PRODUCTION AND DECAY OF THE h MESON*

S. Pakvasa and S. F. Tuan
University of Hawaii, Honolulu, Hawaii
(Received 5 January 1968)

Recently Lee suggested that the field-current identity procedure,[1] successful for a number of applications in the case of the usual electromagnetic current of hadrons J_μ, be extended also to the CP-nonconserving electromagnetic current K_μ.[2] The assumption is made that K_μ is an isosinglet as well as a unitary singlet under SU(3). Application of the field-current identity to K_μ leads to the identification

$$K_\mu(x) = 1^- \text{ meson field.}$$

It would be natural to expect the existence of one (or more) corresponding strongly interacting meson, which may be called the h meson, with the following properties:

$$\text{spin 1, parity } -1,\ C=+1,\ G=+1, \text{ isospin 0, unitary singlet, and charge } Q_J = Q_K = 0, \quad (1)$$

where C is the particle-antiparticle conjugation operator, while Q_J and Q_K are the charges associated with J_μ and K_μ (with $Q = Q_J + Q_K$). It is the purpose of the present note to examine the salient properties and the implications of the existence of the h meson.

General discussion. – The most striking feature about the h meson is that, in terms of the properties delineated in (1), it is not coupled to the $N+\bar{N}$ configuration through strong interactions. In the same way, virtual transitions $h \to \Lambda + \bar{\Lambda}$, $\Sigma + \bar{\Sigma}$, etc. are forbidden in the limit of SU(3) symmetry. Thus the h meson is an abnormal particle in the sense of Gell-Mann.[3] Note that other examples of abnormal particles (with opposite transformation properties under particle-antiparticle conjugation C to those of the normal meson isospin or octet multiplets) have been suggested for the $\kappa(725)$[3] and the $\delta(963)$, the latter in connection with a possible nonchiral SU(2)⊗SU(2) symmetry.[4]

In an entirely analogous fashion, the h meson is not coupled to the quark-antiquark ($q\bar{q}$) system with L excitations,[5] nor with the S-wave states formed out of the $(q\bar{q}q\bar{q})$ configuration. The associated K_μ current's commutation rules, therefore, cannot be inferred by analogy with the currents built up from the quark model, but must have some other raison d'être.[6]

The current-field identity leads explicitly to relations of the type

$$K_\mu(x) = -(m_h^2/g_h)h_\mu(x), \quad (2)$$

where m_h is the mass of the h meson, and $g_h = \langle 0|K_\mu|h\rangle$. Fourier decomposition of the propagator $\langle 0|T[K_\mu(x)K_\nu(0)]|0\rangle$ may have more than one complex pole corresponding to possible resonances, h, h', $\cdots$, of different masses but with quantum numbers given by (1).

Since h is a unitary singlet under SU(3), its existence raises the interesting speculation that other abnormal particles may exist with SU(3) classifications $\underline{1}$, $\underline{8}$, $\underline{10}$, $\underline{10}^*$, $\underline{27}$, $\cdots$, etc. For instance, compounding h with the normal mesons can lead to other abnormal mesons. If $\delta(963)$ should be abnormal[4] with quantum numbers $I=1$, $J^{PG}=0^{-+}$, then $\rho\delta \to h$ would suggest that the δ meson is a member of an abnormal octet.

Production of h. – The lack of direct coupling between h and the systems $N\bar{N}$, 2π, 3π, $K\bar{K}$, together with the absence of virtual transitions to the hyperon-antihyperon configurations in SU(3)-symmetry limit, suggests that the h meson is likely to have low production rates in many processes. This can be attributed, at least partially, to the absence or smallness of many pole terms (one-particle exchange) that are fully allowed in the case of normal particles. Typically, suppression of the matrix element of production by one order of magnitude from the norm is not unreasonable. Thus, if the strong-production cross section for normal mesons is of order 100 μb, that for h and other abnormal particles[7] can be at the 1-μb level!

Restricting our discussion to the more prominent one-particle-exchange processes for production of h, it is evident that the reaction

$$K^- p \to h^0 \Gamma(\Lambda, \Sigma, Y_0^*, Y_1^*) \quad (3)$$

with K^* exchange represents a favorable process; here Γ can be any member of the complex of (hypercharge zero) hyperons or hyperon resonances. Both (3) and the reaction

$$\pi^- p \to h^0 \Gamma'(N_{1/2}, N_{1/2}^*), \quad (4)$$

with Γ' any member of the complex of $I=\frac{1}{2}$ nucleon or nucleon resonances, can proceed via

$N_{1/2}^*$ exchange [e.g., $N_{1/2}^*(1525)$, $N_{1/2}^*(1688)$, etc.]. However it is known empirically[8] that resonance production which cannot be directly attributed to one-meson exchange is usually suppressed by at least one or two orders of magnitude. Finally, h^0 can be observed from the reaction $p\bar{p} \to h^0\rho^0$ with ρ^0 in the direct channel presumably dominating the process.

