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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.*

Comment on ''When can hadronic loops scuttle the Okubo-Zweig-Iizuka rule?''

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Previous calculations by Geiger and Isgur showed that systematic cancellations among hadronic loops occur for $u\bar{u} \leftrightarrow s\bar{s}$ mixing in all the low-lying nonets except 0^{++}. They suggested it is due to $^3P_0$ dominance of the effective quark-antiquark $(q\bar{q})$ pair creation operator. Here we give a general argument that there should be a large mixing for 0^{++} nonet from hadronic loops no matter what kind of model is assumed for $q\bar{q}$ creation. By the same argument we show that the Okubo-Zweig-Iizuka (OZI) rule should be best obeyed in the 1^{--}, 2^{++}, and 3^{--} nonets, but not very well obeyed in the 0^{-+}, 1^{+-}, and 1^{++} nonets. All these model independent expectations are compatible with calculations by Geiger and Isgur using the $^3P_0$ model as well as experimental data. A similar argument also suggests a large hadronic loop contribution for the $p\bar{p} \to \phi\phi$ reaction. [S0556-2821(96)01511-1]

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Previous calculations [1,2] by Geiger and Isgur showed that systematic cancellations among hadronic loops occur for $u\bar{u}$-$s\bar{s}$ mixing in all the low-lying nonets except 0^{++}. In their $^3P_0$ model, the contribution of hadronic loops is composed of an alternating series of terms which they show cancel exactly in the closure-plus-spectator approximation except for the 0^{++} nonet. Taking the 1^{--} nonet as their prototype [2], they found that the dominant cancellations are those between the relative $L=1$ S-wave + S-wave states and the relative $L=0$ S-wave + P-wave states. Their results are based on assuming the $^3P_0$ dominance of the effective quark-antiquark $(q\bar{q})$ pair creation operator. However we find that the large violation of the Okubo-Zweig-Iizuka (OZI) rule [3] in 0^{++} nonet may not depend on the $^3P_0$ model though this model is quite possibly correct. Our arguments are as follows.

Let us assume that initial $q\bar{q}$ states are pure $s\bar{s}$ and $n\bar{n} \equiv (1/\sqrt{2})(u\bar{u}+d\bar{d})$ states. They can mix with each other by strange meson loops. The first term in the alternating series of terms considered by Geiger and Isgur corresponds to the contribution of S-wave + S-wave meson loops, i.e., $K\bar{K}$, $K\bar{K}^*$, $\bar{K}K^*$ and $K^*\bar{K}^*$ loops. The second term corresponds to S-wave (K,K^*) + P-wave (K_0^*,K_1^*,K_2^*) meson loops. The other terms include even heavier strange mesons. At energies around 1.5 GeV, only the first term has an on-shell loop contribution. The others have only virtual off-shell loop contributions which are very model dependent. They may cancel part of the off-shell part of the first term as indicated in [1,2], but cannot cancel the on-shell part of the first term. We expect $K\bar{K}$, $K\bar{K}^*$, $\bar{K}K^*$, and $K^*\bar{K}^*$ loops have the biggest contributions, and only consider these loops here. We want to show that the cancellation or lack thereof between these loops gives a natural model independent explanation of the relative size for $u\bar{u}$-$s\bar{s}$ mixing of different nonets. These effects are included in the $^3P_0$ model calculations of [1,2] but without highlighting their important role. The cancellation effects from other terms stressed in [1,2] are quite model dependent and may be only responsible for the absolute size of the mixing.

