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THE π^0 - η - η' MIXING AND CP VIOLATION IN THE $K^0 \rightarrow \pi^0 \pi^0$ MODE

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A B S T R A C T

We find that the effect of π^0 - η - η' mixing on the value of η^{00} is comparable to that of ϵ' , leading to a reduction of η_{00} , contrary to previous analyses. Also, it decreases ϕ_{00} , the phase of η^{00} , by less than 0.4 degrees, while experimentally ϕ_{00} was reported to be 9.8 ± 5.4 degrees larger than ϕ_{+-} .

*) Part of this work is based on the Master Thesis of Zhiqin Zhang, May 1987.

It is now widely accepted that a significant phase difference between η^{+-} and η^{00} would be a signature of CPT violation, as shown in the work by Barmin et al.¹⁾, where⁰⁾

$$\eta^{+-} = \frac{A(K_L \rightarrow \pi^+ \pi^-)}{A(K_S \rightarrow \pi^+ \pi^-)} \equiv |\eta^{+-}| e^{i\phi_{+-}}, \quad (1)$$

$$\eta^{00} = \frac{A(K_L \rightarrow \pi^0 \pi^0)}{A(K_S \rightarrow \pi^0 \pi^0)} \equiv |\eta^{00}| e^{i\phi_{00}}. \quad (2)$$

According to Ref. 1), the allowed phase difference $|\phi_{00} - \phi_{+-}|$ should be less than 0.1° if CPT is an exact symmetry, which is to be compared with the apparent value in the Particle Data book of $\phi_{00} - \phi_{+-} = 9.8 \pm 5.4^\circ$. This discrepancy is almost entirely from the reported and expected values of ϕ_{00} , because the theoretical and the experimental values of ϕ_{+-} are consistent. A refined measurement of the phase difference is on the way²⁾. However, a weakness of Ref. 1) is that isospin symmetry is assumed in their analysis. Since the CPT is much more fundamental than isospin symmetry, the effect of isospin violation should be considered before making any conclusions on CPT. It is the job of filling this blank that we would like to assume. The isospin violation has three aspects in the $K_{L,S} \rightarrow 2\pi$ decays: the π^0 - η - η' mixing, the electromagnetic penguin³⁾ and the electromagnetic final state interaction⁴⁾. In this short article, we shall concentrate on the first aspect, and leave the others (which do not affect ϕ_{00}), for a future detailed publication. Some recent articles examined the mixing and electromagnetic penguin effects^{5),6)}. However, these authors did not explicitly discuss the phase problem, though Ref. 5) briefly mentioned a conclusion. What is important practically is that we claim a decrease in η^{00} due to the π^0 - η - η' mixing while Refs. 5) and 6) claim an increase. Also, we have been using a different approach, which we believe is better for estimating both phases and magnitudes. Unfortunately, we find that the mixing can hardly produce an appreciable correction on the phase ϕ_{00} , in agreement with Ref. 5).

If isospin is a good symmetry, one should have

$$\eta^{+-} \cong \epsilon + \epsilon', \quad (3)$$

$$\eta^{00} \cong \epsilon - 2\epsilon'. \quad (4)$$

These relations become invalid when isospin is broken, in particular the π^0 - η - η' mixing causes a change in η^{00} but not in η^{+-} . Let us first examine the π - η mixing, then include η' as well. Now, the π^0 has a small isosinglet component

$$\pi^0 = \pi^3 + \theta_\eta \eta + \theta_{\eta'} \eta' \quad (\pi^3 = \frac{1}{\sqrt{2}} (\bar{u}u - \bar{d}d)) \quad (5)$$

The values of the mixing angles θ_η and $\theta_{\eta'}$ have been calculated in Refs. 7), 8) and 9), $\theta_\eta = 0.011$ to 0.018 , $\theta_{\eta'} = 0.003$ to 0.005 . Let η_m^{00} be the modified version of the η^{00} parameter (4), after including the effect of Eq. (5), which gives

$$\eta_m^{00} = \eta^{00} \left[1 + 2\theta_\eta \frac{A(K_L \rightarrow \pi^3 \bar{\eta})}{A(K_L \rightarrow \pi^3 \pi^3)} - 2\theta_{\eta'} \frac{A(K_S \rightarrow \pi^3 \bar{\eta})}{A(K_S \rightarrow \pi^3 \pi^3)} \right], \quad (6)$$

