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NOTE ON BOSON RESONANCES

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Abstract

It is pointed out that a simple model for boson resonances in terms of spin-½ baryon-antibaryon pairs is in striking qualitative accord with current data and may merit further pursuit. An empirical test is available, since the model anticipates five sets of positive parity resonances in the region ≳ 1 Bev., with spins 2, 1, and 0. A complication implied by the model is the presence of other symmetry clashes beside those including SU_3, in order to interpret the 1^- mass values and their correlation with charge parity.

1. Introduction

The earliest and simplest model for boson resonances was to regard the π meson as a nucleon-antinucleon compound [1]. The following note considers a minimal extension of this simple model to incorporate strange particles:

I) The dominant term in the 'internal structure' of a boson resonance is still represented as a baryon-antibaryon combination from the spin-½ octet $N\Lambda\Sigma\Xi$.

II) The strong interaction responsible for this compound structure has a charge space symmetry determined by various (incompatible) subgroups of R_8: *viz.*, SU_3, R_7, G_2.

Although this model must be greatly oversimplified, it is in complete qualitative accord with present data on boson resonances. It may therefore be worth while to discuss it in some detail as a sort of zero-order approximation, experimental deviations from which would be of particular interest to establish.

The assumptions above must be qualified by remarking that many secondary terms may occur in the boson internal structure; among these we consider only the two-boson term and conclude that it appears secondary to (I). The effect of (II) is to restrict the model to charge octets, which is the smallest representation (not necessarily irreducible) common to all the groups invoked. Since R_7 and G_2 can have only $\mathbf{8} = \mathbf{7} + \mathbf{1}$, the singlet representation is already involved for at least these subgroups, and we do not anticipate any additional charge singlets. One other subgroup of R_8 could in principle contribute to charge octets: namely, R_4 where $\mathbf{8} = \mathbf{4} + \mathbf{4}$. No present empirical evidence favors R_4 charge symmetry in strong interactions, however, and it will not be introduced here.

On this basis the $(\pi\eta K)$ mesons appear at once as ${}^1S_0$ states of the baryon-antibaryon pair. Observation of the vector mesons $(\rho\omega K^*)$ immediately suggested [2] the same model in ${}^3S_1$ states. Subsequent discoveries of many boson resonances have obscured this simple picture, which can be sufficiently restored by overcoming the following difficulties:

i) An isosinglet ϕ of spin 1^- occurs at 1010 MeV [3].

ii) An isospinor κ of spin $\gtrsim 1$ has appeared at about 725 MeV [4].

iii) An isosinglet ABC of spin 0^+ is mooted just above 300 MeV [5].

iv) An isosinglet enhancement of probable spin 0^+ is inferred around 1000 MeV [6].

The next section discusses the implications of (i)–(iv) for the model; section 3 discusses mass symmetries and correlates them with an important charge parity operator; section 4 applies the model to boson resonances now emerging at $M \gtrsim 1$ Bev.

2. Triplet Doubling and Boson Interactions

Consider first items (i) and (ii). The baryon-antibaryon model anticipates doubling of the 1^- states by strong tensor effects that mix $^3S_1$ and $^3D_1$ components [7] just as in the deuteron. The two members of a doublet will be 'radially' orthogonal (*i.e.*, in the S-D mixture) but will be identical in all external quantum numbers. Thus, the (ω, ϕ) can be associated at once as radial doublets and the (K^*, κ) by the plausible assumption of spin 1^- for the κ; where is the doublet partner for the ρ? Earlier experimental literature offered two possibilities: the ζ [8] with a mass around 575 MeV on the double-humped ρ [9] in which the two components were separated by the order of a half-width and therefore hardly resolvable. Further experiment seems to have disposed of the first, but the second is intrinsically much more difficult to rule out and in fact appears to draw support from quite recent measurements [10]. We therefore assume two components, $\rho_{1,2} = 750 \pm 30$ MeV.