Ten years ago, one of us gave a general symmetry argument showing [4] that $K\bar{K}^*$ and $\bar{K}K^*$ loops have opposite phase to $K\bar{K}$ and $K^*\bar{K}^*$ loops. It is these loop cancellations that make the OZI rule appear to work very well for ϕ-ω mixing. However, for some nonets, either $K\bar{K}$ or $K^*\bar{K}+K\bar{K}^*$ loops are forbidden by parity conservation. In Table I, we list the relative phase from each hadronic loop for the low-lying nonets, while 0 stands for forbidden. For 1^{--}, 2^{++}, and 3^{--} nonets, all four loops are allowed and we expect the largest cancellations; for 1^{+-}, 1^{++}, and 0^{-+} nonets, the $K\bar{K}$ loop is forbidden and we expect weaker cancellations; for the 0^{++} nonet, $K^*\bar{K}+K\bar{K}^*$ loops are forbidden and there is *no* cancellation. In Table I, we also list the results of hadronic loop contributions to the mixing amplitudes, $A'(u\bar{u} \leftrightarrow s\bar{s})$, by Geiger and Isgur [1] using the $^3P_0$ model, as well as mixing angles obtained from experimental information [5–7]. Both are consistent with our model independent expectations. For the 0^{-+} nonet, the large mixing angle can also be explained by hadronic loops [6] though its U(1) anomaly explanation is not excluded.

Due to the large $s\bar{s}$-$n\bar{n}$ mixing for 0^{-+} nonets, $\eta\eta$, $\eta\eta'$, and $\eta'\eta'$ loops can also contribute to the $s\bar{s}$-$n\bar{n}$ mix-

TABLE I. Hadronic loop contributions to the $s\bar{s}\leftrightarrow n\bar{n}$ mixing. $+$ and $-$ represent the relative phases of loops. 0 stands for forbidden. $A'(m_{s\bar{s}})$ are mixing amplitudes from the $^3P_0$ model [1] in units of MeV. δ is the $s\bar{s}$-$n\bar{n}$ mixing angle obtained from experimental data.

J^{PC}	$K\bar{K}$	$K\bar{K}^*$	$K^*\bar{K}$	$K^*\bar{K}^*$	$A'(m_{s\bar{s}})$	$\lvert\delta(m_{s\bar{s}})\rvert$
1^{--}	$+$	$-$	$-$	$+$	8.6	0.7∼3.4° [5]
2^{++}	$+$	$-$	$-$	$+$	-7.1	7∼9° [5]
3^{--}	$+$	$-$	$-$	$+$	7.4	6∼7° [5]
1^{+-}	0	$-$	$-$	$+$	-59.4	∼18° [6]
1^{++}	0	$-$	$-$	$+$	89.5	∼26° [6]
0^{-+}	0	$-$	$-$	$+$		45∼58° [5]
0^{++}	$+$	0	0	$+$	-537	∼36° [7]

ing of some nonets. But it is a second-order effect and much smaller than strange meson loops [8]. Note also that the $\eta\eta$ loop has the same phase as $K\bar{K}$ [8].

There is another important point for the 0^{++} nonet. The on-shell $K\bar{K}$ loop can give a very large imaginary part to the $s\bar{s}\leftrightarrow n\bar{n}$ transition amplitude because no centrifugal barrier factor is present here for S-wave decay. This is also the reason for the narrow peak structure of $f_0(980)$ [7,9]. The on-shell $K\bar{K}$ loop contribution is suppressed by the centrifugal barrier factor for other nonets. The A' listed in Table I is only the real part of the transition amplitude [1]. So due to no cancellations to the $K\bar{K}$ loop, both the real and imaginary parts of the $s\bar{s}\leftrightarrow n\bar{n}$ transition amplitude are very large. There is no nearly pure $s\bar{s}$ 0^{++} meson.

The strange meson loops also play a significant role in explaining the large cross section for $p\bar{p}\rightarrow\phi\phi$ around 2.2 GeV observed by the JETSET collaboration [10]. A calculation [11] showed that the $K\bar{K}$ loop can explain the observed cross section very well. This calculation was criticized [12] for not considering the $K\bar{K}^*$, $K^*\bar{K}$, and $K^*\bar{K}^*$ loops which may have opposite phase to the $K\bar{K}$ loop [4]. This criticism is fair. But here we show that the summation of all four loops gives a result similar to that obtained by considering only $K\bar{K}$ loops. The key point is shown in Table II. In allowed partial waves for $p\bar{p}\rightarrow\phi\phi$, only half can go through a $K\bar{K}$ loop while all of them can go through the other three loops. Even if the summation of the $K\bar{K}^*$, $K^*\bar{K}$, and $K^*\bar{K}^*$ loops has similar size and opposite phase, the summation of four loops will give a similar result to considering only the $K\bar{K}$ loop since the loops from different partial waves cannot cancel each other. Therefore combining the calculation of [11] and arguments here, we conclude the strange meson loops can explain the large cross section for $p\bar{p}\rightarrow\phi\phi$ and it is not necessarily due to the presence of strange quarks in the nucleon [13].

