COUPLING CONSTANTS $g_{\phi\sigma\gamma}$ AND $g_{\phi a_0\gamma}$ AS DERIVED FROM QCD SUM RULES

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We employ QCD sum rules and utilize $\omega\phi$-mixing to calculate the coupling constants $g_{\phi\sigma\gamma}$ and $g_{\phi a_0\gamma}$ by studying the three point $\phi\sigma\gamma$- and $\phi a_0\gamma$-correlation functions. Our results are consistent with the previous estimations of these coupling constants in the literature.

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1. Introduction

The studies of $\phi(1020)$ meson and in particular its radiative decays have been important sources of information in hadron physics in areas such as SU(3) symmetry, the quark model, and the Okubo–Zweig–Iizuka (OZI) rule. The analysis of the dynamics of the vector meson physics, in general, is nontrivial and complicated from the theoretical point of view since the characteristic energy scale, which is in about 1 GeV region, is below the domain of perturbative QCD. Moreover, in this energy region resonance effects are known to be present and low-mass scalar mesons may play an important role which have fundamental importance in understanding low energy QCD. From the experimental point of view, isoscalar $f_0(980)$ and isovector $a_0(980)$ are well established. The existence of the isoscalar σ meson has long been controversial, but recently direct experimental evidence seems to emerge from the $D^+ \to \sigma\pi^+ \to 3\pi$ decay channel observed by the Fermilab E791 Collaboration, where σ meson is seen as a clear dominant peak with $M_\sigma = 478$ MeV and $\Gamma_\sigma = 324$ MeV [1]. On the other hand, the nature and the quark substructure of these scalar mesons have long been controversial and a subject of debate [2–6].

The vertices $\phi a_0\gamma$ and $\phi\sigma\gamma$ are interesting and important for several reasons. The $\phi a_0\gamma$-vertex plays a role in the study of the radiative $\phi \to \pi^0\eta\gamma$

decay [7]. Moreover, it has been noted that $\phi \to a_0\gamma$ decay along with the decay $\phi \to f_0\gamma$ can differentiate between the different models of the structure of the scalar mesons a_0 and f_0 [7–9]. The knowledge of the $\phi\sigma\gamma$-vertex is needed in the analysis of the decay mechanism of the $\phi \to \pi^0\pi^0\gamma$ decay [10], and also in the study of the structure of the ϕ meson photoproduction amplitude on nucleons in the near threshold region based on the one-meson exchange and Pomeron-exchange mechanisms [11].

In this work, we estimate the coupling constants $g_{\phi\sigma\gamma}$ and $g_{\phi a_0\gamma}$ by employing QCD sum rules which provide an efficient method to study many hadronic properties, and which have been employed to study hadronic observables such as decay constants and form factors in terms of nonperturbative contributions proportional to the quark and the gluon condensates [12–14]. In the next section, we give a QCD sum rule analysis of the scalar current, derive the sum rules for the overlap amplitudes λ_σ and λ_{a_0}, and estimate these amplitudes since they are not available experimentally. We then, by taking into account $\omega\phi$-mixing, derive the sum rules for the coupling constants $g_{\phi\sigma\gamma}$ and $g_{\phi a_0\gamma}$, and utilizing the experimental value of λ_ϕ and the calculated values of λ_σ and λ_{a_0}, and the known values of the condensates, estimate the coupling constants $g_{\phi\sigma\gamma}$ and $g_{\phi a_0\gamma}$.

