CM-P00056974

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A DYNAMICAL SCHEME OF MESON SUPERMULTIPLETS, POSSIBLE ASSIGNMENTS,
AND BRONZAN-LOW ¹⁾ QUANTUM NUMBERS

Chan Hong-Mo and C. Wilkin
CERN, Geneva

An attempt is made to fit the mesonic resonances reported to-date into a scheme suggested by a dynamical model ²⁾⁻⁶⁾. It is found that all reasonably well-established enhancements fit comfortably into the scheme except for the $I_z = 3/2$ enhancement reported at 1270 MeV ⁷⁾. A suggestion of Bronzan and Low ¹⁾ for a new empirical quantum number is taken up and tentative assignments are made to the new resonances. The resulting list (Table I) shows some remarkable regularities. Decay modes of further resonances suggested by the scheme are listed in Table II.

1. In recent investigations ²⁾⁻⁵⁾ on the consequences of the bootstrap hypothesis in low-energy mesonic interactions, it was found that in addition to the well-known vector and pseudoscalar octets, one requires for self-consistency a singlet ²⁾ and an octet ²⁾⁻⁴⁾ of scalar mesons, a singlet of pseudoscalar meson ⁵⁾, and an octet of pseudovector mesons ⁵⁾. Further, the forces in the $J^P = \text{even} +$ and even $-$ channels were found to be strong enough to "bind" spin 2 resonances ^{2),5)}. An estimation by the model yields the mass values of ~ 1 GeV and 1.5 GeV for the singlet and octet respectively both for 2^+ and 2^- ^{2),5)}. Most of the calculations of masses and coupling constants were performed using a crude bootstrap mechanism, namely that of Zachariasen and Zemach ⁸⁾, and are thus significant at most in an order-of-magnitude sense. However, it is believed that the qualitative predictions are consequences of more general dynamical assumptions frequently made in models of strong interactions. These are namely :

- (i) dominance of low-threshold processes in low-energy interactions;
- (ii) dominance of one-particle-exchange forces;
- (iii) approximate SU_3 symmetry.

In an extension of the model to higher energy ⁶⁾, the 1^- and 1^+ singlet channels which were absent in earlier models for obvious kinematical reasons, also show strong attractive forces and resonances are expected.

The meson supermultiplets predicted by these models are listed together with their charge conjugation properties in Table I ^{*)}.

Many of the resonances suggested here have also been proposed by other authors on various grounds. In particular in a symmetry scheme of strong interactions under $SU_3 \times SU_3$ suggested by Gell-Mann and others ^{9),10)}, particles are required to belong to super-supermultiplets containing particles of both parities. The pseudoscalar octet has been assigned by Gell-Mann ⁹⁾ to the $(3^*,3)-(3,3^*)$ representation in order to satisfy the Goldberger-Treiman relation in the symmetric limit. This assignment requires exactly the 18 spin 0 mesons with the charge conjugation properties listed in Table I ^{**)}. The $2^+, 2^-$ resonances suggested here, being Regge recurrences of the $0^+, 0^-$ mesons, presumably have the same assignment in this scheme. Similarly the 18 spin 1 resonances listed may be accommodated in a $(3^*,3)-(3,3^*)$ super-supermultiplet ^{***)}. Gell-Mann ⁹⁾, however, has chosen the more natural assignment, $(1,8)-(8,1)$, for the spin 1 mesons, namely the same assignment as for the currents. The pseudovector octet of his assignment has the opposite charge conjugation parity to those suggested here.

2. We next attempt to fit the mesonic resonances reported to-date into our present scheme. It should be noted that this model differs from usual symmetry schemes in one important aspect. Namely, since definite dynamical assumptions

^{*)} In Table I and throughout this paper we denote meson supermultiplets by $J^P(X^C)$, where J = spin, P = parity, X = dimension of SU_3 representation, C = charge conjugation parity.

^{**)} These scalar mesons have the opposite charge conjugation to those proposed by Riazuddin and R.E. Marshak, Phys. Lett. 11, 182 (1964).

^{***)} This assignment is subject to the same criticism of J.J. Sakurai (Dubna Conference 1964) as the other nonet assignments of the vector mesons.

have been made, it allows us not only to predict the existence of certain supermultiplets but also to exclude the existence of others. The contention of the model in its present form is thus that only those supermultiplets listed in Table I and no others should exist at "low" energy.

Only the recently reported or reconfirmed resonances will be discussed below. Where several possible assignments exist we choose the one preferred by the dynamics of the model. Thus, for example, since the singlet channels usually show stronger attractive forces than the octet channels ^{2),5)}, those assignments are preferred where the singlets have lower masses than the octets.