Of course so simple a model has very severe limitations: One would not expect it to be reliable or consistent for computing matrix elements, which appear to vary strongly between corresponding members of a 'radial doublet' [11]. An important exception to this variation in the vector mesons should be their decay rates into two pseudoscalar mesons. The two-pseudoscalar component in a vector wave function is a 'radial singlet' and should therefore have comparable matrix elements for both members of the radial doublet formed by the baryon-antibaryon interaction. This expectation is borne out in Table I, where the observed decay widths are compared to the kinetic factor (p^3M^{-2}) with p the decay momentum and M the initial mass. The good qualitative agreement of the two columns indicates that there is no substantial difference in effective coupling constants. This suggests that the K^*, κ, ρ and ϕ are quite comparable, in spite of apparent strong differences in production and decay.

TABLE I
Comparative Decay Widths

Decay	Γ	p^3/M^2
$K^* \to \pi + K$	~50 MeV	30 MeV
$\kappa \to \pi + K$	< 20	7
$\rho \to 2\pi$	~100	75
$\phi \to 2K$	~3	1.8

Now consider items (iii) and (iv). On the present model of dominant baryon-antibaryon effects only one true scalar resonance is expected ($^3P_0$) and that in the range ~1.5 Bev. Then (iii) and (iv) must be multiboson effects alone and as such too weak to be real resonances. They represent instead a threshold effect: the rapid increase of a phase shift with energy from zero at the threshold to some maximum value less than $\pi/2$, followed by a monotonic decline with increasing energy. This behavior is already established for the π–π phase shift [12] and can perhaps be made plausible in general. Any two-meson state with the parameters of the vacuum can be connected to the vacuum by quadratic terms $\delta m^2(\Psi^*\Psi)$, and such terms will always produce a net attractive 'potential' for non-relativistic states near threshold. A weak attractive potential produces just the phase shift behavior described by distorting the distribution of final states [13] in a reaction. Hence one observes a pseudoresonance in a variable energy region immediately above the threshold. Such pseudoresonances are expected at $\gtrsim 300$ MeV for π–π and $\gtrsim 1000$ MeV for K–$\bar{K}$; we must ascribe the π–π attraction in η decay [14] to this effect.

The arguments of the last two paragraphs indicate that boson-boson interactions are of secondary importance in determining the existence of boson resonances, which is just the complement of the model assumption (I). It is consistent with this view that attempts to estimate spin and parity for the f_0 and B from boson-boson models [15] should lead to a fairly random assortment in the range $J^P = (1 \text{ or } 2)^\pm$.

3. Mass Systematics and Charge Parity

The m^2 values of the ${}^1S_0$ mesons obey very closely a formula expressing deviation from a fundamental SU_3 symmetry [16]. If one demands equally reassuring systematics from the $({}^3S_1 + {}^3D_1)$ masses, the inclusion of other symmetries is clearly necessary. A sufficient possibility is to allow arbitrary admixtures of three incompatible subgroups of R_8: SU_3, R_7 and G_2. The details of this situation have been examined [17], and the most general mass formula resulting for bosons is (I = isospin, Y = hypercharge)

$$m^2 = m_0^2 + a\left\{\left[I(I+1) - \frac{9}{8}\right] - \frac{1}{4}\left(Y^2 - \frac{1}{2}\right)\right\} + b\left\{\left[I(I+1) - \frac{9}{8}\right] + \frac{5}{4}\left(Y^2 - \frac{1}{2}\right)\right\}. \tag{1}$$

Since terms linear in Y cannot occur for bosons, Eq. (1) is the most general form. Clashes between SU_3 and G_2 or between SU_3 and R_7 yield $a \neq 0$; interference between G_2 and R_7 yields $b \neq 0$.

Table II shows values of m_0, a, and b for the pseudoscalar mesons and the two possible associations of vector mesons (under neglect of the small mass difference between ρ_1 and ρ_2). As is well known, the pseudoscalar mesons give a good approximation to $b = 0$; but the vector mesons do not. Association (1) of vector mesons in Table II is preferred over (2) because it minimizes the coefficient b. It is interesting to

TABLE II

Boson Mass Parameters

Bosons	m_0	a	b
$K\pi\eta$	0.41 Bev.	-0.15 (Bev)^2	0.00 (Bev)^2
1 $K^*\rho\phi$	0.85	-0.15	-0.10
1 $\kappa\rho\omega$	0.74	0.02	-0.05
2 $K^*\rho\omega$	0.82	-0.15	0.12
2 $\kappa\rho\phi$	0.78	0.02	-0.26

note that one octet of vector mesons has the same a value as the pseudoscalar octet, while the other octet has $a \approx 0$ within the $\rho_1 - \rho_2$ mass uncertainty. To a first approximation one might say that $(K^*\rho\phi)$ reflects $(SU_3 + G_2 + R_7)$, while the almost degenerate octet $(\kappa\rho\omega)$ does not involve SU_3.

