[4]H. R. Crouch et al., Phys. Rev. Letters 13, 640 (1964).

[5]R. C. Chase, thesis, Physics Department, Northeastern University at Boston (unpublished).

[6]J. K. dePagter, A. M. Boyarski, G. Glass, J. I. Friedman, H. W. Kendall, M. Gettner, J. F. Larrabee, and Roy Weinstein, Phys. Rev. Letters 12, 739 (1964).

[7]J. D. Bjorken, S. D. Drell, and S. C. Frautschi, Phys. Rev. 112, 1409 (1958).

[8]S. D. Drell, Ann. Phys. (N. Y.) 4, 75 (1958).

[9]H. F. Ehrenberg, R. Hofstadter, U. Meyer-Berkhout, D. G. Ravenhall, and S. F. Sobottka, Phys. Rev. 28, 214 (1956).

[10]This value of B is equal to that given in our previous Letter; however, the errors are somewhat larger. This reflects the different cut of data used here and the more conservative estimate of the systematic errors used in the QED comparison. We also note that in the previous Letter the theory for $\rho\rightarrow 2\mu$ assumed the muon pair to be in an S state. Recently, S. Berman in a private communication has suggested $(1+\cos^2\theta)$ as the appropriate decay distribution for the theory. This would change our best value for B, which comes from our previous Letter, to $B=0.44_{-0.09}^{+0.21}\times 10^{-4}$. The values of A and β are unaffected by this change.

[11]A. Alberigi-Quaranta, M. DePretis, G. Marini, A. Odian, G. Stoppini, and L. Tau, Phys. Rev. Letters 9, 226 (1962).

[12]G. Charpak, F. J. Farley, R. L. Garwin, T. Muller, J. C. Sens, and A. Zichichi, Phys. Letters 1, 16 (1962).

[13]The comparison made here of the μ pair and g-2 experiments as tests of QED is based on the conventional breakdown model, which simply modifies the muon propagator. However, J. McClure and S. Drell have shown, in Nuovo Cimento 37, 1638 (1965), that the application of the Ward-Takahashi identity requires an accompanying change in the vertex function, which makes the two experiments independent and complimentary probes of the theory.

[14]A. Krass, Phys. Rev. 138, B1268 (1965).

[15]R. B. Blumenthal, D. C. Ehn, W. L. Faissler, P. M. Joseph, L. J. Lanzerotti, F. M. Pipkin, and D. G. Stairs, Phys. Rev. 144, 1199 (1966).

[16]R. Talman et al., Bull. Am. Phys. Soc. 11, 380 (1966).

[17]F. Pipkin, personal communication.

[18]E. L. Lomon, Phys. Letters 21, 555 (1966). Recent radiative corrections, such as suggested by Lomon, which are large for electron pair production, give less than a 1% correction to muon-pair yields.

$K\rightarrow 2\pi$ DECAY AND SU(3) SYMMETRY

David G. Boulware
Physics Department, University of Washington, Seattle, Washington

and

Lowell S. Brown*
Summer Institute for Theoretical Physics, University of Washington, Seattle, Washington

(Received 29 August 1966)

It is well known[1,2] that all two-pion decay modes of the K meson are forbidden in the limit of exact SU(3) symmetry if the decay Hamiltonian is of the current-current form, and if octet dominance is assumed. We shall show in this brief note that these decay modes remain forbidden if the requirement of octet dominance is relaxed, and the decay Hamiltonian is allowed to contain a part that transforms like the 27-dimensional representation. Thus both the $K_1^0\rightarrow 2\pi$ and $K^\pm\rightarrow 2\pi$ decays occur through SU(3) breaking, and the small $K^\pm$ decay rate can perhaps be accounted for by a small 27 part. Since both decay modes are suppressed, an octet enhancement relative to the 27 on the order of a factor 25 is required to explain the ratio of the two decay rates rather than the much larger factor that would be required if the 27 were not also forbidden in the exact symmetry limit. We should like to note that the observed decay rates may be attributed principally to the large K-π mass difference, which can give rise to a large kinematical SU(3) breaking of otherwise symmetrical amplitudes.