Decay of h.—The h meson is forbidden to decay[2] into 2π, 3π, $2\eta^0$, and $\bar{K}K$. The 2π mode is forbidden by isospin conservation and also by $C_{\rm st}$ symmetry. The other modes, 3π, $2\eta^0$, and $\bar{K}K$, are, respectively, forbidden by G parity, Bose statistics, and $C_{\rm st}$ symmetry.

If the mass of h is sufficiently high, the possible strong decay modes are

$$h \to 2\rho,\ 2\omega,\ \omega\varphi,\ 2\varphi,\ K^*\bar{K}^*,\ K^*\bar{K}+\bar{K}^*K,\ \pi\pi\rho,\ \pi\pi\eta,\ \bar{K}K\pi,\ 4\pi,\ \text{etc.} \tag{5}$$

The electromagnetic modes are

$$h \to 2\gamma,\ \eta\gamma,\ \eta'\gamma,\ \rho^0\gamma,\ \omega^0\gamma,\ \varphi^0\gamma,\ \pi\pi\gamma,\ \eta\pi\gamma,\ \text{etc.} \tag{6}$$

Typically, a rough phenomenological estimate for the decay widths of h [assuming a radius of interaction $(m_h)^{-1}$ and setting strong coupling constant $g^2/4\pi \sim 1$] yields the following for a 1-BeV h meson: $h \to \eta\gamma$, 0.2 MeV; $\rho^0\gamma$, 0.24 MeV; $\omega^0\gamma$, 0.06 MeV; and $\gamma\gamma$, 0.04 MeV. The $\eta\gamma$ mode is suppressed by SU(3) considerations and hence may be substantially smaller than the given estimate; three- and four-body strong and electromagnetic decays are not competitive here. For $m_h \sim 2$ BeV, the strong two-body decays dominate: $h \to \rho\rho$, 75 MeV; $\omega\omega$, 65 MeV; $K^*\bar{K}^*$, 20 MeV; $K^*\bar{K}+K\bar{K}^*$, 250 MeV. It is important to note that since h has relatively low spin (and hence low barrier factors), its strong decays into the more familiar two-body channels can have large widths—especially if it should turn out to be a massive boson. In short, if the h meson is light, its decays will be predominantly electromagnetic and it will have a narrow width; if the h meson is sufficiently heavy, it will decay strongly and show up as a very broad resonance.

Implications for CP nonconservation.—The experimental consequences of the existence of an isosinglet (and unitary singlet) K_μ current for the CP problem have been summarized in detail by Lee.[2,6] They are compatible with the currently available data.

It must be emphasized that an $I=0$ unitary singlet K_μ can also be constructed from a bilinear a-particle description.[2,6,9] The general case of a K_μ with isotensor components has been constructed by Adler[10] from the known nonets of vector and axial-vector mesons. However, to the extent that field-current identity is relevant, the existence of a K_μ current should guarantee in principle at least the existence of the associated physical meson field or fields (e.g., the h meson). The hypothesis that K_μ is an isosinglet is particularly appealing, since this can be readily incorporated into the algebra of fields[1] in which the group extension is just from, say, chiral SU(2)⊗SU(2) to U(1)⊗SU(2)⊗SU(2)—thus retaining most of the successful results derived previously.

L'envoi.—From the discovery that $K_L^0 \to 2\pi$, one knows that CP is not conserved. If CPT invariance is assumed, then it follows that the time-reversal symmetry is also violated. However, at present it is not clear whether the origin of this CP nonconservation is due to the electromagnetic interaction or due to the weak interaction. What is evident is that there must be some additional current which together with the known electromagnetic or weak currents generates CP nonconservation. If the violation of time-reversal invariance is due to the electromagnetic interaction, then the type of K_μ hadronic current discussed above is relevant. Field-current identity then leads naturally to the physical manifestation of the h meson. If the violation of time-reversal invariance is due to the weak interaction, then there should exist a T- ($=T_{\rm st}$-)nonconserving weak interaction. As an example, such a nonconservation could be due to the existence of a $T=+1$ and $CP=C_{\rm st}P_{\rm st}=+1$ hadronic current $K_\mu^{\rm wk}$ which, for instance, may violate the $\Delta S=\Delta Q$ rule.[11,12] Application of field-current identity here would lead to other exotic particles!

Recent survey of meson resonances[13] suggests that abnormal and exotic particles which cannot be accomodated in the simple quark model[5] must have very low production cross sections. Nevertheless, the very existence of CP nonconservation which can imply their physical reality should provide sufficient incentive for further experimental efforts in this direction.

We are greatly indebted to Professor T. D. Lee for his lectures at the Second Hawaii Topical Conference which stimulated the present investigation.

Note added in proof.—In trying to clarify the

Regge behavior of scattering of unequal-mass particles, Freedman and Wang[14] introduced the notion of daughter trajectories. The first daughter trajectory of the Pomeranchuk has $Y=T=0$, $G=+1$, and odd signature. So the lowest physical particle on this trajectory (which has $J^P=1^-$) has the same quantum numbers as the h meson (see, e.g., Low[15]).

