SELECTION RULE FOR BOSONS*

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(Received 9 April 1964)

(A) In this Letter we point out that the evidence on boson decays is consistent with an empirical selection rule, which we call A invariance.[1] A invariance is compatible with, but does not require, unitary symmetry. Violation of the rule seems to occur with a probability of a few percent. We discuss several theoretical bases for A invariance and point out some further experimental consequences.

The operator A is diagonal on the known bosons and has the following eigenvalues:

$$A_\gamma = A_\rho = A_\varphi = A_{K^*(888)} = A_{f^0} = A_{B(1220)} = 1,$$

$$A_\pi = A_\eta = A_K = A_\omega = A_{\overline{K}K^*(1410)} = -1.$$

The identification of $A_{K^*(725)}$ is not yet clear. If the $K^*(725)$ spin $J=0$, it must have odd A; if $J>0$, then A must be even.

(B) In a world without baryons, one could understand the existence of the A quantum number in a very simple way. By parity conservation any renormalizable field theory of bosons and photons must be quadratic and quartic in the pseudoscalar field operators, and linear and bilinear in the electromagnetic vector potential. It must therefore automatically allow the transformation $\varphi(x) \to -\varphi(x)$ for all pseudoscalar fields and $A_\mu(x) \to A_\mu(x)$ for the electromagnetic field.[2] The presence of baryons with Yukawa coupling to the bosons would then, in general, violate A invariance. However, as long as the nucleons are virtual, they may be relatively unimportant for boson phenomena, since the threshold for pair excitation is high, and the contribution of intermediate pair states is limited by unitarity.

A firmer basis for A invariance would exist were there a mechanism for canceling the contributions of baryon loops against each other in the limit of some mass degeneracy. A theoretical possibility is the antiparticulation operation A of Peaslee[3] or equivalently Gell-Mann's[4] hypercharge reflection $R=CA$, where C is the charge conjugation operator.[5] Even zeroth-order R invariance, however, is in strong disagreement with the electromagnetic properties of the baryons. Since, under R, $p \to \Xi^-$, $n \to \Xi^0$, $\Sigma^+ \to \Sigma^-$, $\Lambda \to \Lambda$, we have $Rj_\mu R^{-1} = -j_\mu$, where j_μ is the electric current operator. Therefore $j_\mu j_\nu \to j_\mu j_\nu$, and electromagnetic energy differences are R invariant. In fact, $m_{\Xi^-} - m_{\Xi^0} \neq m_p - m_n$ and $m_{\Sigma^+} - m_{\Sigma^0} \neq m_{\Sigma^-} - m_{\Sigma^0}$. Furthermore, the baryon particle spectrum does not appear to be hypercharge-reflection invariant. Finally, in the unitary symmetric limit, calculations[6] have shown that the decuplet structure can be understood with a Yukawa coupling which is primarily of the D type, whereas the one required for our type of R invariance would be pure F type.

Another possibility which is not at present in disagreement with experiment is that all baryon states are doubled, the double being either of the same or opposite parity. A candidate for the nucleon's partner N' already exists in the highly inelastic object found by Roper[7] at 556 MeV in the π-N, $I=\frac{1}{2}$, $P_{1/2}$ state. The $Y_0^*(1405)$ is a possible partner of the Λ. Since the $Y_0^*(1405)$ decays strongly into $\Sigma+\pi$ and the proposed N' has a normal width one would (according to unitary symmetry) expect the N' to be strongly coupled to $N+\eta$, since it is only weakly coupled to $N+\pi$. The transformation of the nucleon octet would then be $ANA^{-1} = iN'$. The unitary symmetric $\overline{N}'NP$ coupling would be approximately $(D-F)$ to account for the absence of $N' \to \pi + N$. (An alternative scheme is to superpose a hypercharge reflection on the transformation $N \to N'$, i.e., to let $ANA^{-1} = CRN'$. This is not compatible with both unitary symmetry and absence of $N' \to N+\pi$, however, since the $\overline{N}'NP$ coupling in this case would have to be either pure F or pure D, neither of which could forbid $N' \to N+\pi$. We therefore prefer the simpler alternative $ANA^{-1} = iN'$.)

(C) We now consider the application of A invariance to the individual bosons.

(i) The π^0 decay is forbidden. In fact, it appears to be suppressed by a factor of 1/40 over a natural lifetime for so light a particle.

(ii) The $\eta \to 2\gamma$ and $\eta \to \pi^+ + \pi^- + \gamma$ are consistent with each other, since the three-body phase space is about 1/100 of the two-body; $\eta \to \pi^+ + \pi^- + \pi^0$ is anomalously high, since it has both the three-body phase space and an internal electromagnetic interaction. However, the three-π decay is allowed by A invariance, whereas the other two modes are not. This suffices to produce qualitative agreement.

