Superweak Interactions and TCP Invariance

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We examine the role of TCP invariance in theories in which CP nonconservation arises solely through perturbation of the K^0-$\bar{K}^0$ effective Hamiltonian. While the assumption of TCP invariance requires that the observed CP nonconservation arise from an interaction obeying $|\Delta S|=2$, the assumption that the superweak interaction obeys $|\Delta S|=2$ leads to the same predictions as TCP invariance, regardless of whether it possesses that symmetry.

SOME time ago Wolfenstein[1] made the interesting suggestion that the observed CP nonconservation[2] in $K_2^0 \to 2\pi$ decays could be ascribed entirely to the effect of a superweak CP-noninvariant interaction, with a coupling constant F of the order of $10^{-8}G$ which introduces a CP-even component into the long-lived neutral kaon state $|K_2^0\rangle$. This idea was developed further by Lee and Wolfenstein,[3] who showed that, if TCP invariance is assumed, all CP-noninvariant phenomena in neutral kaon decays are determined by a single parameter[4] $|\epsilon|$, if we neglect quantities of relative order F/G. Leaving aside the controversial question of the magnitude of η_{00}, all measurements[5] of neutral kaon decay are consistent with this hypothesis, and there has been no unambiguous observation of a CP-noninvariant effect in other phenomena, also in agreement with the superweak hypothesis.

While Wolfenstein showed[1] that a superweak CP-noninvariant interaction would suffice to yield the observed magnitude[2] of CP nonconservation if it obeyed the selection rule $|\Delta S|=2$, it can be shown conversely[6] that if TCP invariance is assumed, such a superweak interaction *must* induce $K^0 \leftrightarrow \bar{K}^0$ transitions, i.e., satisfy $|\Delta S|=2$, if it is to account for CP nonconservation in $K_2^0 \to 2\pi$ decay. A $|\Delta S|=1$ CP-noninvariant interaction would have to have a coupling constant of order $10^{-3}G$ to cause the observed $K_2^0 \to 2\pi$ decay rate; possible $\Delta S=0$ CP-noninvariant interactions would not, in lowest order, have any influence on neutral kaon decay unless they also violated TCP invariance.[7] Examination of the argument[8,6] shows that TCP invariance imposes no condition on $K^0 \leftrightarrow \bar{K}^0$ transitions. It follows that if the sole cause of CP nonconservation in neutral kaon decays is a superweak CP-noninvariant interaction which induces $K^0 \leftrightarrow \bar{K}^0$ transitions, there is no way of telling whether it obeys TCP invariance or not (if we neglect quantities of relative order F/G). The same conclusion may be reached from the analysis[3] of superweak models by Lee and Wolfenstein: if TCP invariance is not assumed, all CP-nonconserving phenomena in K^0, $\bar{K}^0$ decays are determined by two real parameters E_2 and E_3 which represent the effects of superweak interactions obeying $|\Delta S|=2$ and $\Delta S=0$, respectively. The restriction $E_3=0$ follows *either* from the assumption of TCP invariance *or* from the requirement that the superweak interaction satisfy $|\Delta S|=2$.

We conclude that if CP noninvariance is attributed solely to Wolfenstein's $|\Delta S|=2$ superweak interaction, and effects of relative order $F/G \sim 10^{-9}$ are neglected, all CP-noninvariant phenomena are restricted to the neutral kaon system[9] where they are determined by a single parameter ϵ with prescribed phase ϕ_ϵ, whether or not the superweak interaction satisfies TCP invariance. The idea that the superweak interaction may not be TCP invariant will appeal to those who believe that there is a connection between the strength of a particular type of interaction and the degree of symmetry associated with it.

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[1] L. Wolfenstein, Phys. Rev. Letters **13**, 562 (1964).
[2] J. H. Christenson, J. W. Cronin, V. L. Fitch, and R. Turlay, Phys. Rev. Letters **13**, 138 (1964).
[3] T. D. Lee and L. Wolfenstein, Phys. Rev. **138**, B1490 (1965).
[4] See also, B. G. Kenny and P. K. Kabir, Phys. Rev. D **2**, 257 (1970).
[5] For a recent summary, see J. Steinberger, in *Proceedings of the Lund International Conference on Elementary Particles, 1969*, edited by G. von Dardel (Berlingska, Lund, Sweden, 1969), p. 41.
[6] See, for example, P. K. Kabir, in *Springer Tracts in Modern Physics*, edited by G. Höhler (Springer-Verlag, Berlin, 1970), Vol. 52, p. 103.
[7] P. K. Kabir, *The CP Puzzle* (Academic, London, 1968), p. 41.
[8] J. S. Bell and J. Steinberger, *Proceedings of the Oxford International Conference on Elementary Particles, 1965*, edited by T. R. Walsh *et al.* (Rutherford Laboratory, Chilton, England, 1966), p. 200.
[9] And other possible homologous systems.