are only approximate so one expects a hierarchy in diffractive production—some reactions are fully allowed, others occur only through a violation of the model.

The example we shall consider in this paper is the quark model. We expect, in addition to the usual rules for diffractive production, no change in the SU(6) representation and [for SU(3) substates] no change in "quark spin" or in the generalized charge conjugation number $\mathfrak{C}$.[4]

We shall list the consequences of these rules for some practical cases and discuss their relation to the data. A summary of the predictions is presented in Tables I and II.

$\underline{\pi N \to \pi^* N.}$—In the usual quark model, the π is a $^1S_0$, $G=-1$ state of $q\bar{q}$ in the $\underline{35}$ representation of SU(6). Thus it should go preferentially to $^1L_{J=L}$, $G=-1$, $\underline{35}$ π^* states such as $^1D_2$ (1640 MeV?), $^1S_0$ satellites, etc. It can go via violation of quark-spin-conservation to $^3P_1$ (A_1) and $^3P_2$ (A_2). This will give a small "constant" component to the production cross section of these states. It cannot go to $^1P_1$ (B) because of G conservation.

$\underline{KN \to K^*N.}$—The K is a $^1S_0$ state, a member of a $\mathfrak{C}=+1$ octet in the $\underline{35}$ representation of SU(6). It should go preferentially to $^1L_{J=L}$, $\mathfrak{C}=+1$, $\underline{35}$ K^* states such as $^1D_2$ (1780?), $^1S_0$ satellites, etc. The K can go via violation of quark-spin conservation to $^3P_1$ (1240) and $^3P_2$ (1420) yielding small "constant" cross sections. It can go via $\mathfrak{C}$ violation [i.e., SU(3) breaking] to $^1P_1$ (1320).

$\underline{NN \to N^*N.}$—The nucleon is a qqq compound, a $\underline{56}$, $L=0$ state with quark spin $S=\frac{1}{2}$. Thus it should go preferentially to $S=\frac{1}{2}$ members of $\underline{56}$, L states[5] such as $N^*(1688)$ ($\underline{56}$, $L=2$), $N^*(1470)$ ($\underline{56}$, $L=0$ satellite?), etc. It can go via SU(6) breaking to $\underline{70}$, $L=1$, $S=\frac{1}{2}$ states such as $N^*(1518)$, and via SU(6) and quark-spin breaking to $\underline{70}$, $L=1$, $S=\frac{3}{2}$ states such as $N^*(1710)$.

Morrison's[1] rule $[\Delta P=(-1)^{\Delta J}]$ for diffraction dissociation can be derived theoretically for production occurring via natural-parity exchange if particle a is spinless and if only the zero-helicity state of c is produced. These assumptions hold at 0° for a nonconspiring Pomeranchukon and at all angles for spinless c. In other cases, the rule has a purely empirical basis. It is therefore of interest to investigate Morrison's rule in other theoretical models. The rules proposed here agree with Morrison's in a number of cases; for example, quark-spin conservation would forbid $\pi N \to A_2 N$. Since quark-spin conservation is only approximate, we would, however, expect a small constant component to the A_2-production cross section. In addition our rules allow transitions, such as $NN \to N^*(\underline{56}, L=2, J^P=\frac{3}{2}^+)N$, which are forbidden by Morrison. Also, there are many cases where $\Delta P=(-1)^{\Delta J}$ allows transitions that are forbidden by our rules, such as $NN \to N^*(\underline{70}, L=1, J^P=\frac{3}{2}^-)N$.

Our results are also similar, in some respects, to those of Chou and Yang.[2] If we deal only with the conventional quark-model states ($\underline{35} \oplus \underline{1}$ all L mesons; $\underline{56}$ even L, $\underline{70}$ odd L for baryons), our class of allowed reactions $a+b \to c+b$ is the same

Table I. Summary of quark-model predictions for diffraction dissociation into low-lying nucleon resonances: $N+N \to N^*+N$.

