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COMMENTS

Comments are short papers which criticize or correct papers of other authors previously published in the **Physical Review**. *Each Comment should state clearly to which paper it refers and must be accompanied by a brief abstract. The same publication schedule as for regular articles is followed, and page proofs are sent to authors.*

Tests of T and CPT in neutral-kaon decays

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Recent proposals by Lavoura, to extract possible T- and CPT-violating parameters from measurements on neutral-kaon decays, are related to earlier suggestions. One apparently new test for CPT is shown, after correction of a conceptual oversight, to be subject to the same difficulties that Lavoura has emphasized for the test of T proposed earlier.

Lavoura recently suggested [1] that decays of K^0 and $\bar{K}^0$ be compared in order to test T and CPT invariance, and to extract measures of T and CPT noninvariance. The idea is reasonable, but it is not as novel as the author declares, nor has he proposed any relation which substantially differs from those previously published [2–7]. In this Comment, I show how his tests are related to the earlier ones; for the seemingly new test which he suggests, it will be shown that its implementation is possible only with additional measurements, which are open to the same objections that he cites against my proposed test [4] of T invariance.

Lavoura's definitions of the real T-violating parameter χ and the complex CPT-violating parameter θ possess the didactic merit of being immediately recognizable as quantities that must vanish in the limit of the corresponding symmetries. Change of parametrization alone cannot, however, alter relations between physical observables. Since the quantities that Lavoura wishes to relate are the same as those defined by earlier authors, if he could find a *new* relation, it would mean that previous authors had failed to make a complete analysis. Lavoura's tests do not constitute such a challenge.

Assuming, as usual, that neutral-kaon decays are adequately described by *two* exponentially decaying states, each with its characteristic decay amplitude to any given channel k, then the rate of K^0 decay into a channel k has the general form

$$r_k = a_k e^{-\gamma_S t} + b_k e^{-\gamma_L t} + e^{-(\gamma_S+\gamma_L)t/2}(c_k \cos \Delta mt + d_k \sin \Delta mt) \ . \quad (1)$$

The time-evolution parameters $\gamma_S = \tau_S^{-1}$, $\gamma_L = \tau_L^{-1}$, and $\Delta m = m_L - m_S$, and the decay coefficients a_k, b_k, c_k, and d_k, completely determine the rate of decay to the channel k from initial K^0's, while the same formula, Eq.(1), with primed coefficients a'_k, b'_k, c'_k, and d'_k, describes the corresponding decay rate r'_k of $\bar{K}^0$'s into the same (self-conjugate) channel k. We shall now relate Lavoura's proposed tests to ones given earlier; equations from Ref. [1] will henceforth be designated with the prefix R, e.g., Eq. (R6) will mean Lavoura's Eq. (6). The quantity called χ by Lavoura was previously introduced in Ref. [4] and calculated there to be

$$\chi = \frac{2 \sin \sigma \cos \delta}{\cos^2 \delta + \sin^2 \sigma} \quad (2)$$

in terms of the T-violating parameter $\sigma = \pi/2 - (\alpha_1 + \alpha_2)$ and the TCP-noninvariance parameter $\delta = \alpha_1 - \alpha_2$, which were defined in Ref. [6]. As required by their definitions, χ and σ vanish together. Direct substitution of Eqs. (7a) and (7b) of Ref. [5] into the first expresssion in Eq. (R11) yields an expression which is readily transformed into Eq. (2) above, while substitution of Eq. (7c) into the second expression in Eq. (R11) again leads to the same formula. The *tests* of T invariance, found by requiring these expressions to vanish, were given explicitly in Eqs. (T4) and (T6), when applied to Eqs. (G2) and (G3), of Ref. [3]. Similarly, substitution of the same cited Eqs.(7a) and (7c) and Eqs. (7b) and (7c) respectively, into the two expressions of Eq. (R12) yield the same quantity. Using the exact forms of Eqs. (10a) and (10b) of Ref. [6], one finds that this quantity is nothing other than the difference of the diagonal elements of the neutral-kaon quasi-Hamiltonian ("mass matrix" in Lavoura's language) measured in terms of the (complex) splitting of its eigenvalues, which is *defined* as θ in Eq. (R5). The restrictions imposed by CPT invariance, obtained by setting the expressions in Eq. (R12) to zero, were given in Eqs. (L3) and (L4) of Ref. [3].

We finally turn to a test of CPT posssessing special advantages, according to Lavoura, based on measurement of the time dependence of the transition [8] probability from K^0 to K^0. While his calculations are correct—the two expresssions in Eq. (R8) do equal the quantity θ just mentioned—Lavoura's proposed application is based on the erroneous premise that Eq. (R7) can be used to fit a *decay* curve. While this would be a reasonable presumption in the case of a typical unstable particle—for which the probability that it survived is the complement of the probability that it decayed—in the case of a K^0, there is the additional possibility that it could have changed into a $\bar{K}^0$. Therefore, to extract the coefficients A, B, C, D of Eq. (R7) from measurements of a K^0 decay curve, it would be necessary also to measure the probability of $K^0 \to \bar{K}^0$ transitions. Since these are the very transitions that Lavoura wished to avoid, it is clear that no gain is achieved from his suggestion to use Eq. (R7).

Lavoura's "new" tests have been shown to be repetitions of those already published. His proposal to use survival curves offers no advantage over previous suggestions.

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[7] No representation is made for the completeness of Refs. [2–6] beyond the assertion that they contain every test of T and CPT proposed in Ref. [1].
[8] It may be more appropriate to call this the *nontransition*, or *survival*, probability.