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Radiative decays involving $f_0(980)$ and $a_0(980)$ and mixing between low and high mass scalar mesons

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Abstract

We analyze the experimental data for $\phi \to f_0(980)\gamma$, $\phi \to a_0(980)\gamma$, $f_0(980) \to \gamma\gamma$ and $a_0(980) \to \gamma\gamma$ decay widths in a framework where $f_0(980)$ and $a_0(980)$ are assumed to be mainly $qq\bar{q}\bar{q}$ low mass scalar mesons and mixed with $q\bar{q}$ high mass scalar mesons. Applied the vector meson dominance model (VDM), these decays amplitudes are expressed by coupling parameters B describing the S ($qq\bar{q}\bar{q}$ scalar meson)–V (vector meson)–V (vector meson) coupling and B' describing the S' ($q\bar{q}$ scalar meson)–V–V coupling. Adopting the magnitudes for B and B' as $\sim 2.8\ \mathrm{GeV}^{-1}$ and $\sim 12\ \mathrm{GeV}^{-1}$, respectively, the mixing angle between $a_0(980)$ and $a_0(1450)$ as $\sim 9°$, and the mixing parameter λ_{01} causing the mixing between $I = 0$ $qq\bar{q}\bar{q}$ state and $q\bar{q}$ state as $\sim 0.24\ \mathrm{GeV}^2$, we can interpret these experimental data, consistently.
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1. Introduction

From the recent experimental and theoretical analyses for the $f_0(600)$ and $\kappa(900)$, these scalar mesons are considered as the light scalar nonet together with the $f_0(980)$ and $a_0(980)$ [1]. From the status that though the masses of $f_0(980)$ and $a_0(980)$ are degenerate, the $f_0(980)$ state has the strangeness flavor rich character, many authors suggest

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this nonet as non-$q\bar{q}$ structure, e.g., $K\bar{K}$ molecule [2], $qq\bar{q}\bar{q}$ state [3]. On this standpoint, many literatures assume that the higher mass scalar mesons, $f_0(1370)$, $a_0(1450)$, $K_0^*(1430)$, $f_0(1500)$ and $f_0(1710)$ would be traditional $q\bar{q}$ nonet and glueball state.

In order to confirm the structure of the light scalar mesons, that is whether the light scalar mesons are constituted of $q\bar{q}$ or $qq\bar{q}\bar{q}$, the radiative decays of the ϕ meson to the scalar mesons $f_0(980)$ and $a_0(980)$, $\phi \to f_0\gamma$ and $\phi \to a_0\gamma$, have long been analyzed by assuming the model, in which the decay $\phi \to f_0(a_0)\gamma$ proceeds through the charged K loop, $\phi \to K^+K^- \to f_0(a_0)\gamma$ [4]. Almost reference suggests that $f_0(980)$ and $a_0(980)$ mesons contain significant $qq\bar{q}\bar{q}$ content, specifically being $(u\bar{u} \pm b\bar{b})s\bar{s}$.

The two γ decays of the $f_0(980)$ and $a_0(980)$ mesons are also analyzed by using the various models, the linear sigma model [5], vector meson dominance model (VDM) [6] and the quark–hadron duality idea [7]. Work [5] suggested that the $f_0(980)$ meson is mostly composed of $s\bar{s}$ component under the picture of the nonet scalar for light scalar mesons $f_0(600)$, $\kappa(900)$, $a_0(980)$ and $f_0(980)$. Work [6] studied the $a_0(980) \to \gamma\gamma$ and $f_0(980) \to \gamma\gamma$ decays and further $\phi \to f_0(980)\gamma$ and $\phi \to a_0(980)\gamma$ decays comprehensively assuming the VDM and the $qq\bar{q}\bar{q}$ structure for light scalar mesons. It could explain the experimental results for radiative decays except for the $\phi \to f_0(980)\gamma$ decay. Work [7] considered the nonet scalar for light scalar mesons and assumed that these were composed of $q\bar{q}$ or $qq\bar{q}\bar{q}$ states. The author analyzed the two γ decays considering the mixing between $qq\bar{q}\bar{q}$ and $q\bar{q}$, latter of which is the dominant structure of the higher mass scalar mesons.

We analyzed the mixing between the light scalar nonet, $f_0(600)$, $\kappa(900)$, $a_0(980)$, $f_0(980)$ assumed as $qq\bar{q}\bar{q}$ states dominantly and high mass scalar nonet + glueball, $f_0(1370)$, $a_0(1450)$, $K_0^*(1430)$, $f_0(1500)$, $f_0(1710)$ assumed as $L = 1$ $q\bar{q}$ states dominantly + glueball state, in our previous work [8]. The estimated mixing is very strong because of the fact that the high mass scalar meson masses are very high compared with the masses supposed from the $L = 1$ $q\bar{q}$ 1^{++} and 2^{++} meson masses and relation $m^2(2^{++}) - m^2(1^{++}) = 2(m^2(1^{++}) - m^2(0^{++}))$ resulting from the $L \cdot S$ force. Work [9] took the similar conclusion to ours in the mixing for $I = 1$ mesons and $I = 1/2$ mesons. That the mixing between $qq\bar{q}\bar{q}$ state and $q\bar{q}$ state is strong is recognized from the fact that the transition between $qq\bar{q}\bar{q}$ and $q\bar{q}$ states is caused by the OZI rule allowed diagram. In next work [10], we pursued this problem analyzing the decay processes in which light scalar mesons and high mass scalar meson decays to two pseudoscalar mesons, and get the result that the mixing angle between $I = 1$ $a_0(980)$ and $a_0(1450)$ is $\sim 10^\circ$.

In the present work, we will analyze the $\phi(1020) \to a_0(980)\gamma$, $\phi(1020) \to f_0(980)\gamma$, $a_0(980) \to \gamma\gamma$ and $f_0(980) \to \gamma\gamma$ decays assuming that the light scalar mesons have the $qq\bar{q}\bar{q}$ and $q\bar{q}$ component, and we will reveal the mixing ratio for these components. We analyze this problem using the vector dominance model (VDM) interaction for $\phi\gamma f_0$ or $\phi\gamma a_0$ vertex. The $K\bar{K}$ loop interaction have been used to explain the $\phi \to \gamma a_0$ and $\phi \to \gamma f_0$ decays by many authors [4]. The spectra in $\phi \to \gamma f_0 \to \gamma\pi\pi$ and $\phi \to \gamma a_0 \to \gamma\eta\pi$ are explained successfully using the $K\bar{K}$-loop mechanism [11]. We realize that the interaction, considered in the paper, cannot explain the observed spectra of the $\phi \to \gamma f_0/a_0 \to \gamma\pi\pi/\eta\pi$ decays, but we would like only to emphasize a potentially important effect of mixtures of four quark and two quark states.

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