Baryon-Baryon-Meson Coupling Constants in QCD

T. M. Aliev

Physics Department
Middle East Technical University
Ankara-Turkey

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Collaborators: K. Azizi, A.Ozpineci, M. Savci, V. Zamiralov

Outline

1. Introduction
2. Sum rules for the coupling constants of baryon-baryon-meson
   - vector mesons-octet-octet baryons
   - vector mesons- decuplet–octet baryons
3. Numerical results of the coupling constants
   - vector mesons- octet–octet baryons
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- In the experiments performed at Jefferson Laboratory, MAMI, BNL, MIT on meson– nucleon, nucleon–hyperon, hyperon–hyperon reactions very rich data are accumulated.
- To describe the existing data, the coupling constants of pseudoscalar and vector mesons with baryons are needed
- These coupling constants belong to the low energy sector of QCD, so for calculation of them some non-perturbative methods are needed.
- QCD sum rules
- importance of the approach used: all coupling constants are described by only one universal function for ODV, ODP and DDP even if $SU(3)_f$ symmetry breaking effects are switched into the game. However, all OOV and OOP couplings are stated interms of three functions.

$$\eta = A\varepsilon^{abc}\Big\{(q_1^{aT}Cq_2^b)\gamma_5 q_3^c - (q_2^{aT}Cq_3^b)\gamma_5 q_1^c + \beta(q_1^{aT}C\gamma_5 q_2^b)q_3^c - \beta(q_2^{aT}C\gamma_5 q_3^b)q_1^c\Big\} ,$$

$$\eta_\mu = A'\varepsilon^{abc}\Big\{(q_1^{aT}C\gamma_\mu q_2^b)q_3^c + (q_2^{aT}C\gamma_\mu q_3^b)q_1^c + (q_3^{aT}C\gamma_5 q_1^b)q_2^c\Big\} ,$$

where a, b, c are the color indices, β is an arbitrary parameter, C is the charge conjugation operator.

- except the Λ current, all octet and decuplet currents can be obtained from Σ^0 and Σ^{*0} currents with the help of appropriate replacements among quark flavors.
- The following relations between the currents of the Λ and Σ^0 are also obtained

$$
\begin{aligned}
2\eta^{\Sigma^0}(d \to s) + \eta^{\Sigma^0} &= -\sqrt{3}\eta^{\Lambda} \,, \\
2\eta^{\Sigma^0}(u \to s) + \eta^{\Sigma^0} &= \sqrt{3}\eta^{\Lambda} \,. \qquad (1)
\end{aligned}
$$

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	A	q_1	q_2	q_3
Σ^0	$-\sqrt{1/2}$	u	s	d
Σ^+	$1/2$	u	s	u
Σ^-	$1/2$	d	s	d
p	$-1/2$	u	d	u
n	$-1/2$	d	u	d
Ξ^0	$1/2$	s	u	s
Ξ^-	$1/2$	s	d	s

Table:

	A'	q_1	q_2	q_3
Σ^{*0}	$\sqrt{2/3}$	u	d	s
Σ^{*+}	$\sqrt{1/3}$	u	u	s
Σ^{*-}	$\sqrt{1/3}$	d	d	s
Δ^{++}	$1/3$	u	u	u
Δ^{+}	$\sqrt{1/3}$	u	u	d
Δ^{0}	$\sqrt{1/3}$	d	d	u
Δ^{-}	$1/3$	d	d	d
Ξ^{*0}	$\sqrt{1/3}$	s	s	u
Ξ^{*-}	$\sqrt{1/3}$	s	s	d
Ω^{-}	$1/3$	s	s	s

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In $SU(3)_f$ symmetry, coupling constants of all vector mesons with baryons in terms of two constants $\mathcal{F}$ and $\mathcal{D}$:

$$\begin{aligned} \mathcal{L}_{BBM} &= \sqrt{2}\mathcal{F}\,\mathrm{Tr}\bar{B}[V,B] + \sqrt{2}\mathcal{D}\,\mathrm{Tr}\bar{B}\{V,B\} \\ &- \frac{1}{\sqrt{2}}(\mathcal{F}+\mathcal{D})\mathrm{Tr}(\bar{B}B)\mathrm{Tr}V\ , \end{aligned} \tag{2}$$

and we assume ideal mixing of the octet and singlet isosinglets giving observable ρ^0 and ω mesons. Ideal mixing corresponds to the mixing angle $\theta = \cos^{-1}\sqrt{2/3} = 35.3^0$, which is very close to the experimental value $\theta = 37.5^0$.