TABLE II. Hadronic loops for $p\bar{p}\rightarrow\phi\phi$.

Allowed initial states	$K\bar{K}$	$K\bar{K}^*,K^*\bar{K},K^*\bar{K}^*$
$S=0$, $L=$even, $J=L$	Forbidden	Allowed
$S=1$, $L=$odd, $J=L$		
$S=1$, $L=$odd, $J=L+1$	Allowed	Allowed
$S=1$, $L=$odd>1, $J=L-1$		

In summary, from a general proper consideration of loop cancellations we can explain naturally the small $s\bar{s}$-$n\bar{n}$ mixing for the 1^{--}, 2^{++}, and 3^{--} nonets as well as larger mixing for other low-lying nonets. In particular, there is no cancellation to the $K\bar{K}$ loop for the 0^{++} nonet so that no nearly pure $s\bar{s}$ 0^{++} meson exists. These results do not depend on the model assumed for the $q\bar{q}$ creation operator, though the $^3P_0$ model may enhance our conclusions with the arguments in [1]. A similar argument also suggests a large hadronic loop contribution to the $p\bar{p}\rightarrow\phi\phi$ reaction.

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[1] P. Geiger and N. Isgur, Phys. Rev. D **47**, 5050 (1993).

[2] P. Geiger and N. Isgur, Phys. Rev. Lett. **67**, 1066 (1991); Phys. Rev. D **44**, 799 (1991).

[3] S. Okubo, Phys. Lett. **5**, 1975 (1963); G. Zweig, in *Developments in the Quark Theory of Hadrons*, edited by D.B. Lichtenberg and S.P. Rosen (Hadronic Press, Massachusetts, 1980); J. Iizuka, Prog. Theor. Phys. Suppl. **37**, 38 (1966).

[4] H.J. Lipkin, Nucl. Phys. B **291**, 720 (1987); **244**, 147 (1984).

[5] Particle Data Group, L. Montanet *et al.*, Phys. Rev. D **50**, 1173 (1994).

[6] N.A. Törnqvist, Ann. Phys. (N.Y.) **123**, 1 (1979); Phys. Rev. Lett. **49**, 624 (1982); Nucl. Phys. **B203**, 268 (1982); Phys. Rev. D **29**, 121 (1984); M. Roos and N.A. Törnqvist, Z. Phys. C **5**, 205 (1980).

[7] N.A. Törnqvist, Z. Phys. C **68**, 647 (1995).

[8] H.J. Lipkin, in *New Fields in Hadronic Physics*, Proceedings of the Eleventh Rencontre de Moriond, Flaine-Haute-Savoie, France, 1976, edited by J. Tran Thanh Van (Universite de Paris-Sud, Orsay, France, 1976), Vol. I, p. 327.

[9] B.S. Zou and D.V. Bugg, Phys. Rev. D **48**, R3948 (1993).

[10] JETSET Collaboration, L. Bertolotto *et al.*, Phys. Lett. B **345**, 325 (1995).

[11] Y. Lu, B.S. Zou, and M.P. Locher, Z. Phys. A **345**, 207 (1993); M.P. Locher and Y. Lu, *ibid.* **351**, 83 (1994).

[12] V. Mull, K. Holinde, and J. Speth, Phys. Lett B **334**, 295 (1994).

[13] J. Ellis, E. Gabathuler, and M. Karliner, Phys. Lett. B **217**, 173 (1989); J. Ellis, M. Karliner, D.E. Kharzeev, and M.G. Sapozhnikov, *ibid.* **353**, 319 (1995).