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PROPERTIES AND EFFECTS OF ζ DECAYS

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(Received March 20, 1962)

Several recent experiments[1-4] seem to indicate the existence of charged particles, called $\zeta^\pm$, with a mass of about 560 Mev. The limited evidence points to the isotopic spin assignment $T=1$ for ζ, insofar as production is concerned. In the one experiment[4] in which 2π can only be produced in a pure $T=1$ state, the ζ^+ width appears to be small. It is the purpose of this note to emphasize the importance of the relative properties of $\zeta^\pm$ and ζ^0 and to consider the influence of ζ on other pion resonances as well as on weak interactions.

The argument hinges on the 2π-decay properties of ζ and more specifically on the behavior of ζ^0 under charge conjugation. We consider three alternatives denoted by (a), (b1), and (b2) and show that these may be distinguished by measuring the 2π-decay modes of the ζ's.

(a) $\zeta\to 2\pi$ is T-allowed. Therefore ζ has odd angular momentum and even G. In this case,[5]

$$\text{(a)}\ \Gamma(\zeta^+\to\pi^+\pi^0)=\Gamma(\zeta^0\to\pi^+\pi^-),\quad \Gamma(\zeta^0\to 2\pi^0)=0, \tag{1}$$

so that ζ^+ and ζ^0 have essentially the same width. The relevance of this obvious remark lies in the following. It has been pointed out[6] that the decay of ω^0 into $\zeta+\pi$ [allowed by assumption (a)] would lead to a characteristic band effect in the Dalitz plot for ω^0. It was further observed[7] that in this case $\omega^0\to\zeta+\pi$ would actually be the most prominent π^0 mode, provided that the dimensionless effective (ω^0,ζ,π) coupling constant is ~1. No band structure in the ω^0-decay plot has been reported. Thus if Eq. (1) were to be true experimentally, we would have learned that the coupling constant just mentioned is small (which cannot be excluded by any principles we know of).

If Eq. (1) is in disagreement with experiment, we learn that $\zeta\to 2\pi$ is not T-allowed, which would be consistent with a narrow width. If this is the case, ζ must have even spin. This opens the possibility of assigning a spin and parity to ζ in such a way as to forbid the decays $\omega\to\zeta+\pi$, $\rho\to\zeta+\pi$. The unique assignment which does this is zero spin, even parity.

While in case (a) it follows automatically that ζ^0 is odd under charge conjugation (C), we have now further to distinguish two cases.

(b1) $\zeta\to 2\pi$ is T-forbidden and ζ^0 is odd under C; hence ζ is even under G. In a recent note,[8] Peierls and Treiman discussed the assignment 0^+ for spin and parity of ζ. They were forced to take ζ^0 odd under C because they consider the ζ to be something like a 4π molecule, a picture which we find hardly compelling. Assumption (b1) gives

$$\text{(b1)}\ \Gamma(\zeta^0\to\pi^+\pi^-)=\Gamma(\zeta^0\to 2\pi^0)=0, \tag{2}$$

and the principal ζ^0 mode is $\zeta^0\to\pi\pi\gamma$ ($\zeta^0\to 2\gamma$ is also forbidden). As was pointed out,[8] in this case the lowest multipole order is $E2$. The width of ζ^0 should therefore be much smaller than the one for ζ^+ which does decay into 2π by electromagnetic violation of T. See the remark after Eq. (5) below.

(b2) $\zeta\to 2\pi$ is T-forbidden and ζ^0 is even under C; hence ζ is odd under G. In general, both ζ^+

and ζ^0 can now undergo 2π decay by electromagnetic violation of T. It is safe to treat this electromagnetic effect to second order, and it can then be shown that the transition matrix transforms like an isotopic vector. This yields

$$\frac{\Gamma(\zeta^+ \to \pi^+\pi^0)}{\Gamma(\zeta^0 \to \pi^+\pi^-) + \Gamma(\zeta^0 \to 2\pi^0)} = \frac{3}{4 + 2z^2} \qquad (3)$$

$$\frac{\Gamma(\zeta^0 \to \pi^+\pi^-)}{\Gamma(\zeta^0 \to 2\pi^0)} = \frac{2(1 + z^2 - 2z\cos\phi)}{4 + z^2 + 4z\cos\phi}, \qquad (4)$$

where $z \geq 0$ is proportional to the ratio of the absolute values of the $T = 0$ and the $T = 2$ transition amplitudes and ϕ is their relative phase angle. It is evident from Eqs. (1)-(4) that measurements of the three 2π modes of the ζ's are sufficient to distinguish among the cases (a), (b1), and (b2). For example, if $\Gamma(\zeta^0 \to 2\pi^0) \neq 0$ we have case (b2). If $\Gamma(\zeta^0 \to 2\pi^0) = 0$, then the ratio $\Gamma(\zeta^0 \to \pi^+\pi^-)/\Gamma(\zeta^+ \to \pi^+\pi^0) = 1$, 0, and 4 for cases (a), (b1), and (b2), respectively.