Produced Particle	J^P	Quark Classification	Allowed?	Forbidden By
N(940)	$1/2^+$	$\underline{56}$, L = 0, S = 1/2	yes	
N^*(1470)	$1/2^+$	$\underline{56}$, L = 0, S = 1/2	yes	
N^*(1518)	$3/2^-$	$\underline{70}$, L = 1, S = 1/2	no	SU(6)
N^*(1550)	$1/2^-$	$\underline{70}$, L = 1, S = 1/2	no	SU(6)
N^*(1680)	$5/2^-$	$\underline{70}$, L = 1, S = 3/2	no	SU(6), S
N^*(1710)	$3/2^-$	$\underline{70}$, L = 1, S = 3/2	no	SU(6), S
N^*(1730)	$1/2^-$	$\underline{70}$, L = 1, S = 3/2	no	SU(6), S
N^*(1688)	$5/2^+$	$\underline{56}$, L = 2, S = 1/2	yes	
N^*(1860?)	$3/2^+$	$\underline{56}$, L = 2, S = 1/2	yes	
N^*(1750)	$1/2^+$	$\underline{56}$, L = 0, S = 1/2	yes	
N^*(2190)	$7/2^-$	$\underline{70}$, L = 3, S = 1/2	no	SU(6)

Table II. Summary of quark-model predictions for diffraction dissociation into low-lying meson resonances: $\pi(K)+N\to\pi^*(K^*)+N$.

Produced Particle	J^P	Quark Classification	Allowed?	Forbidden By
$\pi(140)$	0^-	$^1S_0$	yes	
$\rho(750)$	1^-	$^3S_1$	no	G
B(1220)	1^+	$^1P_1$	no	G
$\delta(962)$	0^+	$^3P_0$	no	P[a], S
$A_1(1070)$	1^+	$^3P_1$	no	S
$A_2(1315)$	2^+	$^3P_2$	no	S, P[b]
$\pi_A(1640)$?	2^-	$^1D_2$	yes	
	1^-	$^3D_1$	no	G, S, P[b]
	2^-	$^3D_2$	no	G, S
	3^-	$^3D_3$	no	G, S, P[b]
K(495)	0^-	$^1S_0$	yes	
$K^*(890)$	1^-	$^3S_1$	no	S, $\mathcal{C}$, P[b]
$K^*(1320)$	1^+	$^1P_1$	no	$\mathcal{C}$
$K\pi(1100)$	0^+	$^3P_0$	no	P[a], S
$K^*(1240)$	1^+	$^3P_1$	no	S
$K^*(1420)$	2^+	$^3P_2$	no	S, P[b]
L(1780)?	2^-	$^1D_2$	yes	
	1^-	$^3D_1$	no	S, $\mathcal{C}$, P[b]
	2^-	$^3D_2$	no	S, $\mathcal{C}$
	3^-	$^3D_3$	no	S, $\mathcal{C}$, P[b]

[a]Absolutely forbidden for natural-parity exchange.
[b]Production of helicity-zero state vanishes for natural-parity exchange.

as theirs in the forward direction.[6] Chou and Yang predict forward dips for all forbidden reactions. In contrast, we expect a small constant cross section for "forbidden" processes, with a t dependence similar to that for "allowed" reactions. We do, however, expect forward dips in $\pi(K)N\to\pi^*(K^*)N$, where π^* (K^*) has natural parity $(1^-, 2^+, \cdots)$.[7] This dip may be used as an aid in separating the resonant production amplitude from background.

For $a+b\to c+d$ there are further disagreements with Chou and Yang. For example, they allow $N+N\to N^*(1518)(\frac{3}{2}^-)+N^*(1518)(\frac{3}{2}^-)$, while according to our rules it is doubly forbidden.

The data on diffraction dissociation into particular states are very tentative. It is hard to separate peaks from background, and the J^P of peaks is not directly identified in most cases. These difficulties are reflected in the fact that measurements of the same cross section at similar energies by different groups typically differ by factors of 2.