2. Analysis and results

In QCD sum rules method the properties of hadrons are studied through correlation functions of appropriately chosen currents [12–14]. We choose the interpolating $j_s = \frac{1}{2}(\overline{u}u + (-1)^I \overline{d}d)$ scalar current for isoscalar $I = 0$ σ meson and for isovector $I = 1$ a_0 meson. We study the scalar current correlation function

$$\Pi(p^2) = i \int d^4x e^{ip\cdot x} \langle 0|T\{j_s(x)j_s(0)\}|0\rangle \,. \tag{1}$$

The three-loop expression for the scalar current correlation function $\Pi(p^2)$ in perturbative QCD was calculated [15], and it is given by the expression

$$\begin{aligned}\Pi_{\rm pert}(p^2) \;=\; & \frac{3}{16\pi^2}(-p^2)\ln\left(\frac{-p^2}{\mu^2}\right)\left\{1 + \left(\frac{\alpha_s}{\pi}\right)\left[\frac{17}{3} - \ln\left(\frac{-p^2}{\mu^2}\right)\right]\right.\\ & \left. + \left(\frac{\alpha_s}{\pi}\right)^2\left[45.846 - \frac{95}{6}\ln\left(\frac{-p^2}{\mu^2}\right) + \frac{17}{12}\ln^2\left(\frac{-p^2}{\mu^2}\right)\right]\right\} \,. \end{aligned} \tag{2}$$

QCD vacuum condensate contributions to the scalar current correlation function $\Pi(p^2)$ were obtained by the operator product method [16], and they were found in the m_u=m_d=0 limit as

$$\Pi(p^2=-Q^2)_{\rm cond} = \frac{3}{2Q^2}\langle m_q\overline{q}q\rangle + \frac{1}{16\pi Q^2}\langle\alpha_s G^2\rangle - \frac{88\pi}{27Q^4}\left\langle\alpha_s(\overline{q}q)^2\right\rangle . \quad (3)$$

In this equation the magnitude of the condensate $\langle m_q\overline{q}q\rangle$ can be obtained by making use of the Gell-Mann–Oakes–Renner relation as $-f_\pi^2 m_\pi^2/4$, which is independent of quark mass [12].

The correlation function $\Pi(p^2)$ satisfies the standard subtracted dispersion relation [12]

$$\Pi_{\rm pert}(p^2) = p^2\int_0^\infty \frac{ds'}{s'(s'-p^2)}\rho(s') + \Pi(0)\,, \quad (4)$$

where the spectral density function is given as $\rho(s')=(1/\pi){\rm Im}\,\Pi(s')$. The spectral density contains a single sharp pole $\pi\lambda_s\delta(s'-m_s^2)$ corresponding to the coupling of the scalar meson s, with s denoting σ or a_0, to the scalar current j_s where the overlap amplitude λ_s is defined by $\lambda_s=\langle 0|j_s|s\rangle$. The continuum contribution of the higher states to the spectral density is estimated in the form $\rho(s')=\rho_h(s')\theta(s'-s_0)$ where s_0 denotes the continuum threshold and ρ_h is given by the expression $\rho_h(s')=(1/\pi){\rm Im}\,\Pi_{\rm OPE}(s')$ with $\Pi_{\rm OPE}(s')$ obtained from Eq. (2) and Eq. (3) as $\Pi_{\rm OPE}(s')=\Pi_{\rm pert}(s')+\Pi_{\rm cond}(s')$. After performing the Borel transformation we obtain the QCD sum rule for the overlap amplitude λ_s of σ or a_0 meson

$$\begin{aligned}\lambda_s^2{\rm e}^{-m_s^2/M^2} = {} & \frac{3}{16\pi^2}M^4\Bigg\{\left[1-\left(1+\frac{s_0}{M^2}\right){\rm e}^{-s_0/M^2}\right] \\ & \times\left[1+\frac{\alpha_s}{\pi}\frac{17}{3}+\left(\frac{\alpha_s}{\pi}\right)^2 31.864\right] \\ & -\frac{\alpha_s}{\pi}\left[2+\frac{95}{3}\left(\frac{\alpha_s}{\pi}\right)\right]\int_0^{s_0/M^2} w\ln w{\rm e}^{-w}dw \\ & +\left(\frac{\alpha_s}{\pi}\right)^2\frac{17}{4}\int_0^{s_0/M^2} w[\ln w]^2{\rm e}^{-w}dw\Bigg\} \\ & +\frac{3}{2}\langle m_q\overline{q}q\rangle + \frac{1}{16\pi}\langle\alpha_s G^2\rangle - \frac{88\pi}{27M^2}\langle\alpha_s(\overline{q}q)^2\rangle\,. \end{aligned} \quad (5)$$