Brown and Singer[8] have suggested that the enhancement of the three-π mode be produced by a neutral scalar meson, σ, such that

$$\eta \to \sigma + \pi^0$$
$$\hookrightarrow \pi^+ + \pi^-$$
$$\hookrightarrow \pi^0 + \pi^0,$$

so that the three-π rate be essentially given by two-body phase space. The data on the π^0 energy distribution in the $\pi^+ + \pi^- + \pi^0$ mode are in agreement with their hypothesis. (There is no necessary disagreement between their point of view and ours since the width of the σ must be ~50 MeV, so that its enhancement might be incomplete, and both mechanisms operative.) The data on $\eta \to$ three neutrals appear to be contradictory[9]; they also fail to resolve the $3\pi^0$ mode from the $\pi^0 + 2\gamma$ mode. According to A invariance the $\pi^0 + 2\gamma$ mode should be enhanced and therefore comparable with the other η modes, whereas the pure Brown and Singer mechanism would not enhance it. Another test of the dominance of the Brown and Singer mechanism is the branching ratio $r = \Gamma(\pi^+ + \pi^- + \pi^0)/\Gamma(3\pi^0)$ which should be $\sim\frac{2}{1}$ (as opposed to $\frac{2}{3}$ for no final-state interaction). Other mechanisms, such as an intermediate vector particle, can account for the energy distribution in the $\pi^+ + \pi^- + \pi^0$ mode,[10] but will give different values of r. It would be interesting to have more information on the branching ratios and energy distribution of the three-body neutral modes.

(iii) $\varphi \to n\pi$ is forbidden by G for even n and by A for odd n. Therefore the dominant decay mode is $K\bar{K}$, in spite of the very small Q value.

(iv) $\omega \to 3\pi$ is allowed, since the 9-MeV width is normal, and $\omega \to \pi^+ + \pi^- + \gamma$ does not compete strongly with $\omega \to 3\pi$. There are two difficulties associated with the ω - φ system. One is connected with unitary symmetry (or rather with the usual way in which unitary symmetry is supposed to be broken) where one makes ω and φ into particle mixtures. We would like to consider the actual particles as approximate eigenstates of A. The second difficulty is the 2% $\omega \to 2\pi$ mode, which is anomalously large, since it is forbidden both by G and A conservation. It would be interesting to check the decay angular distribution of the 2π shoulder at 780 MeV to make sure that one is really observing the ω.

(v) $\rho \to 2\pi$, $K^* \to K + \pi$, and $B(1220) \to \omega + \pi$ are allowed, as shown by the known widths of these particles. Hence the identification given above.

(vi) The $\bar{K}K^*(1410)$ observed by Armenteros et al.[11] has not been observed in either 3π or 4π spectra. It therefore presumably has odd A and even G.

(vii) The failure of the $K^*(880)$ to decay into $K^*(725) + \pi$ as well as the very small $K^*(725)$ width can be accounted for in two ways: $K^*(725)$ has $J = 0$ and odd A, or $K^*(725)$ has $J = 1$ and even A.

(D) Further predictions regarding electromagnetic properties are the following:

(i) $\Gamma(\varphi \to e^+ + e^-)/\Gamma(\omega \to e^+ + e^-) \gg 1$. This can be directly measured in the decay or eventually with colliding beams of electrons and positrons. The isotopic scalar nucleon form factor should be dominated by the φ rather than the ω.

(ii) $\Gamma(\rho \to (\pi \text{ or } \eta) + \gamma)/\Gamma(\omega \to (\pi \text{ or } \eta) + \gamma) \ll 1$. This can be directly measured, or inferred from peripheral ω and ρ (and possible π) production by photons.

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*Work supported in part through funds provided by the Atomic Energy Commission under Contract No. AT(30-1)-2098.

[1]A preliminary report on some parts of this work was delivered at the Siena International Conference on Elementary Particles, Siena, Italy, 1963 (unpublished).

[2]The possibility of a similar invariance for the neutral ϕ^4 theory has been previously observed by L. Schiff and called amplitude parity [L. Schiff, Proceedings of the International Conference on High Energy Nuclear Physics, Geneva, 1962 (CERN Scientific Information Service, Geneva, Switzerland, 1962)]. An extension to the case of pions and photons has been given by Barton. His classification is different from ours in that he assigns positive A parity to the η; G. Barton, Nuovo Cimento 27, 1179 (1963).

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