Table I. Decay predictions for isovector octet mesons.

J^{PC}	$\eta\pi$	$K\bar{K}$	$\rho\pi$
$1^{-+}, 3^{-+}$, etc.	Forbidden by SU(3)	Forbidden by GP	Allowed
$2^{++}, 4^{++}$, etc.	Unique $\eta\pi/K\bar{K}$ branching ratio	Allowed. K_1K_1 for neutrals	Allowed. Branching ratio to $\eta\pi$ or $K\bar{K}$ not predicted by SU(3)
0^{++}	Same unique $\eta\pi/K\bar{K}$ branching ratio	Allowed. K_1K_1 for neutrals	Forbidden by J, P
$1^{--}, 3^{--}$, etc.	Forbidden by G	Allowed. K_1K_2 for neutrals	Forbidden by G

and neutral states.

Table I summarizes predictions if SU(3) is good and η is a pure octet. If both $\eta\pi$ and $\rho\pi$ are allowed, only 2^{++}, 4^{++}, etc. classifications are possible. This would suggest the 2^{++} classification for both halves of the A_2.

*Work supported in part by office of Naval Research Contract No. NAonr 10-69.

†This research has been sponsored in part by the U. S. Air Force Office of Scientific Research through the European Office of Aerospace Research of the U. S. Air Force under Contract No. F61052-68-C-0070.

[1]M. Gell-Mann and G. Zweig, unpublished. H. Harari, in Proceedings of the Fourteenth International Conference on High Energy Physics, Vienna, Austria, September, 1968 (CERN Scientific Information Service, Geneva, Switzerland), p. 195.

[2]C. A. Levinson, H. J. Lipkin, and S. Meshkov, Nuovo Cimento 32, 1376 (1964).

[3]D. J. Crennell, U. Karshon, K. W. Lai, J. M. Scarr, and I. O. Skillicorn, Phys. Rev. Letters 20, 1318 (1968).

[4]B. French, in Proceedings of the Fourteenth International Conference on High Energy Physics, Vienna, Austria, September, 1968 (CERN Scientific Information Service, Geneva, Switzerland), p. 95.

[5]H. J. Lipkin, Phys. Rev. 176, 1709, 1715 (1968).

ADDITIONAL EXPERIMENTAL PROOF OF *CP* NONCONSERVATION? WHO NEEDS IT?

Harry J. Lipkin
Department of Nuclear Physics, Weizmann Institute of Science, Rehovot, Israel
(Received 31 December 1968)

Experimental data are still consistent with Uretsky's model, which is CP invariant at the price of one extra neutral kaon which has no strong interactions but is degenerate with K^0 and $\bar{K}^0$ and mixes with them in weak decays. Long formal discussions of whether or not CP nonconservation is proved by present data are completely irrelevant as long as this model fits the data. CP nonconservation is presently accepted as the most reasonable interpretation of present data, not as an inevitable consequence.

A recent paper[1] suggests that CP nonconservation has not yet been proved experimentally. So what?

Kaon decay experiments have been explained without CP nonconservation[2,3] by postulating the existence of additional neutral kaons very nearly degenerate with the K_1 and K_2. These models have not been taken seriously because of their extremely contrived and ad hoc character, particularly since interference experiments ruled out models with additional hadrons.[4] That a third neutral kaon with only weak and no strong interactions should have a very precise accidental mass degeneracy with the strongly interacting kaons seems much less reasonable than giving up CP invariance.

However, as long as such peculiar models are not in disagreement with experiment, there has been no rigorous experimental proof of CP nonconservation. This does not necessarily justify a great experimental effort to disprove these models. We simply wish to point out that these models are still consistent with present data, and that complicated formal proofs which attempt to show that CP nonconservation has not yet been proved experimentally[1] are entirely superfluous.

As an example, consider one version of Uretsky's three neutral kaons[3] which we denote by K_1, K_2, and K'. These three states are all assumed to be eigenstates of CP and also to have pure exponential decays with the following lifetimes:

$$CP|K_1\rangle = |K_1\rangle, \quad \tau_{K_1} = 0.87\times 10^{-10}\text{ sec}; \tag{1a}$$

$$CP|K_2\rangle = -|K_2\rangle, \quad \tau_{K_2} = 5.30\times 10^{-8}\text{ sec}; \tag{1b}$$

$$CP|K'\rangle = |K'\rangle, \quad \tau_{K'} = \tau_{K_2} = 5.30\times 10^{-8}\text{ sec}. \tag{1c}$$