We assume that the nonleptonic decay Hamiltonian has the current-current structure

$$\mathcal{H}_w=\tfrac{1}{2}\{J,J^\dagger\},$$

where the current, J, transforms like[3]

$$j=(\lambda^1+i\lambda^2)\cos\theta+(\lambda^4+i\lambda^5)\sin\theta,$$

and its adjoint, $J^\dagger$, transforms like $j^\dagger=j^{\mathrm{T}}$. Since J and $J^\dagger$ occur symmetrically in the decay Hamiltonian, the SU(3) invariants that represent its matrix elements must be invariant under the interchange of j and j^{T}. This restricts $\mathcal{H}_w$ to transform as a combination of a unitary singlet, an octet, and a 27-dimensional representation. Since the parity-nonconserving part of the Hamiltonian is responsible for $K\to 2\pi$ decay, CP conservation requires that the decay amplitude $A^{abc}(p_a^2, p_b^2, p_c^2)$ be odd under charge conjugation. Bose statistics requires that this amplitude remain invariant if any of the SU(3) indices a, b, or c are interchanged together with the interchange of the corresponding momenta p_a, p_b, or p_c. All the meson masses are equal in the exact-symmetry limit, $p_a^2 = p_b^2 = p_c^2 = m^2$, and the decay amplitude A^{abc} is completely symmetrical in the indices a, b, c. In this limit it can be expanded in terms of the following complete set[4] of SU(3) invariants:

$$\mathrm{tr}\lambda^a\lambda^b\lambda^c\{j, j^{\mathrm{T}}\} + \mathrm{perm.}, \qquad (1)$$

$$\mathrm{tr}\lambda^a\lambda^b\,\mathrm{tr}\lambda^c\{j, j^{\mathrm{T}}\} + \mathrm{perm.}, \qquad (2)$$

$$\mathrm{tr}\lambda^a\lambda^b j\,\mathrm{tr}\lambda^c j^{\mathrm{T}} + \mathrm{tr}\lambda^a\lambda^b j^{\mathrm{T}}\,\mathrm{tr}\lambda^c j + \mathrm{perm.} \qquad (3)$$

We have indicated by +perm. the additional terms necessary to give complete symmetry in the indices a, b, c. All of these SU(3) invariants are even under the charge-conjugation operation which takes each of the λ matrices into its transpose λ^{T}. Since the decay amplitude must be odd under this operation, it must, in fact, vanish.

The SU(3)-invariant decay amplitude $A^{abc}(p_a^2, p_b^2, p_c^2)$ does not vanish if the momenta take on their physical values, say $p_a^2 = p_b^2 = m_\pi^2$, $p_c^2 = m_K^2$. Bose statistics now requires only that the amplitude be symmetrical in the two pion indices a and b, and charge-conjugation invariance is maintained by two independent SU(3) invariants which we take to be

$$\mathrm{tr}[\{\lambda^a, \lambda^b\}, \lambda^c]\{j, j^{\mathrm{T}}\}, \qquad (4)$$

and

$$\mathrm{tr}([\lambda^a, \lambda^c] j \lambda^b j^{\mathrm{T}} + [\lambda^a, \lambda^c] j^{\mathrm{T}} \lambda^b j), \qquad (5)$$

where the parentheses in the latter indicate symmetrization of a and b. Invariant (4) corresponds to the pure octet part of the decay Hamiltonian, while (5) contains a <u>27</u> part as well as an octet contribution. This kinematical breaking of SU(3) invariance might well be large, perhaps on the order of the mass difference $m_K^2 - m_\pi^2$ divided by a characteristic mass of (1 BeV)^2, or a factor of $\frac{1}{4}$. There is, of course, in addition, a symmetry breaking of a more dynamical nature that involves SU(3) structures that are not invariants, but that transform like λ^8. This additional symmetry breaking, however, does not give rise to any additional structure for the 2π decay modes of the K, since the kinematical breaking already yields both $\Delta T = \frac{1}{2}$ and $\Delta T = \frac{3}{2}$ terms.

We have enjoyed conversations with M. A. B. Bég and N. Cabibbo.

---

*Present address: Physics Department, Yale University, New Haven, Connecticut.

[1]N. Cabibbo, Phys. Rev. Letters <u>12</u>, 62 (1964).

[2]M. Gell-Mann, Phys. Rev. Letters <u>12</u>, 155 (1964).

[3]We employ the notation of M. Gell-Mann, Phys. Rev. <u>125</u>, 1067 (1962).

[4]We have omitted the singlet term $\mathrm{tr}\lambda^a\lambda^b\lambda^c\,\mathrm{tr}jj^{\mathrm{T}}$ +perm., which obviously does not contribute to the physical decay amplitude. We have also omitted the invariant $\mathrm{tr}\lambda^a\lambda^b(j\lambda^c j^{\mathrm{T}} + j^{\mathrm{T}}\lambda^c j) + \mathrm{tr}\lambda^a\lambda^b\lambda^c\{j, j^{\mathrm{T}}\}$ +perm., which is completely symmetrical under the interchange of any pair of the five λ matrices. However, the trace of any completely symmetrical combination of four or more three-dimensional matrices can be written as the sum of products of traces each containing fewer than four matrices. Thus this invariant is a linear combination of (2), (3), and the singlet term. The invariants (1) and (2) correspond to singlet and octet parts of the decay Hamiltonian, while (3) contains a <u>27</u> part as well.