where $\bar{\eta}$ is the physical η (see later) being put on the π^0 mass shell. In Refs. 5) and 6), the $\pi^3 \eta$ final state is transferred into an $I = 2$ one, in which unclear phase conventions are involved. Instead, we shall identify the $K_{S,L} \rightarrow \pi^3 \eta$ decay amplitude as an $I = 1$ piece. Since θ_η is small, to the accuracy of omitting ϵ' relative to ϵ , we can take only the $I = 0$ part of $K_{L,S} \rightarrow \pi^3 \pi^3$ decays. Defining

$$\langle \pi^3 \bar{\eta} | K^0 \rangle = a_1 e^{i\delta_1} \quad (7)$$

$$\langle \pi^3 \pi^3 | K^0 \rangle_{\Delta I = \frac{1}{2}} = \tilde{a}_0 e^{i\delta_0} \quad (8)$$

where δ_0 and δ_1 are respectively S wave phase shifts of $I = 0$, $I = 1$ final states. Under the phase convention $\text{Im } a_2 = 0$, we have

$$\frac{\Delta \eta^{00}}{\eta^{00}} \equiv \frac{\eta_m^{00} - \eta^{00}}{\eta^{00}} = -\sqrt{2} \theta_\eta (\gamma_S - \gamma_L) \frac{\text{Im } a_1 \tilde{a}_0^*}{\text{Im } M_{12} \tilde{a}_0^2} e^{i(\theta' + \delta_1 - \delta_0)} \quad (9)$$

where $\text{tg } \theta' = -2(m_S - m_L)/(\gamma_S - \gamma_L) \equiv \text{ctg } \theta$. This formula can be transformed into the following elegant one:

$$\frac{\Delta \eta^{00}}{\eta^{00}} = -2\sqrt{2} \theta_\eta S \omega^{-1} \left(\frac{\text{Im } a_1}{\text{Im } \tilde{a}_0} - \frac{\text{Re } a_1}{\text{Re } \tilde{a}_0} \right) e^{i(\delta_1 - \delta_2)} \frac{\epsilon'}{\epsilon} \quad (10)$$

$$S = \text{Sign} \left[\frac{\text{Re } a_2}{\text{Re } a_0} \right] = -\sqrt{2} \text{Sign} \frac{\text{Re } \tilde{a}_2}{\text{Re } \tilde{a}_0}, \quad (11)$$

noting $(\omega = |\text{Re } a_2 / \text{Re } a_0| \simeq 1/18)$

$$\epsilon = \frac{1}{2\sqrt{2}} \cdot \frac{\text{Im} M_{12} \tilde{a}_0^2}{\text{Re} M_{12} \tilde{a}_0^2} e^{i\theta}, \quad (12)$$

$$\epsilon' = \frac{1}{\sqrt{2}} e^{i(\frac{\pi}{2} + \delta_2 - \delta_0)} \text{Im}(a_2/a_0). \quad (13)$$

From (9), we immediately find that $\Delta\eta^{\circ\circ} = 0$ in the superweak theory¹⁰⁾ where both $\text{Im } a_0$ and $\text{Im } a_1$ vanish. The bracket in Eq. (10) may also vanish, if (i) a_1 and $\tilde{a}_0$ are governed by the same dynamics; and (ii) their real and imaginary parts are both dominated by the same operator, in other words, if a_1 and $\tilde{a}_0$ have the same phase. The bracket is written as a difference of two ratios, which will probably serve the purpose of cancelling as much as possible uncertainties related to our poor understanding of the $\Delta I = \frac{1}{2}$ rule. For this purpose, we shall calculate $\text{Re } a_1$ and $\text{Re } \tilde{a}_0$ in the same basis though $|\tilde{a}_0|$ is experimentally known. Equation (10) is valid only for non-zero ϵ'/ϵ , because when $\epsilon'/\epsilon = 0$, $\text{Im } \tilde{a}_0$ vanishes. ϵ'/ϵ has been calculated by many authors with values 0.002-0.01¹¹⁾. In getting Eq. (10), all the phases are carefully examined as in Ref. 12). Equation (10) is free from any possible ambiguities due to phase conventions in I-spin decompositions, because in dealing with $\tilde{a}_0, \tilde{a}_2$, we stick to the $K^0 \rightarrow \pi^3\pi^3$ mode so as to use the convention by even number of times^{*)}. Until now, our formulas are clean without any assumptions and exact without gross approximations.

