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THE NATURE OF THE LIGHT SCALAR MESONS FROM THEIR RADIATIVE DECAYS

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Abstract

The nature of the light scalar mesons is one of the most intriguing open challenges in hadronic spectroscopy. It is argued that radiative decays involving these scalars can serve as an important decisive tool in establishing their nature. In particular, special emphasis is made on the radiative decays of the scalars themselves (in addition to the radiative decays of the ϕ-meson with the scalars appearing in the final state), including their two-photon decays. All the above mentioned processes are considered in detail in the (point-like) kaon molecule model of the scalars and explicit predictions for the decay widths are made. In addition, finite-range corrections to the point-like results are investigated, with a special attention payed to gauge invariance of the decay amplitude. Finally, the conclusion is made that experimental data on the radiative decays with the light scalar mesons involved strongly support the molecule assignment for the latter.

1 Introduction

Understanding the properties of light scalar mesons is one of the most challenging problems of the hadrons spectroscopy. In particular, investigations of the nature of the $a_0(980)$ and $f_0(980)$ mesons attract considerable theoretical and experimental efforts. This interest should not come as a surprise since the given states reside at the very kaon–antikaon threshold and thus the admixture of the kaon molecular component in the wave function is expected to be large. Indeed, experimental data [1–3] unambiguously show a prominent $K\overline{K}$ contribution. Other assignments for these mesons are also suggested and studied in the literature, such as the genuine $q\bar{q}$ assignment [4],

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or the compact four–quark assignment [5,6]. Many experimental tests have been suggested so far in order to distinguish between these assignments and thus to disclose the nature of the scalars $a_0/f_0(980)$. For example, the importance of measurements of the radiative decays of the $\phi(1020)$ to scalar mesons was argued in [7]. In the meantime, another class of radiative decays — the radiative decays of the scalars themselves — can be studied as well and provide new important data. As compared to the radiative decays $\phi \to \gamma S$ ($S = a_0/f_0$), the decays $S \to \gamma V$ ($V = \rho, \omega, \gamma$) possess a number of advantages, such as a considerable phasespace in the final state and a possibility to probe the nonstrange component of the scalars w.f. These radiative decays can serve therefore as a complementary source of information and to deliver decisive information on the structure of these long–debated objects [8].

Both types of radiative decays can be described with the single vertex function $VS\gamma$. Gauge invariance imposes quite restrictive constrains on the structure of the transition matrix element: $iW^{\mu\nu} = M(m_V^2, m_S^2)[P_V^\mu P_\gamma^\nu - g^{\mu\nu}(P_V P_\gamma)]$, where P_V and P_γ are the vector and the photon four-momenta.

2 Evaluation of the decay widths in various assignments for the scalars

In the quark–antiquark assignment, the $a_0/f_0(980)$ mesons are treated as the genuine quark–antiquark $^3P_0$ states. Their radiative decays can be studied in the framework of nonrelativistic quark models [9,10] yielding the width of 125 keV, for the decays $a_0 \to \gamma\omega$ and $f_0 \to \gamma\rho$, 14 keV, for the decays $a_0 \to \gamma\rho$ and $f_0 \to \gamma\omega$, and 4.5 keV, for the decays $a_0/f_0 \to \gamma\gamma$. The radiative decays widths of the genuine quark–antiquark mesons $f_1(1285)$ ($\Gamma(f_1(1285)) \to \gamma\rho) = 1320 \pm 312$keV) and $f_2(1270)$ ($\Gamma(f_2(1270) \to \gamma\gamma) = 2.61 \pm 0.30$ keV) were used here in order to fix the radial w.f. matrix element [8].

In the molecule assignment for the scalars, the radiative decays proceed via a kaon loop, and the scales involved into the problem possess the hierarchy $\varepsilon \ll m \lesssim \beta$, where β is the intrinsic scale of the binding force, m is the kaon mass, and $\varepsilon = 2m - m_S$ is the binding energy. It was argued in [11] that, for the realistic values of the parameters ($\beta \approx m_\rho \approx 800$ MeV, $m = 495$ MeV, and $\varepsilon = 10$ MeV), this hierarchy can be achieved starting prom the point-like limit of $\beta \to \infty$ and taking into account finite-range corrections in the inverse power of β. The point-like $SK\overline{K}$ coupling constant, $g_S^2/(4\pi) = 32m\sqrt{m\varepsilon} \approx 1.12$ GeV^2 was obtained in [12]. The two remaining couplings can be obtained from the $\rho\pi\pi$ constant ($g_V = g_\rho = g_\omega = \frac{1}{2}g_{\rho\pi\pi} \approx 2.13$) and from the total width of the ϕ ($g_\phi^2/(4\pi) \approx 1.77$). Then the point-like

Table 1: The widths (in keV) of the radiative decays involving scalars; θ is the (small) $\phi - \omega$ mixing angle.

	Quark–antiquark	Molecule	Data (PDG)
$\phi \to \gamma a_0$	$0.37\sin^2\theta$	0.6	0.32 ± 0.02
$\phi \to \gamma f_0(\bar{n}n)/f_0(\bar{s}s)$	$0.04\sin^2\theta/0.18$	0.6	0.47 ± 0.03
$a_0 \to \gamma\gamma$	$2 \div 5$	0.22	0.30 ± 0.10
$f_0 \to \gamma\gamma$	$2 \div 5$	0.22	$0.29^{+0.07}_{-0.09}$
$a_0\gamma\omega/\rho$	125/14	3.4	
$f_0(\bar{n}n)\gamma\rho/\omega$	125/14	3.4	pending
$f_0(\bar{s}s)\gamma\rho/\omega$	$0/31\sin^2\theta$	3.4	

predictions for the widths are $\Gamma(\phi \to \gamma S) = 0.6$ keV, $\Gamma(S \to \gamma V) = 3.4$ keV, and $\Gamma(S \to \gamma\gamma) = 0.22$ keV. It can be demonstrated explicitly that no large corrections to these results, of order $\mathcal{O}(m^2/\beta^2)$, appear [11–13]. Thus one concludes that inclusion of the finite–range corrections does not change these prediction appreciably, giving only moderate (of order $10 \div 20\%$ in the amplitude) corrections, provided they are included in a self-consistent and gauge-invariant way [11–13].

3 Conclusions

In Table 1 we give the widths for the radiative decays involving scalars. Comparing the predictions made in the quark–antiquark and molecule assignment with the experimental data we conclude that the molecule picture is strongly supported by the data (Belle reports the new result $\Gamma(f_0 \to \gamma\gamma) = 0.205^{+95+0.147}_{-0.83-0.117}$ keV [14] which is in even better agreement with the molecule prediction). An important property revealed by the radiative decays of the scalars is that the theoretical predictions for these decays differ drastically depending on the assignment made for the nature of the scalars. This makes such radiative decays an important tool in establishing the structure of the $a_0/f_0(980)$ mesons. We conclude that experimental data on the radiative decays $a_0/f_0 \to \gamma\rho/\omega$ are strongly needed, as an important, and possibly decisive, source of information about the scalar mesons.

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