Considerable confusion in interpreting measured cross sections arises from the question of what fraction of the Deck effect should be counted as resonant. We would like to point out that one can sometimes sidestep this question by choosing decay modes for a given resonance for which the Deck contribution will be unimportant.[8] For example, Rushbrooke[9] has shown that in $N+N\to N+(\pi N)$ the Deck effect contributes dominantly to the $\frac{1}{2}^+$ and $\frac{1}{2}^-$ (πN) states. Thus the production of $\frac{3}{2}^{\pm}$, $\frac{5}{2}^{\pm}$, $\cdots$, resonances decaying into $\pi+N$ will not be contaminated by a Deck background. For $N+N\to N+(\pi\Delta)$ the Deck effect contributes dominantly to $\frac{1}{2}^{+}$ and $\frac{3}{2}^{-}$ $(\pi\Delta)$ states, allowing a clean determination of the $\frac{1}{2}^{-}$, $\frac{3}{2}^{+}$, $\cdots$, production.

There is also a theoretical complication in estimating the cross sections for high-mass resonances whose production is allowed by our model. For example, in $\pi+N\to\pi^*+N$, the cross sections for the production of the pion recurrences cannot all be equal, since their sum would soon exceed the "constant" total cross section. Presumably this is accomplished by a damping of the production of massive recurrences, though it is hard to estimate what rate of damping one should expect.

In N^* production,[10] we note that the dominant features are peaks at 1400 and 1690 MeV which, in our model, correspond to allowed $\frac{1}{2}^{+}$ and $\frac{5}{2}^{+}$ resonances (see Table I). Smaller peaks are also seen at 1520 and 2190 MeV corresponding to the SU(6)-forbidden $\frac{3}{2}^{-}$, $(\frac{1}{2}^{-})$, and $\frac{7}{2}^{-}$ resonances. The size of the cross sections for production of these resonances is evidence for the degree of SU(6) breaking. No peaks have been seen which correspond to the other allowed states in Table I [N^*(1750, N^*(1860)]. However, these states have been seen only in phase-shift analyses and appear there with large widths.

In meson production, the ambiguities in the data and the previously mentioned difficulties of interpretation prevent a meaningful test of our rules at the present time.

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*Work supported in part by the U. S. Atomic Energy Commission. Prepared under Contract No. AT(11-1)-68 for the San Francisco Operations Office, U. S. Atomic Energy Commission.

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[3]D. R. O. Morrison, Phys. Letters 22, 528 (1966).

[4]R. Carlitz (to be published) has made an independent derivation of these rules in a more detailed model involving duality.

[5]Quark-model assignments are given in Table I. A. Donnachie, in Proceedings of the Fourteenth International Conference on High Energy Physics, Vienna, Austria, September, 1968, edited by J. Prentki and J. Steinberger (CERN Scientific Information Service, Geneva, Switzerland, 1968), p. 155.

[6]Had we used a different quark-model classification, including, for example, 56 odd-L states, then our results would not be the same.

[7]This follows from the general rule for production by natural-parity exchange at zero degrees.

[8]R. Silver and G. Zweig, to be published.

[9]J. G. Rushbrooke, Phys. Rev. 177, 2357 (1969).

[10]C. Belletini et al., Phys. Letters 18, 167 (1965); E. W. Anderson et al., Phys. Rev. Letters 16, 855 (1966); J. M. Blair et al., Phys. Rev. Letters 17, 789 (1966); C. Gellert et al., Phys. Rev. Letters 17, 884 (1966); K. J. Foley et al., Phys. Rev. Letters 19, 397 (1967).

CABIBBO ANGLE AND SELF-CONSISTENCY CONDITION*

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A solution of the c-number self-consistency condition $a_l-d_{ljk}a_ja_k=h_l$ is obtained, where a_l represents the matrix elements of unitary octet vector charge and h_l is a driving term. With a reasonable choice of a driving term, we obtain $\sin\theta=0.22-0.14$ for the Cabibbo angle θ. The choice of h_l that leads to $\tan\theta=m_n/m_\Lambda$ (where m_n and m_Λ are the quark masses) is also pointed out.

It is conjectured that the weak and electromagnetic properties of hadrons are determined by self-consistency requirements and, in particular, that the Cabibbo angle is an inherently weak effect. A solution of the c-number equations ($i=1, 2, \cdots, 8$)

$$a_l-d_{ljk}a_ja_k=0, \qquad (1)$$