The δ_2 is measured, about -6° . The δ_1 is calculable. The current algebra calculation with soft pion technique gives $\delta_1 = 0$ ¹³⁾. The $a_0(980)$ pole dominance

*) Equations (3) and (4) are under the following phase convention:

$$\begin{aligned} a_{+-} &= \sqrt{2/3} a_0 e^{i\delta_0} + \sqrt{1/3} a_2 e^{i\delta_2}, \\ a_{00} &= \pm (\sqrt{1/3} a_0 e^{i\delta_0} - \sqrt{2/3} a_2 e^{i\delta_2}), \end{aligned}$$

Since a_{+-} and a_{00} never interfere, so their relative phase which is irrelevant in Eqs. (3) and (4) and in our later calculation, can be arbitrary. Actually it turns out that our phase convention ($|\pi^+\rangle = C|\pi^-\rangle$) coincides with the minus sign in the above expression for a_{00} . The relative phase between a_0 and a_2 is though physical, however, one can always make the following change, say, $a'_2 = -a_2$ and

$$\begin{aligned} a_{+-} &= \sqrt{2/3} a_0 e^{i\delta_0} - \sqrt{1/3} a'_2 e^{i\delta_2}, \\ a_{00} &= \pm (\sqrt{1/3} a_0 e^{i\delta_0} + \sqrt{2/3} a'_2 e^{i\delta_2}). \end{aligned}$$

To avoid this ambiguity, we use one phase in I-spin decomposition by even number of times consistently in our final results.

approximation gives $0 < \delta_1 < 2^\circ$, which is consistent with Ref. 13)*). Therefore, $\Delta\eta^{\circ}/\eta^{\circ}$ is almost real ($\delta_1 - \delta_2 \approx 6^\circ$), which means that the π° - η mixing cannot contribute an appreciable phase difference $\phi_{00} - \phi_{+-}$. Then, how large is the value of $\Delta\eta^{\circ}/\eta^{\circ}$ and what is its sign? To answer these questions, one has to calculate the other unknowns of Eq. (10).

For simplicity, we shall make an approximation by assuming that both $\text{Re } a_1$ and $\text{Re } \tilde{a}_0$ are dominated by the operator O_1 ($\Delta I = \frac{1}{2}$)

$$O_1 = \bar{s}_L \gamma_\mu d_L \bar{u}_L \gamma^\mu u_L - \bar{s}_L \gamma_\mu u_L \bar{u}_L \gamma^\mu d_L,$$

and both $\text{Im } a_1$ and $\text{Im } \tilde{a}_0$ by O_5 ($\Delta I = \frac{1}{2}$)

$$O_5 = \bar{s}_L \gamma_\mu \lambda^a d_L \left(\sum_{u,d,s} \bar{q}_R \gamma^\mu \lambda_a q_R \right).$$

These operators and their running coupling constants are given in Ref. 14) and it is shown there that our assumption is plausible. Incidentally, this assumption is also taken in Refs. 5) and 6). Our assumption can be formulated as

$$\text{Re } a_1 / \text{Re } \tilde{a}_0 = \langle \pi^3 \bar{\eta} | O_1 | K^0 \rangle / \langle \pi^3 \pi^3 | O_1 | K^0 \rangle, \quad (14)$$

$$\text{Im } a_1 / \text{Im } \tilde{a}_0 = \langle \pi^3 \bar{\eta} | O_5 | K^0 \rangle / \langle \pi^3 \pi^3 | O_5 | K^0 \rangle, \quad (15)$$

$$S = - \text{sign} \frac{C_4 \langle \pi^3 \pi^3 | O_4 | K^0 \rangle}{C_1 \langle \pi^3 \pi^3 | O_1 | K^0 \rangle}. \quad (16)$$

Equations (14) to (16) show that the values of the running coupling constants C_i in Ref. 14) do not appear in our approximation, except for the relative sign of C_1 and C_4 in Eq. (16). Since these ratios are probably not sensitive to how we estimate

*) In these calculations, one has to extrapolate the isospin singlet particles to the pion mass-shell, which causes some uncertainties. For example, one might think that the $a_0(980)$ should co-move with the isosinglets, in which case $\delta_1 < 14^\circ$. We shall take 14° as the maximal possible value in the text. $\delta_1 > 0$, because it is an attractive channel. We must say that the δ_1 calculations involve assumptions which have not been directly tested.

them, we shall simply use the vacuum insertion^{*)} to calculate the matrix elements following the recipe in Ref. 15) which is consistent with the related theorems in current algebra¹⁶⁾.

