Physics Letters B 696 (2011) 220–226

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

# Strong coupling constants of light pseudoscalar mesons with heavy baryons in QCD

T.M. Aliev [a,1], K. Azizi [b,*], M. Savcı [a]

[a] Physics Department, Middle East Technical University, 06531 Ankara, Turkey
[b] Physics Division, Faculty of Arts and Sciences, Doğuş University, Acıbadem-Kadıköy, 34722 Istanbul, Turkey

ARTICLE INFO

*Article history:*
Received 9 October 2010
Received in revised form 13 December 2010
Accepted 15 December 2010
Available online 17 December 2010
Editor: A. Ringwald

*Keywords:*
Strong coupling constants
QCD sum rules

ABSTRACT

We calculate the strong coupling constants of light pseudoscalar mesons with heavy baryons within the light cone QCD sum rules method. It is shown that sextet–sextet, sextet–antitriplet and antitriplet–antitriplet transitions are described by one universal invariant function for each class. A comparison of our results on the coupling constants with the predictions existing in literature is also presented.



## 1. Introduction

In this decade exciting experimental results have been obtained in heavy baryon spectroscopy. During these years, the $\frac{1}{2}^+$ and $\frac{1}{2}^-$ antitriplet states, $\Lambda_c^+$, $\Xi_c^+$, $\Xi_c^0$ and $\Lambda_c^+(2593)$, $\Xi_c^+(2790)$, $\Xi_c^0(2790)$ and the $\frac{1}{2}^+$ and $\frac{3}{2}^+$ and sextet states, $\Omega_c^*$, $\Sigma_c^*$, $\Xi_c^*$ have been observed in experiments [1]. Among the s-wave bottom hadrons, only $\Lambda_b$, $\Sigma_b$, $\Sigma_b^*$, $\Xi_b$ and $\Omega_b$ have been discovered. Moreover, in recent years many new states have been observed by BaBar and BELLE collaborations, such as $X(3872)$, $Y(3930)$, $Z(3930)$, $X(3940)$, $Y(4008)$, $Z_1^+(4050)$, $Y(4140)$, $X(4160)$, $Z_2(4250)$, $Y(4260)$, $Y(4360)$, $Z^+(4430)$, and $Y(4660)$ which remain unidentified.

Of course, establishing these states is a remarkable progress in hadron physics. It is expected that LHC, the world's largest highest-energy particle accelerator, will open new horizons in the discovery of the excited bottom baryon sates [2]. The experimental progress on heavy hadron spectroscopy stimulated intensive theoretical studies in this respect (for a review see [3,4] and references therein). A detailed theoretical study of experimental results on hadron spectroscopy and various weak and strong decays can provide us with useful information about the quark structure of new hadrons at the hadronic scale.

This scale belongs to the nonperturbative sector of QCD. Therefore, for calculation of the form factors in weak decays and coupling constants in strong decays, some nonperturbative methods are needed. Among many nonperturbative methods, QCD sum rules [5] is more reliable and predictive. In the present work, we calculate the strong coupling constants of light pseudoscalar mesons with sextet and antitriplet baryons, in light cone version of the QCD sum rules (LCSR) method (for a review, see [6]). Note that some of the strong coupling constants have already been studied in [7–9] in the same framework.

The outline of this Letter is as follows. In Section 2, we demonstrate how coupling constants of pseudoscalar mesons with heavy baryons can be calculated. In this section, the LCSR for the heavy baryon–pseudoscalar meson coupling constants are also derived using the most general form of the baryon currents. Section 3 is devoted to the numerical analysis and a comparison of our results with the existing predictions in the literature.

## 2. Light cone QCD sum rules for the coupling constants of pseudoscalar mesons with heavy baryons

Before presenting the detailed calculations for the strong coupling constants of pseudoscalar mesons with heavy baryons, we would like to make few remarks about the classification of heavy baryons. Heavy baryons with a single heavy quark belong to either $SU(3)$

* Corresponding author.
*E-mail addresses:* taliev@metu.edu.tr (T.M. Aliev), kazizi@dogus.edu.tr (K. Azizi), savci@metu.edu.tr (M. Savcı).
1 Permanent address: Institute of Physics, Baku, Azerbaijan.

0370-2693/$ – see front matter 
doi:10.1016/j.physletb.2010.12.027

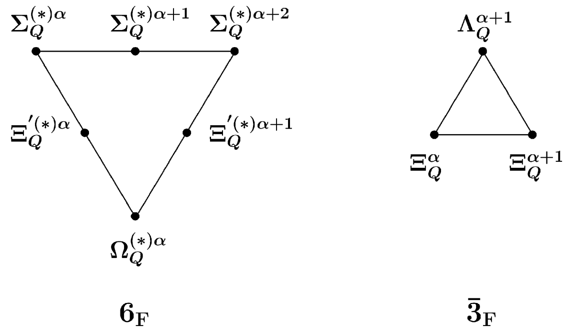


**Fig. 1.** Sextet ($6_F$) and antitriplet ($\bar{3}_F$) representations of heavy baryons. Here $\alpha$, $\alpha+1$, $\alpha+2$ determine the charges of baryons ($\alpha=-1$ or 0), and ($*$) denotes $J^P=\frac{3}{2}^+$ states.

antisymmetric $\bar{3}_F$ or symmetric $6_F$ flavor representations. Since we consider the ground states, the total spin of the two light quarks must one for $6_F$ and zero for $\bar{3}_F$, due to the symmetry property of their colors and flavors, as a result of which we can write $J^P=\frac{1}{2}^+/\frac{3}{2}^+$ for $6_F$ and $J^P=\frac{1}{2}^+$ for $\bar{3}_F$. Graphically, $6_F$ and $\bar{3}_F$ representations are given in Fig. 1, where $\alpha$, $\alpha+1$, $\alpha+2$ determine the charges of baryons ($\alpha=-1$ or 0), and the asterisk ($*$) denotes $J^P=\frac{3}{2}^+$ states. In this work, we will consider only $J^P=\frac{1}{2}^+$ states.