- (a) $K(725)$, $(K-\pi)$ resonance, 725 MeV ¹¹⁾. Further evidence of its existence has recently been reported. Data suggest $I = \frac{1}{2}$, $J^P = 0^+$. We assign it to $0^+(8^+)$.
- (b) B , $(\pi-\omega)$ resonance, 1220 MeV ¹²⁾. $I = 1$, $G = +$, i.e., $C = -$. Spin and parity are yet uncertain although the apparent absence of 2π and $2K$ decay modes suggests 1^+ or 2^- . The only possible assignment in the present scheme is $1^+(8^-)$.
- (c) f_0 , (2π) resonance, 1250 MeV ¹³⁾. $I = 0$, $G = +$, i.e., $C = +$. $J^P = 2^+, 4^+, \dots$. It may be assigned here either to $2^+(1^+)$ or $2^+(8^+)$. We prefer $2^+(1^+)$.
- (d) A_2 , $(\pi-\rho)$ resonance, 1320 MeV ¹⁴⁾. $I = 1$, $G = -$, i.e., $C = +$, $J^P = 2^+, 4^+ \dots$. $2K$ decay modes are also seen. The only possible assignment here is $2^+(8^+)$.
- (e) A_1 , $(\pi-\rho)$ resonance, 1080 MeV ¹⁵⁾. Its being a Peierls-Nauenberg-Pais effect is unlikely though not entirely ruled out. Analysis as a resonance gives $I = 1$, $G = -$, i.e., $C = +$, $J^P = 1^+$ or 2^- , with preference for 2^- . A natural assignment in the present scheme is $2^-(8^+)$.
- (f) H , $(\pi-\rho)$ resonance, 975 MeV ¹⁶⁾. This was reported by the Aachen-Berlin-Birmingham-Bonn-Hamburg-London (I.C.)-München group who suggested the quantum numbers $I = 0$, $G = -$, i.e., $C = -$, $J^P = 1^+$ or 2^- . If these quantum numbers are accepted, it may be assigned to $1^+(1^-)$ or to $1^+(8^-)$. We prefer the assignment $1^+(1^-)$.

- (g) C , $(\pi\pi-K^*)$ resonance, 1230 MeV ¹⁷⁾. Little is known about its quantum numbers. The absence of $\pi\pi-K$ decay suggests $J^P = 0^-, 1^+$ or 2^- . If $I = \frac{1}{2}$, it can be assigned to $1^+(8^-)$ or $2^-(8^+)$. We prefer the assignment $2^-(8^+)$.
- (h) X_0 , $(\eta-\pi-\pi)$ resonance, 959 MeV ¹⁸⁾. $I = 0$, $G = +$, i.e., $C = +$. The data suggest $J^P = 0^-,$ or 2^- favouring 0^- . Possible assignments in our scheme are $0^-(1^+)$, $2^-(1^+)$, $2^-(8^+)$. We prefer the assignment $2^-(1^+)$.
- (i) E , $(K-K^*)$ resonance, 1410 MeV ¹⁹⁾. Seen only in charge 0 state suggesting $I = 0$. Little is known about its quantum numbers. Several assignments are possible in our scheme. Our tentative assignment is $2^-(8^+)$ *).
- (j) $K^+-\pi^+-\pi^0$ enhancement with $I_z = 3/2$, 1270 MeV ⁷⁾. There is no possible assignment in the present scheme.

It may be seen that all reasonably well-established mesonic enhancements reported to-date fit comfortably into the scheme except for (j). The possible difficulties of the scheme especially those concerning the scalar mesons are obvious and have been discussed elsewhere ^{2),5),9)}.

3. Bronzan and Low ¹⁾ have suggested an empirical quantum number A for mesons to explain the suppression of certain modes of decay otherwise allowed by known selection rules. A -parity was supposed to be violated by strong interactions to the extent of a few percent in the rates. We shall assume in what follows that such a selection rule does operate and assign to each new resonance a Bronzan-Low quantum number using the available data.

The assignments for π, K, η ; ρ, K^*, ϕ, ω have already been discussed ¹⁾.

*) The tentative assignment of E , C and A to the same octet does not satisfy the Gell-Mann-Okubo mass formula if the squares of the masses are used.

- (a) If $K(725)$ is indeed a scalar resonance then its narrow width¹¹⁾ suggests a very weak coupling, consistent with a suppression due to A-violation, i.e. $A_K = -1$.

Dynamical calculations²⁾ also show a weak coupling of the $0^+(8^+)$ to the pseudoscalar mesons $0^-(8^+)$, g^2 being only of order of a few percent of that for $\rho\pi\pi$ coupling. This is consistent with the Bronzan-Low idea and the present assignment of A.

- (b) $B \rightarrow \pi(A = -) + \omega(A = -)$ is strong¹²⁾, suggesting $A_B = +1$.
- (c) $f_0 \rightarrow \pi(A = -) + \pi(A = -)$ is strong, suggesting $A_f = +1$.
- (d) $A_2 \rightarrow \pi(A = -) + \rho(A = +)$ is strong¹⁴⁾, suggesting $A_{A_2} = -$.
- (e) Similar to (d)¹⁵⁾, $A_{A_1} = -20$.
- (f) Similar to (d)¹⁶⁾, $A_H = -$.
- (g) $C \rightarrow \pi(A = -) + K^*(A = +)$ is strong¹⁷⁾, suggesting $A_C = -20$.
- (h) The decay $X_0 \rightarrow \eta(A = -) + \pi(A = -) + \pi(A = -)$ ¹⁸⁾ has a narrow width, < 12 MeV, whereas the electromagnetic decay $X_0 \rightarrow \pi(A = -) + \pi(A = -) + \gamma(A = +)$ ¹⁸⁾ is appreciable. We therefore suggest $A_X = +$, though this may not be necessary since the $\eta\pi\pi$ decay is already much suppressed by phase space²⁰⁾.
- (i) $E \rightarrow K(A = -) + K^*(A = +)$ ¹⁹⁾ is strong, suggesting $A_E = -1, 20$.
- (j) No comment.