Before going further, we should notice that the physical η is a mixed state of SU(3) octet η_8 and SU(3) singlet η_0 due to SU(3) breaking

$$\begin{aligned}\eta &= \cos\phi \eta_8 - \sin\phi \eta_0 \\ &= \left(\frac{1}{\sqrt{6}} \cos\phi - \frac{1}{\sqrt{3}} \sin\phi\right) (\bar{u}u + \bar{d}d) + \left(\frac{-2}{\sqrt{6}} \cos\phi - \frac{1}{\sqrt{3}} \sin\phi\right) \bar{s}s, \quad (17a)\end{aligned}$$

$$\begin{aligned}\eta' &= \sin\phi \eta_8 + \cos\phi \eta_0 \\ &= \left(\frac{1}{\sqrt{6}} \sin\phi + \frac{1}{\sqrt{3}} \cos\phi\right) (\bar{u}u + \bar{d}d) + \left(\frac{-2}{\sqrt{6}} \sin\phi + \frac{1}{\sqrt{3}} \cos\phi\right) \bar{s}s, \quad (17b)\end{aligned}$$

where $\phi = -20^\circ$ according to Ref. 17). We shall use the following common definitions

$$\langle 0 | \bar{u} \gamma_\mu \gamma_5 u | \pi^3 \rangle = - \langle 0 | \bar{d} \gamma_\mu \gamma_5 d | \pi^3 \rangle = \frac{1}{\sqrt{2}} f_\pi p_\mu, \quad (18a)$$

$$\langle 0 | \bar{s} \gamma_\mu \gamma_5 d | K^0 \rangle = f_K k_\mu, \quad (18b)$$

$$\langle 0 | \bar{u} \gamma_\mu \gamma_5 u | \bar{\eta} \rangle = \langle 0 | \bar{d} \gamma_\mu \gamma_5 d | \bar{\eta} \rangle = \left(\frac{\cos\phi}{\sqrt{6}} - \frac{\sin\phi}{\sqrt{3}}\right) f_\eta p_\mu, \quad (19)$$

etc., and the empirical formulas for the vector currents

$$\langle \pi^3(p) | \bar{s} \gamma_\mu d | K^0 \rangle = \frac{1}{\sqrt{2}} (k+p)_\mu, \quad (20)$$

$$\langle \bar{\eta} | \bar{s} \gamma_\mu d | K^0 \rangle = - \left(\frac{\cos\phi}{\sqrt{6}} + \frac{2 \sin\phi}{\sqrt{3}}\right) (k+p)_\mu. \quad (21)$$

*) Though the vacuum insertion suffers from giving too small a $\Delta I = \frac{1}{2}$ amplitude and too large a $\Delta I = \frac{3}{2}$ amplitude, the enhancing or suppressing factors may be cancelled in Eqs. (14) to (16).

etc. The following equations are useful for getting other required matrix elements from (18)-(21),

$$\bar{\psi}_1 \psi_2 = i \partial_\mu (\bar{\psi}_1 \gamma^\mu \psi_2) / (m_2 - m_1), \quad (22)$$

$$\bar{\psi}_1 \gamma_5 \psi_2 = -i \partial_\mu (\bar{\psi}_1 \gamma^\mu \gamma_5 \psi_2) / (m_2 + m_1), \quad (23)$$

$$CPT |\pi^3\rangle = - \langle \pi^3 |, \quad (24)$$

where m_i are the quark masses. One obtains

$$\langle \pi^3 | \bar{d} \gamma_5 d | 0 \rangle = -(m_{\pi^0}^2 / 2m_d) f_\pi / \sqrt{2}, \quad (25)$$

$$\langle 0 | \bar{s} \gamma_5 d | K^0 \rangle = -[m_K^2 / (m_s + m_d)] f_K, \quad (26)$$

$$\langle \bar{\eta} | \bar{d} \gamma_5 d | 0 \rangle = \left(\frac{\cos \phi}{\sqrt{6}} - \frac{\sin \phi}{\sqrt{3}} \right) \frac{m_{\pi^0}^2}{2m_d} f_\eta, \quad (27)$$