For the numerical evaluation of the above sum rule, we use the values $\langle m_q\bar{q}q\rangle = (-0.82 \pm 0.10) \times 10^{-4}$ GeV^4, $\langle \alpha_s G^2\rangle = (0.038 \pm 0.011)$ GeV^4, $\langle \alpha_s(\bar{q}q)^2\rangle = -0.18 \times 10^{-3}$ GeV^6 [14], and $m_\sigma = 0.5$ GeV, $m_{a_0} = 0.980$ GeV. The running coupling constant $\alpha_s(M^2)$ in Eq. (5) is calculated using the expression to 3-loop order given by the Particle Data Group [17]. The continuum threshold s_0 is chosen below a possible pole in respective channels, it is varied between $s_0 = 1.1$–1.3 GeV^2 for σ meson and between $s_0 = 1.5$–1.7 GeV^2 for a_0 meson, and we study the M^2 dependence of the sum rule. Since the Borel parameter has no physical meaning, we look for a range of its values where the sum rule is almost independent of M^2, we choose the interval of values of the Borel parameter M^2 as 1.2–1.4 GeV^2. The overlap amplitudes λ_{a_0} and λ_σ as a function of M^2 for different values of s_0 are shown in Fig. 1 and in Fig. 2, respectively. We choose the middle value $M^2 = 1.3$ GeV^2 in its interval of variation, and we obtain the overlap amplitudes as $\lambda_{a_0} = (0.23 \pm 0.06)$ GeV^2, and $\lambda_\sigma = (0.15 \pm 0.04)$ GeV^2, where we include the uncertainty due to the variation of the continuum threshold and the Borel parameter M^2 as well as the uncertainty due to the errors attached to the estimated values of the condensates as quoted above. In a previous work [18], we estimated the overlap amplitude λ_σ of σ meson as $\lambda_\sigma = (0.12 \pm 0.03)$ GeV^2 using the two-loop expression for the scalar current correlation function $\Pi(p^2)$ calculated in perturbative QCD. Our new result shows the importance of the higher order effects. The overlap amplitude λ_σ was also recently calculated using light cone QCD sum rules [19], and the value $\lambda_\sigma = (0.2 \pm 0.04)$ GeV^2 is obtained which is consistent with our result.

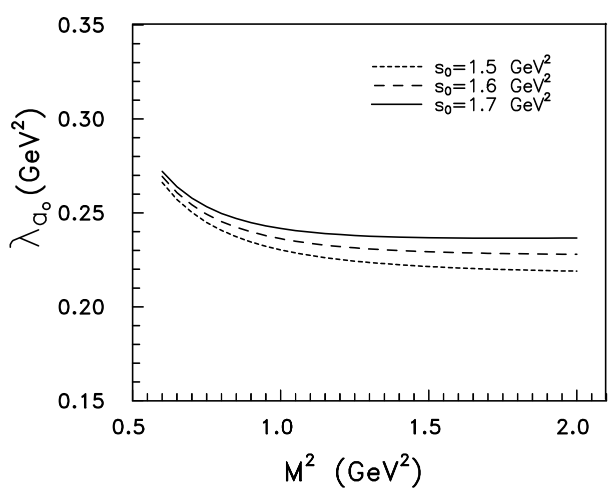

Fig. 1. The overlap amplitude λ_{a_0} as a function of Borel parameter M^2.