The question arises whether the 2π decays will dominate in the cases (b). Presumably, the 2π-decay amplitudes contain a factor $\alpha = 1/137$ whereas the amplitudes for $2\pi\gamma$ decay only contain $\alpha^{1/2}$. It is therefore important to estimate the branching ratio $\Gamma(2\pi\gamma)/\Gamma(2\pi)$ for ζ.[9] Thus let the effective matrix element for 2π decay be $GR^{-1} \times (8m\omega_1\omega_2)^{-1/2}$. Here G is a dimensionless constant; m is the ζ mass; ω_1 and ω_2 are the energies of the pions 1 and 2. R is a length introduced for dimensional reasons. The $2\pi\gamma$ transition is $E1$ in this case and the effective matrix element is taken to be $G\alpha^{-1/2}p_1{}^\mu p_2{}^\nu F^{\mu\nu}R^3 \times (16m\omega\omega_1\omega_2)^{-1/2}$, where ω is the photon frequency. It follows that (μ is the pion mass)

$$\frac{\Gamma(\zeta \to 2\pi\gamma)}{\Gamma(\zeta \to 2\pi)} = \frac{m^6R^8}{24\pi^2\alpha(m^2 - 4\mu^2)^{1/2}} \int_\mu^{m/2} \frac{p^3(m - 2\omega)^3 d\omega}{(m^2 - 2m\omega + \mu^2)^2}. \qquad (5)$$

With $m \simeq 4\mu$ this ratio becomes $\sim 20(\mu R)^8$. Due to the spin-parity of the ζ it is impossible to have a one-pion intermediate state to order $\alpha^{1/2}$. Hence $(2\mu)^{-1}$ is a likely upper bound for R. This would imply that 2π is indeed the dominant ζ mode, though a sizable (~10%) effect due to $2\pi\gamma$ could well exist. As the rate for a $2\pi\gamma$ mode of type $E2$ should still be smaller than for type $E1$, we are led to conclude that in the case (b1) the ζ^0 width will be very narrow.

If we accept the proposed[10] assignment 0^{-+} for η^0, its decay into 3π is T-forbidden. In the case (b2) the (virtual) transition $\eta^0 \to \zeta + \pi$ is T-allowed. Thus in this case the ζ will play a role in the decay $\eta^0 \to 3\pi$ with the T violation occurring in the ζ decay. It is readily seen that, if the ζ^0 width is large compared to the ζ^+ width, there results an asymmetry in the Dalitz plot for $\eta^0 \to \pi^+\pi^-\pi^0$. The decay distribution contains a factor $[m_\zeta{}^2 - (m_\eta - \mu)^2 + 2m_\eta T_{\pi 0}]^{-2}$, which favors small π^0 kinetic energies. There are experimental indications of the existence of such an asymmetry.[10] However, we do not wish to imply that there could be no other causes for this effect.[11]

If neutral decays of the ζ^0, such as $\zeta^0 \to 2\pi^0$, occur appreciably, the approximate mass degeneracy of η^0 and ζ^0 may lead to an experimental complication in determining the ratio of neutral decays to $\pi^+\pi^-\pi^0$ decays for the η^0. Indeed, since the "neutral decay modes of the η^0" are identified by a missing-mass analysis, it is clear that if ζ^0 is produced in the same experiment, its neutral decays would contribute to those events which are called "neutral decays of the η^0." This would lead to an overestimate of the ratio of the true η^0 neutral decays to 3π decays. The true ratio could be measured in an experiment where an isotopic spin or other selection rule in production allows only η^0 to be produced, or perhaps after the ζ^0 decays are analyzed, by a subtraction method.