etc., and

$$\langle \pi^3 | \bar{s} d | K^0 \rangle = -(m_K^2 - m_{\pi^0}^2) / \sqrt{2} (m_s - m_d), \quad (28)$$

$$\langle \bar{\eta} | \bar{s} d | K^0 \rangle = \left(\frac{\cos \phi}{\sqrt{6}} + \frac{2 \sin \phi}{\sqrt{3}} \right) \frac{m_K^2 - m_{\pi^0}^2}{m_s - m_d}, \quad (29)$$

$$\langle \pi^3 | \bar{d} d | \bar{\eta} \rangle = \langle \pi^3 \bar{\eta} | \bar{d} d | 0 \rangle = - \left(\frac{\cos \phi}{\sqrt{6}} - \frac{\sin \phi}{\sqrt{3}} \right) \frac{\sqrt{2} m_{\pi^0}^2}{m_d + m_u}, \quad (30)$$

where we have omitted hairpin contributions in (29) and (30). The phase convention for (18a,b) is that in the SU(3) symmetric limit, $f_\pi = f_K$. Then the phases of the other matrix elements can be calculated, e.g., using a direct quark model calculation. A reasonable set of light quark masses^{9),18)} will satisfy the following relations exactly to 99%,

$$\frac{m_{K^+}^2}{m_s + m_u} = \frac{m_{K^0}^2}{m_s + m_d} = \frac{m_\pi^2}{m_d + m_u} = \frac{m_{K^+}^2 - m_{\pi^+}^2}{m_s - m_d} = \frac{m_{K^0}^2 - m_{\pi^0}^2}{m_s - m_d}. \quad (31)$$

Therefore the ratios of the quark masses in Eqs. (25)-(30) are meaningful and we need only the ratios of the light quark masses.

We are now ready to estimate (14) and (15),

$$\frac{\text{Re } a_1}{\text{Re } \tilde{a}_0} = \frac{-1}{\sqrt{2} f_\pi} \left[\left(\frac{\cos \phi}{\sqrt{6}} + \frac{2 \sin \phi}{\sqrt{3}} \right) f_\pi - \left(\frac{\cos \phi}{\sqrt{6}} - \frac{\sin \phi}{\sqrt{3}} \right) f_\eta \right] = 0.53,$$

$$(\langle \pi^3 \pi^3 | 0_1 | K^0 \rangle = - f_\pi (m_K^2 - m_\pi^2) / 6) \quad (32)$$

where we have taken $f_\eta = f_K = 1.28 f_\pi$,

$$\begin{aligned} \langle \pi^3 \bar{\eta} | 0_5 | K^0 \rangle = & \frac{8}{9} \left[\left(\frac{\cos \phi}{\sqrt{6}} - \frac{\sin \phi}{\sqrt{3}} \right) \frac{\sqrt{2} m_{\pi^0}^2}{m_u + m_d} \frac{m_{K^0}^2}{m_s + m_d} f_K \right. \\ & - \frac{1}{\sqrt{2}} \left(\frac{2 \cos \phi}{\sqrt{6}} + \frac{\sin \phi}{\sqrt{3}} \right) \frac{m_{\pi^0}^2}{2 m_d} \frac{m_{K^0}^2 - m_{\pi^0}^2}{m_s - m_d} f_\eta \\ & \left. - \left(\frac{2 \cos \phi}{\sqrt{6}} + \frac{\sin \phi}{\sqrt{3}} \right) \frac{m_{\pi^0}^2}{2 m_s} \frac{m_{K^0}^2 - m_{\pi^0}^2}{m_s - m_d} f_\eta \right], \quad (33) \end{aligned}$$

$$\langle \pi^3 \pi^3 | 0_5 | K^0 \rangle = - \frac{8}{9} \left[\frac{m_{\pi^0}^2}{m_u + m_d} \frac{m_{K^0}^2}{m_s + m_d} f_K - \frac{m_{\pi^0}^2}{2 m_d} \frac{m_{K^0}^2 - m_{\pi^0}^2}{m_s - m_d} f_\eta \right]. \quad (34)$$