*Work supported in part by the U. S. Atomic Energy Commission.

[1]T. D. Lee, S. Weinberg, and B. Zumino, Phys. Rev. Letters 18, 1029 (1967); T. D. Lee and B. Zumino, "Field Current Identities and The Algebra of Fields," Phys. Rev. (to be published).

[2]T. D. Lee, in Proceedings of the Second Hawaii Topical Conference on Particle Physics, 1967 (University of Hawaii Press, Honolulu, Hawaii, 1967).

[3]See, for instance, M. Gell-Mann and Y. Ne'eman, The Eightfold Way (W. A. Benjamin, Inc., New York, 1964), p. 98.

[4]S. F. Tuan and T. T. Wu, Phys. Rev. Letters 18, 349 (1967).

[5]M. Gell-Mann, Phys. Rev. Letters 14, 334 (1965); R. H. Dalitz, in Proceedings of the Oxford International Conference on Elementary Particles, 1965 (Rutherford High Energy Laboratory, Chilton, Berkshire, England, 1966), p. 157.

[6]See, for instance, Eqs. (33)-(35) of T. D. Lee, in Proceedings of the International Symposium on Electron and Photon Interactions at High Energies, Stanford, California, 1967 (to be published).

[7]M. Crozon (private communication) informs us that the production cross section of δ^+ from $pp\to d\delta^+$ [M. Banner et al., Phys. Letters 25B, 569 (1967)] is consistent with an upper limit of order 1 μb $(\text{GeV}/c)^{-2}$. This lends some support to the hypothesis that the δ^+ (if it exists) is abnormal, since nucleon exchange is forbidden here.

[8]See, for instance, R. H. Dalitz, in Proceedings of the Thirteenth International Conference on High Energy Physics, Berkeley, 1966 (University of California Press, Berkeley, California, 1967), p. 230.

[9]S. Pakvasa, S. F. Tuan, and T. T. Wu, "Some Considerations on the Intermediate Boson Hypothesis and CP Violation" (to be published).

[10]S. Adler, Phys. Rev. Letters 18, 519, 1036(E) (1967).

[11]V. L. Fitch, in Proceedings of the Second Hawaii Topical Conference on Particle Physics, 1967 (University of Hawaii Press, Honolulu, Hawaii, 1967).

[12]A model of this type has been suggested by R. G. Sachs [Phys. Rev. Letters 13, 286 (1964)] which in addition predicts that $|\eta_{00}|=|\eta_{+-}|$.

[13]G. Goldhaber, in Proceedings of the Second Hawaii Topical Conference on Particle Physics, 1967 (University of Hawaii Press, Honolulu, Hawaii, 1967).

[14]D. Z. Freedman and J.-M. Wang, Phys. Rev. Letters 17, 569 (1966).

[15]F. E. Low, in Proceedings of the Thirteenth International Conference on High Energy Physics, Berkeley, 1966 (University of California Press, Berkeley, California, 1967).

K_1^0-K_2^0 MASS DIFFERENCE AND THE INTERMEDIATE VECTOR BOSON*

S. R. Cosslett
Cavendish Laboratory, Cambridge, England
(Received 6 December 1967)

The K_1^0-K_2^0 mass difference is calculated to lowest order in the intermediate-boson model, using Weinberg's first sum rule. A finite result is obtained without requiring equal coupling of strange and nonstrange mesons to the corresponding currents.

The K_1^0-K_2^0 mass difference has recently been calculated by Biswas and Smith[1] from the current-current form of the weak Hamiltonian, convergence being obtained by the use of the Weinberg sum rules[2] for the spectral functions of the propagators of vector and axial-vector currents of chiral SU(3)⊗SU(3). Doubts have been expressed[3] concerning the validity of Weinberg's second sum rule applied to SU(3). In this note we point out that a convergent result may be obtained without this second sum rule, if we assume the existence of an intermediate vector boson of finite mass.[4] An estimate can be made of this mass from the observed K_1^0-K_2^0 mass difference, but depends on some poorly determined parameters.

We follow the method[5] used by Biswas and Smith.[1] The mass difference is[6]

$$\Delta M=\Delta E(K_1^0)-\Delta E(K_2^0)=\mathrm{Re}(2\pi)^3 i\int d^4z\langle K^0|T\{H_w(z)H_w(0)\}|\bar{K}^0\rangle. \tag{1}$$

The second-order weak coupling will be taken as

$$T\{H_w(z)H_w(0)\}=2G^2M_B^{\;4}\int d^4x d^4y\,\Delta_{\alpha\beta}{}^B(y-z)\Delta_{\gamma\delta}{}^B(x)T\{J^\alpha(y)J^{+\beta}(z)J^\gamma(x)J^{+\delta}(0)\}, \tag{2}$$