The understanding of the η^0 decays under the assumption of spin 0^- is complicated by the apparent absence[10] of the mode $\eta^0 \to \pi^+\pi^-\gamma$. We have tried to estimate this mode by a calculation similar to the one above for $\zeta \to \pi\pi\gamma$, and find the ratio $\Gamma(\eta^0 \to \pi\pi\gamma)/\Gamma(\eta^0 \to 3\pi) \sim 2500(\mu R)^6$. This gives a factor of 40 for a radius of $(2\pi)^{-1}$. Some method of enhancing the 3π decay therefore seems called for if the η^0 is 0^-.

We would like to emphasize that the peculiar situation in which strongly interacting particles decay only via T-violating modes may provide a new interpretation of violation of the $\Delta T = \frac{1}{2}$ rule in the nonleptonic decays of K particles. The closeness in mass between K and ζ particles and their common zero spin makes it quite plausible that a one-ζ intermediate state plays a dominant role in the K^+ decay. Consider in fact the sequence

$$K^+ \to \zeta^+ \to \pi^+\pi^0. \qquad (6)$$

The first link in this chain is a weak transition allowed by a pure $\Delta T = \frac{1}{2}$ rule. Therefore, the violation of $\Delta T = \frac{1}{2}$, which necessarily occurs in the $K_{\pi 2}{}^+$ decay, here takes place entirely "away from the weak vertex" in the "strong" decay of the ζ^+.

This model of the K^+ decay may clarify the long-standing problem of why the ratio for $K^+ \to 2\pi$ versus $K_1^0 \to 2\pi$ is equal to 1/500 rather than $\alpha^2 \sim 1/20\,000$. The point is that our sequence gives a decay rate proportional to $(m_K - m_\zeta)^{-2}$. Let us compare this situation with the K_1^0 decay. Since this decay is allowed by $\Delta T = \frac{1}{2}$, the sequence $K_1^0 \to \zeta^0 \to 2\pi$ is unlikely to play an important role.[12] There is no known intermediate state compatible with $\Delta T = \frac{1}{2}$ which can give rise to as small an energy denominator. Therefore this mass effect may produce the necessary enhancement of the K^+ rate even in the absence of strong π-π forces at the K^+-rest energy. However, such arguments would be invalid if close-lying $T=0$, 0^+ particles were to exist.

We further note that if the sequence Eq. (6) indeed dominates the K^+ decay, it follows that the $2\pi\gamma/2\pi$ branching ratio of K^+ would equal that of ζ^+. Also the $2\pi\gamma$ spectrum would be the same in the two cases. Measurements of this could provide a test of our model of the K^+ decays.

In conclusion we reiterate that the relatively straightforward measurement of the various 2π rates of the ζ's is sufficient to determine the isotopic spin character of ζ decay and the charge conjugation quantum number of ζ^0.

We would like to thank Dr. J. Sanford, Dr. E. Pickup, and Dr. B. Sechi Zorn for discussing with us the experimental material, and N. P. Chang and T. Yao for pointing out an error in an earlier version of this note.

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[12]A similar argument shows that if the η^0 decay is T-forbidden, the one-η^0 intermediate state will not play an important role in the K_2^0 mesonic decay. However, it is possible that the decays $K_1^0 \to 2\gamma$, $K_2^0 \to 2\gamma$ could go through intermediate states of a single ζ^0, η^0, respectively.

COMPLEX ANGULAR MOMENTA AND THE RELATION BETWEEN THE CROSS SECTIONS OF VARIOUS PROCESSES AT HIGH ENERGIES

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Recently a connection has been found between the analytical properties of the amplitudes as functions of the angular momenta, and their asymptotic behavior at high energies.[1,2] It is assumed that the asymptotic behavior of the scattering amplitudes of any particles in the diffraction region is determined by the moving pole $j(t)$ of a partial wave in the annihilation channel.[3-6] Several important properties of strong interactions at high energies (s) follow from this assumption. In particular, the amplitude of the elastic scattering of strongly interacting particles must have the form $f(t)s^{j(t)}$ (s and t are the usual Mandelstam variables). The total cross section is constant if $j(0)$ assumes the maximum possible value, equal to 1.[7] The elastic scattering cross section must tend slowly to zero (as $1/\ln s$). The diffraction cone must narrow with increasing energy; this behavior corresponds to the scattering on a system whose transparency and radius increase with the energy.[3] Such behavior seems to be in agreement with the experimental data