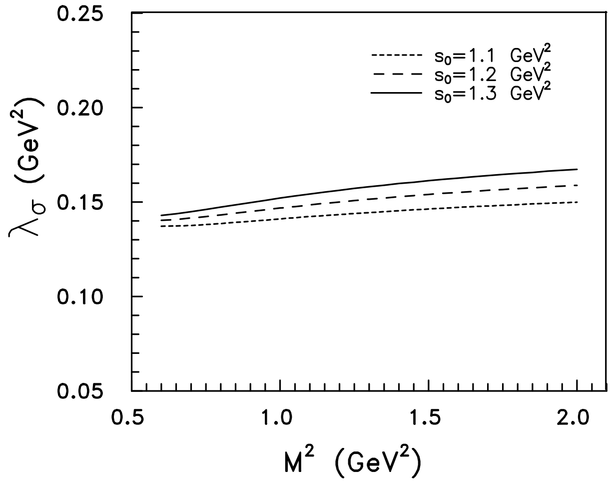

Fig. 2. The overlap amplitude λ_σ as a function of Borel parameter M^2.

In the following, we will analyze radiative $\phi \to a_0\gamma$ and $\phi \to \sigma\gamma$ decays using QCD sum rules. We begin with the observation that the $\phi \to \pi^0\gamma$ decay width vanishes if the ϕ meson is a pure $s\overline{s}$ state. The measured width $\Gamma(\phi \to \pi^0\gamma) = (5.6 \pm 0.5)$ KeV [17] is significantly different from zero which is primarily due to $\omega\phi$-mixing. Bramon *et al.* [20] have recently studied radiative $VP\gamma$ transitions between vector (V) mesons and pseudoscalar (P) mesons, and using the available experimental information they have determined the mixing angle as well as other relevant parameters for the ω–ϕ system and also for the η–η' system. We follow their treatment and we write the physical ω and ϕ meson states as

$$
\begin{aligned}
\mid \omega\rangle &= \cos\theta \mid \omega_0\rangle - \sin\theta \mid \phi_0\rangle\,, \\
\mid \phi\rangle &= \sin\theta \mid \omega_0\rangle + \cos\theta \mid \phi_0\rangle\,,
\end{aligned} \tag{6}
$$

where $\mid \omega_0\rangle = \frac{1}{\sqrt{2}} \mid u\overline{u} + d\overline{d}\rangle$ and $\mid \phi_0\rangle = \mid s\overline{s}\rangle$ are the non-strange and the strange basis states. The mixing angle is determined by Bramon *et al.* as $\theta = (3.4 \pm 0.2)^\circ$ [20]. We, therefore, choose the interpolating currents for ω and ϕ mesons defined in the quark flavour basis as

$$
\begin{aligned}
j_\mu^\omega &= \cos\theta j_\mu^{\omega_0} - \sin\theta j_\mu^{\phi_0}\,, \\
j_\mu^\phi &= \sin\theta j_\mu^{\omega_0} + \cos\theta j_\mu^{\phi_0}\,,
\end{aligned} \tag{7}
$$

where $j_\mu^{\omega_0} = \frac{1}{6}(\overline{u}\gamma_\mu u + \overline{d}\gamma_\mu d)$ and $j_\mu^{\phi_0} = -\frac{1}{3}\overline{s}\gamma_\mu s$ [12].

In order to derive the QCD sum rule for the coupling constants $g_{\phi s\gamma}$, with s denoting σ or a_0, we consider the three-point correlation function

$$T_{\mu\nu}(p,p') = \int d^4x d^4y \mathrm{e}^{ip'\cdot y}\mathrm{e}^{-ip\cdot x}\langle 0|T\{j^\gamma_\mu(0)j^\phi_\nu(x)j_s(y)\}|0\rangle\,, \tag{8}$$

where the electromagnetic current is given as $j^\gamma_\mu = e_u\overline{u}\gamma_\mu u + e_d\overline{d}\gamma_\mu d$, and j^ϕ_ν and j_s are the interpolating currents for ϕ and scalar σ or a_0 meson.