The coefficient of the last term is chosen to eliminate the coupling of the nucleon to the pure $\bar{s}s$ state ϕ. B and V are the octet baryons and octet vector mesons:

$$B^{\alpha}_{\beta} = \begin{pmatrix} \frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & \Sigma^+ & p \\ \Sigma^- & -\frac{1}{2}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & n \\ \Xi^- & \Xi^0 & -\frac{2}{\sqrt{6}}\Lambda \end{pmatrix}, \tag{3}$$

$$V^{\alpha}_{\beta} = \begin{pmatrix} \frac{1}{\sqrt{2}}\rho^0 + \frac{1}{\sqrt{2}}\omega & \rho+ & K^{*+} \\ \rho^- & -\frac{1}{\sqrt{2}}\rho^0 + \frac{1}{\sqrt{2}}\omega & K^{*0} \\ K^{*-} & \bar{K}^{*0} & \phi \end{pmatrix}. \tag{4}$$

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Instead of the $\mathcal{F}$ and $\mathcal{D}$ as independent parameters, one can also choose to work with the coupling $g^{p\to p\rho^0}$ and the ratio $\alpha = \mathcal{F}/(\mathcal{F}+\mathcal{D})$. In terms of these parameters, $\mathcal{F} = \alpha g^{p\to p\rho^0}$, $\mathcal{D} = (1-\alpha)g^{p\to p\rho^0}$. Note also that, There are two pairs of $\mathcal{F}$ and $\mathcal{D}$ values; one for the electric type and one for the magnetic type couplings.

- To construct LCSR for the vector meson–baryon strong coupling constants, the following correlation function is considered:

$$\Pi^{B_1\to B_2V} = i\int d^4xe^{ipx}\left\langle V(q)\left|\mathcal{T}\left\{\eta_{B_2}(x)\bar{\eta}_{B_1}(0)\right\}\right|0\right\rangle \ , \quad (5)$$

- The correlation function can be calculated in terms the hadrons, as well as in the deep Euclidean region $p^2 \to -\infty$, in terms of the quark and gluon degrees of freedom. Using the operator product expansion (OPE) the corresponding sum rules are obtained by equating both representations through the dispersion relations.

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- phenomenological part: insert a complete set of intermediate states with the same quantum numbers as the current operators η_B.

$$\Pi^{B_1 \to B_2 V}(p_1^2, p_2^2) = \frac{\left\langle 0 \left| \eta_{B_2} \right| B_2(p_2) \right\rangle}{p_2^2 - m_2^2} \langle B_2(p_2) V(q) \mid B_1(p_1) \rangle \frac{\left\langle B_1(p_1) \left| \bar{\eta}_{B_1} \right| 0 \right\rangle}{p_1^2 - m_1^2} + \cdots , \tag{6}$$

$p_1 = p_2 + q$, $\cdots$ represents the contributions of the higher states and the continuum.

- The matrix elements

$$\left\langle 0 \left| \eta_{B_i} \right| B_i(p_i) \right\rangle = \lambda_{B_i} u(p_i) \; , \tag{7}$$

$$\langle B_2(p_2) V(q) \mid B_1(p_1) \rangle = \bar{u}(p_2) \left[f_1 \gamma_\mu - f_2 \frac{i}{m_1 + m_2} \sigma_{\mu\nu} q^\nu \right] u(p_1) \varepsilon^\mu \; , \tag{8}$$

- phenomenological part of the correlation function:

$$\Pi^{B_1 \to B_2} = \Pi^{f_1+f_2} \not{p}\not{\varepsilon}\not{q} + \Pi^{f_1} \not{p}(\varepsilon \cdot p) + \cdots \;, \tag{9}$$

where we had set $p_1 = p$ and $p_2 = p + q$.

- Numerous structures in correlation function. Any of these structures, in principle, can be used in determining the baryon–meson coupling constants. The structures $\not{p}\not{\varepsilon}\not{q}$ and $\not{p}(\varepsilon\cdot p)$ exhibit better convergence. From the coefficient functions $\Pi^{f_1+f_2}$ and Π^{f_1} one can extract the values of f_1+f_2 and f_1 respectively.
- For calculation the theoretical part, from the QCD side, baryon interpolating currents are needed which you saw in the previous slides.