This interpretation and the preference for association (1) are reinforced by consideration of the generalized charge parity A, which is defined [18] to have a constant value ± 1 over any irreducible representation of G_2 or R_7. For the $Y = 0$, $I = 1$ triplet this is just the usual operator G, so that in practice the definition of A simply extends the same eigenvalue to the $|Y| = 1$ members of a given octet. The value of A for the corresponding singlet ($I = Y = 0$) of the octet is not determinate, because in R_7 and G_2 the two irreducible components of $\mathbf{8} = \mathbf{7} + \mathbf{1}$ can have opposite parities. This is in fact the most natural choice — the analogue of vector *vs.* scalar in ordinary space — but is not absolutely necessary. On the other hand for SU_3 the representation $\mathbf{8}$ is irreducible, so the A value must be constant for all members of the octet.

Now suppose the baryon-antibaryon 'binding forces' that form the boson states to be mainly A conserving, though a mixture of $SU_3 + R_7 + G_2$. If the boson state is a radial singlet, the presence of SU_3 will force all members of the octet to have the same A; radial doublets, however, can arrange themselves so that the SU_3 is practically concentrated in one charge octet with constant A value, while the other octet has this same A for its charge septet but $-A$ for the $Y = I = 0$ charge singlet. This distinction is in one-to-one correlation with the mass formula:

$$\begin{aligned} &a \neq 0 \text{ implies } A(\text{octet}) = A_0 \\ &a \approx 0 \text{ implies } A(\text{septet}) = -A(\text{singlet}) = A_0. \end{aligned} \tag{2}$$

The 'normal' charge parity on the baryon-antibaryon model is

$$A_0 = P(-1)^S \tag{3}$$

with $P = (-1)^{L+1}$ the real parity of the baryon-antibaryon state of orbital angular momentum L, and $S = 0$ or 1 its spin.

The arguments above then lead to the following assignments:

$$
\begin{aligned}
A &= -1 \text{ for } K,\ \pi,\ \eta,\ \omega \\
&= -1 \text{ for } K^*,\ \kappa,\ \rho_1,\ \rho_2,\ \phi.
\end{aligned}
\tag{4}
$$

Equation (4) corresponds to association (1) of Table II; but this assignment is identical with one made independently on an empirical basis [19] and hence provides further reason to prefer association (1) over (2) in Table II.

It should be emphasized that A is not synonymous with the usual G for two reasons: (i) A extends to $Y = \pm 1$ mesons; and (ii) even where G is defined it does not equal A in the exceptional case of the 'normal' charge singlet, since for both normal and anomalous charge singlet, $G = -A_0$. This leads to a selection rule [19]

$$\text{(normal charge singlet)} \longrightarrow n\pi \text{ is forbidden} \tag{5}$$

since $G = A = (-1)^n$ for $n\pi$. Such resonances are experimentally conspicuous by their tendency to decay exclusively into $K\overline{K}$, $K^*\overline{K}$, or $n\pi + \eta$.

4. Further Resonances

Direct extension of the model suggests that boson resonances of the next higher group all have even parity, being predominantly P states: a doublet set of 2^+ resonances from $({}^3P_2 + {}^3F_2)$, one set of 0^+ from ${}^3P_0$ and two independent sets of 1^+ from ${}^3P_1$ and ${}^1P_1$. These last do not form a doublet in the previous sense, although there may be some mixing of radial components in the $I = Y = 0$ state to form eigenfunctions of A in accord with the discussion of the previous section. It is accidentally the ${}^3P_0$ state that is a radial singlet and should follow the SU_3 mass symmetry.