These assignments are listed in Table I. The various decay modes of the new resonances have not been sufficiently studied either to support or disprove the validity of the Bronzan-Low selection rule. However, the A_2 resonances which decays predominantly into $\pi - \rho$ has also been seen in the mode $K - \bar{K}$ ¹⁴⁾. According to Bronzan and Low¹⁾, the second mode should be suppressed. These authors have suggested that the selection rule may be valid only at low energy where baryon pair effects are negligible. If so the suppression of A-violating decays of high-mass resonances is expected to be less pronounced.

4. The proposed list shows some interesting regularities :

- (i) The parity-doubling of supermultiplets of the type suggested by Gell-Mann⁹⁾, Salam-Ward¹⁰⁾ and others in $SU_3 \times SU_3$ invariant models.
- (ii) Recurrence of resonances with the same quantum numbers and the same signature (Regge recurrence).
- (iii) Where assignments to more than one member of a supermultiplet have been made, A-parity is the same for all members of the supermultiplet^{*)}.
- (iv) Parity-doublets have the same charge conjugation parities and the same A-parities.
- (v) The singlets and octets in the same super-supermultiplets have the same charge conjugation parities but opposite A-parities^{**)}.
- (vi) Regge recurrences have the same charge conjugation parities and the same A-parities.
- (vii) Since $A = RC$ ¹⁾, it follows that R is negative for all the octets and positive for the singlets.
- (viii) Singlets have lower masses than the octets. This regularity is in most cases imposed by the choice of assignments.
- (ix) Within an octet where all members are known we have $m(I = 1) < m(I = \frac{1}{2}) < m(I = 0)$. Where only one or two multiplets are known in a super-multiplet, they are $I = 1, I = \frac{1}{2}$ in that order, so that the unknown members may be assumed to have higher masses, consistent with the mass inequalities above. An exception is the $0^+(8^+)$ octet.

*) The difficulty encountered in reconciling the Bronzan-Low selection rule with the theory of ϕ - ω mixing has been discussed by the original authors, Ref. ¹⁾.

***) It may be relevant to remark in this connection that according to Gell-Mann⁹⁾ $SU_3 \times SU_3$ symmetry may correspond to the limit : baryon mass $\rightarrow$ zero; whereas the Bronzan-Low selection rule is supposed to hold only when the baryon mass is high compared with the energy considered.

5. In Table II we list the quasi-two-particle strong decay modes of the $1^+(8^-)$, $2^-(8^+)$, $2^+(8^+)$ mesons suggested by the present scheme. Dominant modes are expected to be the A-conserving modes. Masses quoted in brackets should be taken as very speculative and at best only as orders of magnitude.

Supermultiplet	Assignments	A	Supermultiplet	Assignments	A
$0^-(1^+)$ $0^-(8^+)$	$X_0 ?$ π, K, η	+ -	$0^+(1^+)$ $0^+(8^+)$	Pomeranchuk ? , $\chi(725)$,	+ -
$1^-(1^-)$ $1^-(8^-)$	ω ρ, K^*, ϕ	- +	$1^+(1^-)$ $1^+(8^-)$	H, B,	- +
$2^-(1^+)$ $2^-(8^+)$	$X_0 ?$ $A_1, C, E ?$	+ -	$2^+(1^+)$ $2^+(8^+)$	f_0 A_2 ,	+ -

TABLE I

$J^P(X^C)$	I	Mass	A-conserving modes	A-violating modes
$1^+(8^-)$	1 $\frac{1}{2}$ 0	B, 1220 MeV (1500) (1700)	$\pi \omega$ $K \omega$ $\eta \omega$	$K \rho, K^* \pi, K^* \eta$ $\pi \rho, \bar{K} K^*, \eta \phi$
$2^-(8^+)$	1 $\frac{1}{2}$ 0	A_1 , 1080 C, 1230 E, 1410	$\pi \rho$ $\pi K^*, K \rho$ $\bar{K} K^*$	$K \omega$
$2^+(8^+)$	1 $\frac{1}{2}$ 0	A_2 , 1320 (1500) (1800)	$\pi \rho$ $\pi K^*, K \rho$ $\bar{K} K^*$	$\pi \eta, \bar{K} \bar{K}$ $\pi K, \eta K, K \omega$ $\pi \pi, \bar{K} \bar{K}, \eta \eta$

TABLE II

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