The K_1 and K_2 have exactly the same properties as in the old days before CP nonconservation. The K' is even under CP, like the K_1, but has a lifetime exactly equal to that of the K_2. The K_1 and K_2 have all the usual decay modes attributed to them before CP nonconservation. The K' has a two-pion decay mode, as well as all other decay modes required to fit experiment. The strongly interacting strangeness eigenstates K^0 and $\overline{K}^0$, and a third state K_W orthogonal to K^0 and $\overline{K}^0$, are expressed as follows in terms of the states K_1, K_2, and K':

$$|K^0\rangle = 2^{-1/2}[\{|K_1\rangle + |K_2\rangle\} - \xi_1|K_1\rangle + \xi'|K'\rangle], \tag{2a}$$

$$|\overline{K}^0\rangle = 2^{-1/2}[\{|K_1\rangle - |K_2\rangle\} - \xi_1|K_1\rangle + \xi'|K'\rangle], \tag{2b}$$

$$|K_W\rangle = \xi'|K_1\rangle - (1-\xi_1)|K'\rangle, \tag{2c}$$

where

$$\xi'^2 = 2\xi_1 - \xi_1^2 \approx 3\times 10^{-3}. \tag{3}$$

All the presently observed effects which apparently violate CP invariance are described without CP nonconservation in this model and arise from the small admixture of the state K' which has the same lifetime as the K_2 but opposite CP. The relation between this formulation and the conventional formulations using CP nonconservation can be seen by defining

$$|K_L^+\rangle = (1+\xi'^2)^{-1}\{|K_2\rangle + \xi'|K'\rangle\}, \tag{4a}$$

$$|K_L^-\rangle = (1+\xi'^2)^{-1}\{|K_2\rangle - \xi'|K'\rangle\}. \tag{4b}$$

Thus,

$$|K^0\rangle = 2^{-1/2}[(1-\xi_1)|K_1\rangle + (1+\xi'^2)|K_L^+\rangle], \tag{5a}$$

$$|\overline{K}^0\rangle = 2^{-1/2}[(1-\xi_1)|K_1\rangle - (1+\xi'^2)|K_L^-\rangle]. \tag{5b}$$

The K^0 and $\overline{K}^0$ are each expressed as a linear combination of a short-lived state and a long-lived state. The long-lived state is not an eigenstate of CP and can therefore decay into all possible final states, including states which are not eigenstates of CP. The interference between the long-lived and short-lived two-pion decays observed by placing regenerators in a kaon beam is described in this model by interference between the K_1 and K' components. Although the observation of this interference effect does eliminate some of the models with extra kaons (in particular the models in which the extra kaons also have strong interactions) and all models with extra pions,[4] <u>such interference effects are perfectly consistent with this model</u>.

The exact formal relation between the Uretsky model and the conventional CP-nonconservation model can be seen by setting all decay matrix elements of the K_L^+ state defined by Eq. (4a) equal to the corresponding decay matrix elements of the K_L in the conventional description. The two descriptions then differ only by (a) the discrepancies between the coefficients in the expression (5a) relating the K^0 to the K_1 and K_L, and (b) the difference between the two long-lived states (4a) and (4b) appearing in the K^0 and $\overline{K}^0$. The difference between the coefficients leads to small effects beyond the precision of present data. The difference between the two long-lived states would show up as a difference between the decays of long-lived kaons which originated as K^0 and those originating as $\overline{K}^0$, <u>but only to final states which are not eigenstates of CP</u>. If the K_L^+ showed an asymmetry between $\pi^+\mu^-\overline{\nu}$ and $\pi^-\mu^+\nu$, the K_L^- should show the opposite asymmetry. One could therefore distinguish between this model and CP nonconservation by comparing decays of long-lived kaons which originally came from K^0 states with those which originally came from $\overline{K}^0$ states.

Until this model has been disproved experimentally, there is no rigorous experimental proof that CP invariance is violated. However, <u>only such a model with extra kaons can save CP</u>. The original observation of the 2π decay mode of the long-lived kaon state showed that both short-lived and long-lived kaons decayed into states[4] which were even under CP. This is consistent with CP invariance only if there are two kaon states with even CP. Subsequent experiments showed that η_{+-} has the same magnitude and phase in all experiments independent of the production process. Thus the long-lived and short-lived kaon states which are even under CP must always be produced in the same coherent linear combination in strong interactions. There is therefore a decoupling from strong interactions of the other linear combination of these two states which is orthogonal to the one produced. In the present model, this decoupled state is K_W defined by Eq. (2c). It is hard to believe that this state should have the same mass as the K^0 and $\bar{K}^0$, despite the difference in strong and electromagnetic interactions such as those responsible for the K^0–$K^\pm$ mass difference or the πK mass difference. It is much easier to believe that there is a CP nonconservation.