In order to obtain the phenomenological part of the sum rule, we consider the double dispersion relation satisfied by the vertex function $T_{\mu\nu}(p,p')$

$$T_{\mu\nu}(p,p') = \frac{1}{\pi^2}\int ds_1 \int ds_2 \frac{\rho_{\mu\nu}(s_1,s_2)}{(p^2-s_1^2)(p'^2-s_2^2)}\,, \tag{9}$$

where we neglected possible subtraction terms since they will not make any contribution after Borel transform. For low values of s_1 and s_2, the spectral density function $\rho_{\mu\nu}(s_1,s_2)$ contains a term proportional to double δ-function $\delta(s_1-m_\phi^2)\delta(s_2-m_s^2)$ corresponding to the transition $\phi\to s\gamma$ where $s=\sigma$ or a_0. We can therefore obtain the physical part by extracting this contribution as

$$\begin{aligned} T_{\mu\nu}(p,p') \;=\; & \frac{\langle 0|j^\phi_\nu|\phi\rangle\langle\phi(p)|j^\gamma_\mu|s(p')\rangle\langle s|j_s|0\rangle}{(p^2-m_\phi^2)(p'^2-m_s^2)} \\ & +\frac{1}{\pi^2}\int_{s_{10}}^\infty ds_1\int_{s_{20}}^\infty ds_2 \frac{\rho^{\mathrm{had}}_{\mu\nu}(s_1,s_2)}{(p^2-s_1^2)(p'^2-s_2^2)}\,, \end{aligned} \tag{10}$$

where s_{10} and s_{20} are continuum thresholds. In this expression, the overlap amplitudes $\lambda_s = \langle s|j_s|0\rangle$ have been estimated above for $s=\sigma$ and a_0. The overlap amplitude λ_ϕ of ϕ meson is defined as $\langle 0|j^\phi_\nu|\phi\rangle = \lambda_\phi u_\nu$ where u_ν is the polarization vector of the ϕ meson. The e^+e^- leptonic decay width of ϕ meson neglecting electron mass is then given by

$$\Gamma(\phi\to e^+e^-) = \frac{4\pi\alpha^2}{3m_\phi^3}\lambda_\phi^2\,. \tag{11}$$

We use the experimental value for the electronic branching ratio $B(\phi\to e^+e^-) = (2.91\pm 0.07)\times 10^{-4}$ of ϕ meson [17], and this way we determine the overlap amplitude λ_ϕ of ϕ meson as $\lambda_\phi = (0.079\pm 0.016)$ GeV^2. The matrix element of the electromagnetic current can be written in the form

$$\langle\phi(p)|j^\gamma_\mu|s(p')\rangle = -i\frac{e}{m_\phi}g_{\phi s\gamma}K(q^2)(p\cdot q\; u_\mu - u\cdot q\; p_\mu)\,, \tag{12}$$

where $q = p - p'$ and $K(q^2)$ is a form factor with $K(0) = 1$. This expression defines the coupling constant $g_{\phi\sigma\gamma}$ through the effective Lagrangian

$$\mathcal{L} = \frac{e}{m_\phi} g_{\phi s\gamma} \partial^\alpha \phi^\beta (\partial_\alpha A_\beta - \partial_\beta A_\alpha) s \tag{13}$$

describing the $\phi s\gamma$-vertex [21]. Furthermore, we invoke the quark-hadron global duality, and therefore assume that the physical and perturbative spectral densities ρ^{had} and ρ^{pert}, respectively, are dual to each other in the sense that they give the same result approximately when integrated above some threshold [14].

We obtain the theoretical part of the sum rule by calculating the perturbative contributions and the power corrections from operators of different dimensions to the three point function $T_{\mu\nu}(p,p')$. If we consider the gauge invariant structure $(p_\mu q_\nu - p\cdot q g_{\mu\nu})$ we can then write for three point correlation function

$$\begin{aligned} T(p,p') &= \frac{1}{\pi^2}\int ds_1 \int ds_2 \frac{\rho^{\text{pert}}(s_1,s_2)}{(p^2-s_1^2)(p'^2-s_2^2)} \\ &\quad + c_3(\approx \langle \overline{q}q\rangle) + c_5(\approx \langle \overline{q}\sigma\cdot Gq\rangle) + \ldots \end{aligned} \tag{14}$$