Using the quark mass ratio (31), we obtain

$$\text{Im } a_1 / \text{Im } \tilde{a}_0 = -1.4. \quad (35)$$

Note that Eq. (34) vanishes when first recovering the SU(2) symmetry, and then the SU(3); Eq. (33) also does it if one neglects the last term [as in Refs. 5), 6)] or alternatively, taking the limit except for putting $\sin \phi = -1/\sqrt{3}$ instead of zero. Let us now discuss the signature factor S, which is related to the sign of ϵ'/ϵ , since ϵ' and ϵ are almost parallel. Because $C_4 > 0$, $C_1 < 0$, $\langle \pi^3 \pi^3 | 0_4 | K^0 \rangle < 0$, so $S = +1$. This implies $\epsilon'/\epsilon > 0$ because

$$- \text{Sign} \frac{\text{Im } \tilde{a}_0}{\text{Re } \tilde{a}_0} = - \text{Sign} \frac{- C_5 \text{Im } V_{ts}^* V_{td} \langle \pi^3 \pi^3 | 0_5 | K^0 \rangle}{C_1 V_{us}^* V_{ud} \langle \pi^3 \pi^3 | 0_1 | K^0 \rangle} > 0. \quad (36)$$

As we know, to first order QCD, the penguin coefficient is proportional to $\sum_i V_{is}^* V_{id} \ln(m_i^2/m_w^2) = C_5 [V_{us}^* V_{ud} - V_{ts}^* V_{td} \ln(m_t^2/m_c^2)/\ln(m_c^2/m^2)]$.

We have also taken $\sin \delta > 0$ ¹⁹⁾. Our result $\epsilon'/\epsilon > 0$, which is consistent with Ref. 20), will not change if we use the notations of Ref. 21). Neither it will, if

05 (instead of 01) dominates in $\text{Re } \tilde{a}_0$ (which seems to be a bad assumption), though in the latter case, $\Delta\eta^{00} = 0$ as discussed before. Now, substituting Eqs. (32) and (35) and $S = +1$ into (10), we have

$$\Delta\eta^{00}/\eta^{00} = -(1.06 - 1.74) \frac{\epsilon'}{\epsilon} e^{i(\delta_1 - \delta_2)} \quad (37)$$

and the one due to the contribution from the π^0 - η' mixing is

$$\Delta\eta^{00'}/\eta^{00} = -(0.64 - 1.1) \frac{\epsilon'}{\epsilon} e^{i(\delta_1 - \delta_0)} \quad (38)$$

Our result can be re-expressed in terms of expected $\eta_{\text{exp}}^{00} \equiv \eta_m^{00}$, combining the calculated values¹¹⁾ of ϵ'/ϵ

$$\begin{aligned} (|\eta^{+-}| - |\eta_{\text{exp}}^{00}|)/3|\eta^{+-}| &= (1 + \frac{1.7 \pm 2.84}{3}) |\frac{\epsilon'}{\epsilon}| \\ &= 0.003 \text{ to } 0.019 \end{aligned} \quad (39)$$

The uncertainties included in Eqs. (37) and (38) are only those due to uncertainties in θ_η and θ'_η . Note that the proportionality of the effect to $|\epsilon'/\epsilon|$ in (37) and (38) is due to the above plausible approximation. Both $\Delta\eta^{00}$ and $\Delta\eta^{00'}$ reduce η^{00} relative to η^{+-} , as ϵ' does. Therefore, our result disagrees with Refs. 5) and 6) in signs although it agrees with them in magnitudes (within a factor of 2). Our conclusion is that the π^0 - η - η' mixing may decrease $|\eta^{00}|$ by an amount of $2.8 |\epsilon'|$ depending on the detailed dynamics and decreases the phase ϕ_{00} by less than 0.4° . In this way, we sharpen the contradiction analyzed in Ref. 1) between the measured apparent phase difference $\phi_{00} > \phi_{+-}$ and the theoretical expectation $\phi_{00} \lesssim \phi_{+-}$. We do not have new claims on the absolute value of the ϵ'/ϵ because it involves the absolute value of $\langle \pi^3 \pi^3 | 0_5 | K^0 \rangle$. The ϵ'/ϵ has to be smaller, if the coefficient before ϵ'/ϵ in Eq. (11) is larger. As the other two I-spin violation effects mentioned in the beginning of this article are expected to be smaller than the π^0 - η - η' mixing effect, we therefore cannot see any possibility of enhancing $\phi_{00} - \phi_{+-}$.

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