Present experimental candidates for the P-state bosons are assembled in Table III. The model assignments are argued as follows:

TABLE III

Higher Boson Resonances

Name	Mass	J^P	I^A	Model	References
f^0	1.25 Bev.	2^+	0^+	${}^3P_2 + {}^3F_2$	20
A_1	1.08	$1^-2^+3^-\ldots$	1^-	${}^3P_2 + {}^3F_2$	21
A_2	1.32	$1^-2^+3^-\ldots$	1^-	${}^3P_2 + {}^3F_2$	21
B	1.22	$(1^-?)$	1^+	${}^1P_1$	22
C	1.23	(1^+)	$\frac{1}{2}\frac{3}{2}^-$	${}^3P_2 + {}^3F_2({}^3P_1?)$	23
K^{**}	1.17		$\frac{1}{2}\frac{3}{2}^-$	${}^3P_2 + {}^3F_2$	24
X^0	.96	0^-1^+	0 ?	${}^3P_1$	25
$(\overline{K}K^*)$	1.41		$-$	${}^3P_2 + {}^3F_2$	26
(4π)	1.34		$+$		27
K^{***}	1.40 and 1.65		$+$		27

The f_0 certainly appears to be the charge singlet of abnormal charge parity for the ${}^3P_2 + {}^3F_2$ double octet. If we assume by analogy with the vector mesons that this octet is practically mass degenerate, the A_2 and C are at once associated with the f^0. There is a rather provisional experimental assignment of spin and parity 1^+ to the C resonance, which would make it ${}^3P_1$ instead of ${}^3P_2$; in any case there should be one more K^{**} in the same energy region, in addition to the two already found.

The A_1 clearly belongs to the other radial doublet of ${}^3P_2 + {}^3F_2$; if we associate the K^{**}, the mass parameter is $a = -0.15$ Bev.^{2}, in striking agreement with the S resonances. The associated $I = Y = 0$

resonance of normal charge parity is not known, but the most likely candidate in Table III appears to be the 1.41 Bev. $\bar{K}K^*$ resonance in accordance with the selection rule Eq. (5). With these assignments the mass parameter $b = -0.27$ Bev.^{2}, a relatively high value.

No organization of the remaining masses appears feasible at present, but the model implies a couple of definite assignments for real spin and parity. Because of its charge parity the B meson must be ^1P or hence $J^P = 1^+$; the tentative experimental assignment of 1^- seems already dubious in the absence of $B^\pm \longrightarrow \pi^0 + \pi^\pm$. The absence of $X^0 \longrightarrow 3\pi$ suggests the $G = -A$ restriction appropriate to charge singlets of normal charge parity; this same rule indicates that $X^0 \longrightarrow \pi\pi\eta$ is allowed (and not electromagnetically induced), since η has also $G = -A$. The A value for the X^0 is therefore given by $(A_\pi^2)A_\eta = -1$, corresponding to ^3P. Of the experimental spin and parity assignments the present model of course indicates $J^P = 1^+$.

Finally, note that the K^{***} mesons with $A = +1$ cannot both be $^1P_3$ which suggests that the lower limit of the D-state with $J^P = 2^-$ and 3^- may be around 1.5 Bev. Present experimental absence of the $^3P_0$ states may perhaps be ascribed to low production rates associated with the small spin value $J = 0$; also, states with $J = 0^+$, $A = -1$ must decay into at least 5 mesons with $J = 0^-$, $A = -1$.

5. Discussion

The chief experimental test of the present model is of course yet to come; but this is already a statement that it has survived the recent spate of resonance data. Its continual survival would seem to require more careful examination of assumptions (I) and (II), both of which run slightly counter to the most popular current ideas: namely, that strong interactions are dominated by SU_3 with minor deviations; and that all elementary particles are equally valid as building blocks for constructing other particles. The second assumption would imply greatly increased multiplicities for bosons of a single J^P, not just simple doubling as for triplet states. The establishment of further 1^- mesons appears crucial here. Further charge singlets additional to the charge octets have frequently been contemplated, but cannot be given firm empirical support at present; they could if necessary be incorporated into the present model as anomalous charge parity states of radial singlets. The most obvious features of a boson not representable as a baryon-antibaryon would be its existence in states of charge 3 or more.

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