where c_3, c_5,... denote the power corrections coming from operators of different dimensions that are proportional to various vacuum condensates. For the perturbative contribution we consider the lowest order bare-loop diagrams shown in Fig. 3(a), therefore in Eq. (8) for the correlation function $T_{\mu\nu}$ we can replace the interpolating current $j_\nu^\phi = \sin\theta j_\nu^{\omega_0} + \cos\theta j_\nu^{\phi_0}$ by $j_\nu^\phi = \sin\theta j_\nu^{\omega_0} = \sin\theta \frac{1}{6}(\overline{u}\gamma_\nu u - \overline{d}\gamma_\nu d)$ with θ denoting the mixing angle of the $\omega\phi$-system. For the power corrections we consider the contributions coming from the operators of different dimensions that are proportional to vacuum condensates $\langle\overline{q}q\rangle$, $\langle\overline{q}\sigma\cdot Gq\rangle$ and $\langle(\overline{q}q)^2\rangle$. Since the gluon condensate contribution proportional to $\langle G^2\rangle$ is estimated to be negligible for the light u and d quark systems, it is not taken into account. We perform the calculation of power corrections in the fixed point gauge [22]. We work in the limit $m_u = m_d = m_q = 0$, and in this limit perturbative bare-loop diagram does not make any contribution. Moreover, in this limit only operators of dimensions $d = 3$ and $d = 5$ make contributions that are proportional to $\langle\overline{q}q\rangle$ and $\langle\overline{q}\sigma\cdot Gq\rangle$, respectively. The relevant Feynman diagrams for power corrections are shown in Fig. 3(b) and Fig. 3(c). We obtain the following power corrections for $\phi s\gamma$-vertex

$$c_3 = i\frac{3}{4}\frac{1}{p^2}\frac{1}{p'^2}\left(e_u\langle\overline{u}u\rangle \pm e_d\langle\overline{d}d\rangle\right)\sin\theta \tag{15}$$

and

$$c_5 = \left(i\frac{5}{32}\frac{1}{p^4}\frac{1}{p'^2} - i\frac{3}{32}\frac{1}{p^2}\frac{1}{p'^4}\right)\left(e_u\langle g_s\overline{u}\sigma\cdot Gu\rangle \pm e_d\langle g_s\overline{d}\sigma\cdot Gd\rangle\right)\sin\theta\,, \tag{16}$$

where the plus sign is for the $\phi\sigma\gamma$-vertex and the minus sign is for the $\phi a_0\gamma$-vertex.

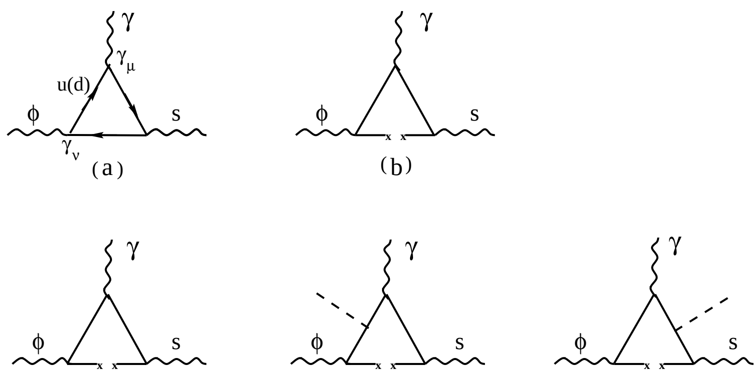

Fig. 3. Feynman diagrams for the $\phi s\gamma$-vertex: (a) — bare loop diagram, (b) — $d = 3$ operator corrections, (c) — $d = 5$ operator corrections. The dotted lines denote gluons.