After this preliminary remarks, we proceed by calculating the strong coupling constants of pseudoscalar mesons with heavy baryons within the LCSR. For this purpose, we start by considering the following correlation function:

$$\Pi^{(ij)}=i\int d^4x\,e^{ipx}\langle\mathcal{P}(q)\big|\mathcal{T}\big\{\eta^{(i)}(x)\bar{\eta}^{(j)}(0)\big\}|0\rangle, \tag{1}$$

where $\mathcal{P}(q)$ is the pseudoscalar meson with momentum $q$, $\eta$ is the interpolating current for the heavy baryons and $\mathcal{T}$ is the time ordering operator. Here, $i=1$, $j=1$ describes the sextet–sextet, $i=1$, $j=2$ corresponds to sextet–triplet, and $i=2$, $j=2$ describes triplet–triplet transitions. For convenience we shall denote $\Pi^{(11)}=\Pi^{(1)}$, $\Pi^{(12)}=\Pi^{(2)}$ and $\Pi^{(22)}=\Pi^{(3)}$. The sum rules for the coupling constants of pseudoscalar mesons with heavy baryons can be obtained by calculating the correlation function (1) in two different ways, namely, in terms of the hadrons and in terms of quark gluon degrees of freedom, and then matching these two representations.

Firstly, we calculate the correlation function (1) in terms of hadrons. Inserting complete sets of hadrons with the same quantum numbers in the interpolating currents and isolating the ground states, we obtain

$$\Pi^{(ij)}=\frac{\langle 0|\eta^{(i)}(0)|B_2(p)\rangle\langle B_2(p)\mathcal{P}(q)|B_1(p+q)\rangle\langle B_1(p+q)|\bar{\eta}^{(j)}(0)|0\rangle}{(p^2-m_2^2)[(p+q)^2-m_1^2]}+\cdots, \tag{2}$$

where $|B_2(p)\rangle$ and $|B_1(p+q)\rangle$ are the $\frac{1}{2}$ states, and $m_2$ and $m_1$ are their masses, respectively. The dots in Eq. (2) describe contributions of the higher states and continuum. It follows from Eq. (2) that in order to calculate the correlation function in terms of hadronic parameters, the matrix elements entering to Eq. (2) are needed. These matrix elements are defined in the following way:

$$\begin{aligned}
&\langle 0|\eta^{(i)}\big|B(p)\big\rangle=\lambda_i u(p),\\
&\big\langle B(p+q)\big|\eta^{(j)}|0\rangle=\lambda_j\bar{u}(p+q),\\
&\big\langle B(p)\mathcal{P}(q)\big|B(p+q)\big\rangle=g\bar{u}(p)i\gamma_5 u(p+q),
\end{aligned} \tag{3}$$

where $\lambda_i$ and $\lambda_j$ are the residues of the heavy baryons, $g$ is the coupling constant of pseudoscalar meson with heavy baryon and $u$ is the Dirac bispinor.

Using Eqs. (2) and (3) and performing summation over spins of the baryons, we obtain the following representation of the correlation function from the hadronic side:

$$\Pi^{(ij)}=i\frac{\lambda_i\lambda_j g}{(p^2-m_2^2)[(p+q)^2-m_1^2]}\{\not{q}\not{p}\gamma_5+\text{other structures}\}, \tag{4}$$

where we kept the structure which leads to a more reliable result.

In order to calculate the correlation function from QCD side, the forms of the interpolating currents for the heavy baryons are needed. The general form of the interpolating currents for the heavy spin $\frac{1}{2}$ sextet and antitriplet baryons can be written as (see for example [10]),

$$\begin{aligned}
\eta_Q^{(s)}&=-\frac{1}{\sqrt{2}}\epsilon^{abc}\big\{\big(q_1^{aT}CQ^b\big)\gamma_5q_2^c+\beta\big(q_1^{aT}C\gamma_5Q^b\big)q_2^c-\big[\big(Q^{aT}Cq_2^b\big)\gamma_5q_1^c+\beta\big(Q^{aT}C\gamma_5q_2^b\big)q_1^c\big]\big\},\\
\eta_Q^{(anti\text{-}t)}&=\frac{1}{\sqrt{6}}\epsilon^{abc}\big\{2\big(q_1^{aT}Cq_2^b\big)\gamma_5Q^c+2\beta\big(q_1^{aT}C\gamma_5q_2^b\big)Q^c+\big(q_1^{aT}CQ^b\big)\gamma_5q_2^c+\beta\big(q_1^{aT}C\gamma_5Q^b\big)q_2^c\\
&\quad+\big(Q^{aT}Cq_2^b\big)\gamma_5q_1^c+\beta\big(Q^{aT}C\gamma_5q_2^b\big)q_1^c\big\},
\end{aligned} \tag{5}$$

where $a,b,c$ are the color indices and $\beta$ is an arbitrary parameter. It should also be noted that the general form of interpolating currents for light spin 1/2 baryons was introduced in [11] and $\beta=-1$ corresponds to the Ioffe current [12]. The quark fields $q_1$ and $q_2$ for the sextet and antitriplet are presented in Table 1.