CP Violation in $K_S \to 3\pi$

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The possible final states for the decay $K^0 \to \pi^+\pi^-\pi^0$ have isospin I=0, 1, 2, and 3. The I=0 and I=2 states have CP=+1 and K_S can decay into them without violating CP symmetry, but they are expected to be strongly suppressed by centrifugal barrier effects. The I=1 and I=3 states, which have no centrifugal barrier, have CP=-1 so that the K_S decay to these requires CP violation.

In order to see CP violation in $K_S \to \pi^+\pi^-\pi^0$, it is necessary to observe the interference between K_S and K_L decay, which determines the amplitude ratio

$$\eta_{+-0} = \frac{A(K_S \to \pi^+ \pi^- \pi^0)}{A(K_L \to \pi^+ \pi^- \pi^0)} \ . \tag{1}$$

If η_{+-0} is obtained from an integration over the whole Dalitz plot, there is no contribution from the I=0 and I=2 final states and a nonzero value of η_{+-0} is entirely due to CP violation.

Only I=1 and I=3 states, which are CP=-1, are allowed for $K^0\to\pi^0\pi^0\pi^0$ decays and the decay of K_S into $3\pi^0$ is an unambiguous sign of CP violation. Similarly to η_{+-0} , η_{000} is defined as

$$\eta_{000} = \frac{A(K_S \to \pi^0 \pi^0 \pi^0)}{A(K_L \to \pi^0 \pi^0 \pi^0)} \ . \tag{2}$$

If one assumes that CPT invariance holds and that there are no transitions to I=3 (or to nonsymmetric I=1 states), it can be shown that

$$\eta_{+-0} = \eta_{000}$$

$$= \epsilon + i \frac{\text{Im } a_1}{\text{Re } a_1} . \tag{3}$$

With the Wu-Yang phase convention, a_1 is the weak decay amplitude for K^0 into I=1 final states; ϵ is determined from CP violation in $K_L \to 2\pi$ decays. The real parts of η_{+-0} and η_{000} are equal to $\text{Re}(\epsilon)$. Since currently-known upper limits on $|\eta_{+-0}|$ and $|\eta_{000}|$ are much larger than $|\epsilon|$, they can be interpreted as upper limits on $\text{Im}(\eta_{+-0})$ and $\text{Im}(\eta_{000})$ and so as limits on the CP-violating phase of the decay amplitude a_1 .