After performing double Borel transform with respect to the variables $Q^2 = -p^2$ and $Q'^2 = -p'^2$, and by considering the gauge-invariant structure $(p_\mu q_\nu - p\cdot q g_{\mu\nu})$ we obtain the sum rules for the coupling constants $g_{\phi\sigma\gamma}$ and $g_{\phi a_0\gamma}$ as

$$\begin{aligned} g_{\phi s\gamma} = {}& \frac{m_\phi}{\lambda_\phi\lambda_s}\mathrm{e}^{m_\phi^2/M^2}\mathrm{e}^{m_s^2/M'^2}(e_u \pm e_d)\langle\overline{u}u\rangle \\ & \times\left(-\frac{3}{4} + \frac{5}{32}m_0^2\frac{1}{M^2} - \frac{3}{32}m_0^2\frac{1}{M'^2}\right)\sin\theta\,, \end{aligned} \tag{17}$$

where the plus sign is for the coupling constant $g_{\phi\sigma\gamma}$ and the minus sign is for the coupling constant $g_{\phi a_0\gamma}$, and we use the relations $\langle\overline{q}\sigma\cdot Gq\rangle = m_0^2\langle\overline{q}q\rangle$ and $\langle u\overline{u}\rangle = \langle d\overline{d}\rangle$.

For the numerical evaluation of the sum rule we use the values $m_0^2 = (0.8\pm0.02)$ GeV^2, $\langle\overline{u}u\rangle = (-0.014\pm0.002)$ GeV^3 [14], and $m_\phi = 1.020$ GeV, $m_{a_0} = 0.980$ GeV and $m_\sigma = 0.5$ GeV. For the overlap amplitudes λ_σ and

λ_{a_0}we use the values $\lambda_\sigma = (0.15 \pm 0.04)$ GeV^2 and $\lambda_{a_0} = (0.23 \pm 0.06)$ GeV^2 that we have estimated previously, and for λ_ϕ we use its experimental value $\lambda_\phi = (0.079 \pm 0.016)$ GeV^2 as obtained from the measured leptonic width $\Gamma(\phi \to e^+e^-)$ of ϕ meson. In order to analyze the dependence of $g_{\phi\sigma\gamma}$ on the Borel parameters M^2 and M'^2, we study the independent variations of M^2 and M'^2. The variation of the coupling constant $g_{\phi\sigma\gamma}$ and $g_{\phi a_0\gamma}$ as a function of Borel parameters M^2 for different values of M'^2 are shown in Fig. 4 and Fig. 5, respectively. The Borel parameter has no physical meaning, and we look for a range of its values where the sum rules are almost independent of M^2. Examination of Fig. 4 and in Fig. 5 indicates that such a stability window is achieved in the interval 1 GeV$^2 < M^2,\ M'^2 < 1.4$ GeV^2 for the coupling constant $g_{\phi\sigma\gamma}$ and in the interval 1 GeV$^2 < M^2 < 1.4$ GeV^2 and 1.4 GeV$^2 < M'^2 < 1.8$ GeV^2 for the coupling constant $g_{\phi a_0\gamma}$. We choose the middle value $M^2 = 1.2$ GeV^2 of the Borel parameter in its interval of variation and obtain the coupling constants as $g_{\phi\sigma\gamma} = (0.043 \pm 0.009)$ and $g_{\phi a_0\gamma} = (0.12 \pm 0.03)$. The errors arise from the numerical analysis of the sum rule due to variations of M^2 and M'^2 and also from the uncertainties in the estimated values of the vacuum condensates.