[1]D. I. Lalovic, Phys. Rev. Letters 24, 1662 (1968).

[2]A. Abashian and H. J. Lipkin, Phys. Letters 14, 151 (1965).

[3]J. Uretsky, Phys. Letters 14, 154 (1965).

[4]J. Prentki, in Proceedings of the Oxford International Conference on Elementary Particles, September, 1965 (Rutherford High Energy Laboratory, Chilton, Berkshire, England, 1966), p. 48, points out that interference experiments rule out all theories with extra hadrons. The possibility of an extra kaon which only interacts weakly is presumably so far-fetched that it is not even discussed. Since the Oxford Conference, there has been no further mention of extra kaon models in review at international conferences.

EXCHANGE DEGENERACY AND SU(3) FOR BARYONS*

Richard H. Capps
Purdue University, Lafyette, Indiana
(Received 2 January 1969)

It is assumed that the contributions of baryon Regge trajectories cancel in the imaginary parts of meson-baryon scattering amplitudes in states of the SU(3) representations $\underline{10}^*$ and $\underline{27}$. Predictions concerning interaction ratios, mass splitting, and particle mixing are made and compared with experiment.

The following "exchange-degeneracy hypothesis" has been useful recently in particle physics: In the imaginary part of any two-hadron scattering amplitude of internal quantum numbers for which no resonances exist, the contributions of t-channel Regge trajectories cancel and those of u-channel trajectories also cancel.[1,2] This usually requires "exchange" degeneracy of trajectories corresponding to physical particles of opposite parity and spins differing by unity. In this paper, we apply the hypothesis to the contributions of baryon trajectories to the scattering of pseudoscalar mesons (P) from $j^P=\frac{1}{2}^+$ baryons (B). Approximate SU(3) symmetry is assumed; the SU(3) implications are surprising because of the different multiplets observed for baryons of even and odd parities.

We first consider the limit of exact SU(3) symmetry. Schmid has pointed out that the $j^P=\frac{5}{2}^-$ $\Sigma^*(1765)$ lies very close to the trajectory of the $j^P=\frac{3}{2}^+$ $\Sigma^*(1382)$, and that this is implied by the exchange-degeneracy hypothesis and the absence of resonances in KN states.[3] Extended to SU(3), the argument implies that the contributions of the $j^P=\frac{3}{2}^+$ decuplet trajectory [denoted by $(\frac{3}{2}^+, \underline{10})$] and the $(\frac{5}{2}^-, \underline{8})$ trajectory must cancel in all PB states of the representations $\underline{10}^*$ and $\underline{27}$. We denote by $R_i=\beta_{i,\,10^*}/\beta_{i,\,27}$ the residue ratio in PB states of representations $\underline{10}^*$ and $\underline{27}$ of a trajectory of SU(3) multiplet i. Our hypothesis implies that the R values of the two exchange-degenerate multiplets must be the same. It can be seen from the octet-octet crossing matrix that $R_{10}=3$ while R_8 is given in terms of the F/D ratio by the formula

$$R_8=(2-6F)/(1+3F^2), \tag{1}$$

where we take $D=1$ so $F=F/D$.[4] The value $R=3$ corresponds to a double root of F, with the value $F=-\frac{1}{3}$. We assume throughout the paper that the ratios of particle-trajectory couplings of the same spin structure are independent of momentum transfer and so are the same in the exchange region and the physical region of the resonance decays. The value $F=-\frac{1}{3}$ is not far from the value -0.14 that is determined from the decays of the $(\frac{5}{2}^-, \underline{8})$ particles.[5,6]

A model that fits very well the observed quantum numbers of resonances is the quark model, or the closely related $SU(6)_W$ model.[7] In quark terminology, the quantum numbers of the lth level of resonances are obtained by adding l units of orbital angular momentum to the basic SU(6) representation $\underline{56}$ (if l is even) or $\underline{70}$ (if l is odd). The spin-$\underline{SU(3)}$ structure of the $\underline{70}$, and the F values that follow from $SU(6)_W$ symmetry, are[7]

$$(\tfrac{1}{2},\underline{1}),\quad (\tfrac{1}{2},\underline{10}),\quad (\tfrac{1}{2},\underline{8})_{F=5/3},\quad (\tfrac{3}{2},\underline{8})_{F=-\frac{1}{3}}. \tag{2}$$

Since the physical multiplet $(\frac{5}{2}^-, \underline{8})$ corresponds