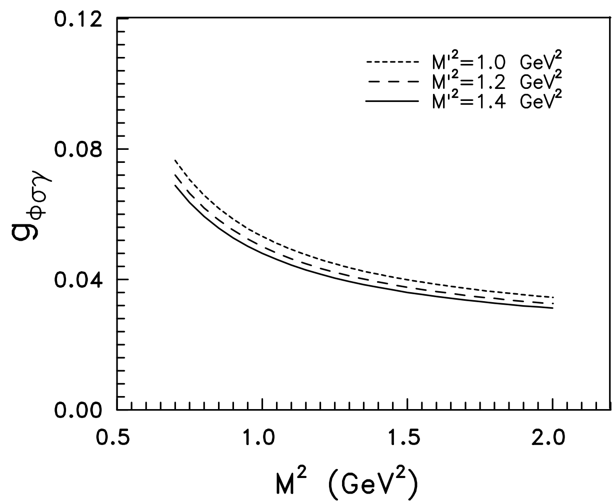

Fig. 4. The coupling constant $g_{\phi\sigma\gamma}$ as a function of the Borel parameter M^2 for different values of M'^2.

In a previous work [10], we followed a phenomenological approach to study the radiative $\phi \to \pi^0\pi^0\gamma$ decay by considering ρ-pole vector meson dominance amplitude as well as scalar σ-pole and f_0-pole amplitudes. By employing the experimental value for this decay rate and by analyzing the interference effects between different contributions in the experimen-

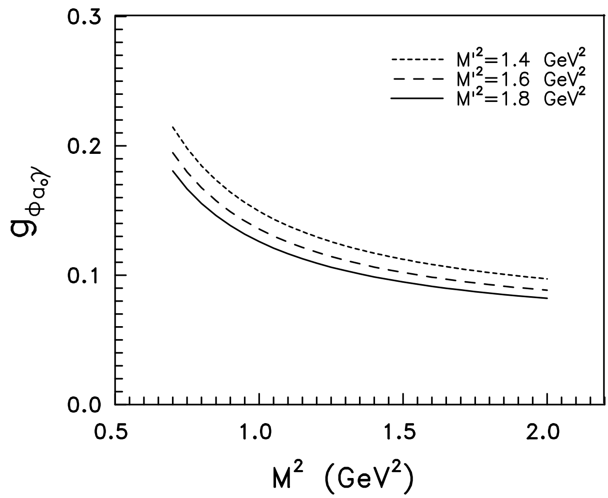

Fig. 5. The coupling constant $g_{\phi a_0 \gamma}$ as a function of the Borel parameter M^2 for different values of M'^2.

tal $\pi^0\pi^0$ invariant mass spectrum for the decay $\phi \to \pi^0\pi^0\gamma$, we estimated the coupling constant $g_{\phi\sigma\gamma}$ as $g_{\phi\sigma\gamma} = (0.025 \pm 0.009)$ which is in reasonable agreement with our present calculation utilizing QCD sum rules. On the other hand, Friman and Soyeur [21] in their study of the photoproduction of ρ^0 mesons on proton targets near threshold showed that photoproduction cross section is given mainly by σ-exchange, and they calculated the $\rho\sigma\gamma$-vertex assuming vector meson dominance of the electromagnetic current, and their result when described using an effective Lagrangian for the $\rho\sigma\gamma$-vertex gave the value $g_{\rho\sigma\gamma} = 2.71$ for this coupling constant. In their study of the structure of the ϕ meson photoproduction amplitude on nucleons near threshold based on the one-meson exchange and Pomeron-exchange mechanisms, Titov *et al.* [11] used this value of the coupling constant $g_{\rho\sigma\gamma}$ to calculate the coupling constants $g_{\phi\sigma\gamma}$ and $g_{\phi a_0 \gamma}$ by invoking unitary symmetry arguments, and they obtained the results $g_{\phi\sigma\gamma} = 0.047$ and $\mid g_{\phi a_0 \gamma} \mid = 0.16$ for these coupling constants. Our results $g_{\phi\sigma\gamma} = (0.043 \pm 0.009)$ and $g_{\phi a_0 \gamma} = (0.12 \pm 0.03)$ are in good agreement with the values of these coupling constants calculated by Titov *et al.* and used in their analysis. However, it should be noted that in order to derive their result Titov *et al.* assumed that σ, f_0, and a_0 are members of a unitary nonet, but in our work we do not make any assumption about the assignment of scalar states into various unitary nonets, which is not without problems.

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