- Relations among the invariant functions. In the exact $SU(3)_f$ limit all coupling constants of vector mesons with octet baryons can be related to each other using symmetry arguments.
- The main advantage of our approach is that it allows us to take $SU(3)_f$ symmetry violating effects into account.
- Relations between the invariant functions are all structure independent

- $\Sigma^0 \to \Sigma^0 \rho^0$ transition, two of the three independent functions. $\Sigma^+ \to \Sigma^+ \rho^0$ and $\Sigma^- \to \Sigma^- \rho^0$ transitions,

$$\Pi^{\Sigma^0 \to \Sigma^0 \rho^0} = g_{\rho \bar{u} u} \Pi_1(u,d,s) + g_{\rho \bar{d} d} \Pi_1'(u,d,s) + g_{\rho \bar{s} s} \Pi_2(u,d,s) \ , (10)$$

$$J_\mu = \sum_{u,d,s} g_{\rho \bar{q} q} \bar{q} \gamma_\mu q \ ,$$

and for the ρ^0 meson $g_{\rho \bar{u} u} = -g_{\rho \bar{d} d} = 1/\sqrt{2}$, $g_{\rho \bar{s} s} = 0$. The invariant functions Π_1, Π_1' and Π_2 describe emission of the ρ^0 meson from u, d and s quarks of Σ^0, respectively.

Σ^0 is symmetric under the replacement $u \leftrightarrow d$, hence $\Pi_1'(u,d,s) = \Pi_1(d,u,s)$. Two independent functions $\Pi_1(u,d,s)$ and $\Pi_2(u,d,s)$. Introduce formal notation,

$$\begin{aligned} \Pi_1(u,d,s) &= \left\langle \bar{u}u \left| \Sigma^0 \bar{\Sigma}^0 \right| 0 \right\rangle \ , \\ \Pi_2(u,d,s) &= \left\langle \bar{s}s \left| \Sigma^0 \bar{\Sigma}^0 \right| 0 \right\rangle \ , \end{aligned} \tag{11}$$

Replacing $d \to u$ in $\Pi_1(d,u,s)$ and using $\Sigma^0(d \to u) = -\sqrt{2}\Sigma^+$, we obtain

$$4\Pi_1(u,u,s) = 2 \left\langle \bar{u}u \left| \Sigma^+ \bar{\Sigma}^+ \right| 0 \right\rangle \ . \tag{12}$$

The factor 4 can be explained as follows. 4 ways for emitting the ρ^0 from u quark. In Σ^+ there is no d quark,

$$\begin{aligned}\Pi^{\Sigma^+\to\Sigma^+\rho^0} &= g_{\rho\bar{u}u}\left\langle \bar{u}u\left|\Sigma^+\bar{\Sigma}^+\right|0\right\rangle + g_{\rho\bar{s}s}\left\langle \bar{s}s\left|\Sigma^+\bar{\Sigma}^+\right|0\right\rangle \\ &= \sqrt{2}\Pi_1(u,u,s)\,. \end{aligned} \tag{13}$$

Similar arguments, for the $\Sigma^- \to \Sigma^-\rho^0$ transition, we get

$$\begin{aligned}\Pi^{\Sigma^-\to\Sigma^-\rho^0} &= g_{\rho\bar{d}d}\left\langle \bar{d}d\left|\Sigma^-\bar{\Sigma}^-\right|0\right\rangle + g_{\rho\bar{s}s}\left\langle \bar{s}s\left|\Sigma^-\bar{\Sigma}^-\right|0\right\rangle \\ &= -\sqrt{2}\Pi_1'(d,d,s) = -\sqrt{2}\Pi_1(d,d,s)\,. \end{aligned} \tag{14}$$

- In the isospin symmetry limit, $\Pi^{\Sigma^+\to\Sigma^+\rho^0} = -\Pi^{\Sigma^-\to\Sigma^-\rho^0}$, and $\Pi^{\Sigma^0\to\Sigma^0\rho^0} = 0$.
- Couplings of ρ^0 meson with proton and neutron: the matrix elements $\langle \bar{u}u \left| \bar{N}N \right| 0 \rangle$ and $\langle \bar{d}d \left| \bar{N}N \right| 0 \rangle$. The matrix involving interpolating current of the proton can be obtained from the current of Σ^+ by the replacement $s \to d$, i.e.,

$$\langle \bar{u}u \left| p\bar{p} \right| 0 \rangle = \langle \bar{u}u \left| \Sigma^+\bar{\Sigma}^+ \right| 0 \rangle (s \to d) = 2\Pi_1(u,u,d)\,. \quad (15)$$

In order to obtain $\left\langle \bar{d}d \left| p\bar{p} \right| 0 \right\rangle$, $\Pi_2(u,d,s)$ is needed. In the first step, making the replacement $d \to u$, we get

$$\Pi_2(u,u,s) = \left\langle \bar{s}s \left| \Sigma^+ \Sigma^- \right| 0 \right\rangle \ , \tag{16}$$

where the factor 2 in the normalization of the current is canceled by the two possible ways of contracting the u quarks. Making the replacement $s \to d$ in the second step,

$$\Pi_2(u,u,d) = \left\langle \bar{d}d \left| p\bar{p} \right| 0 \right\rangle \ . \tag{17}$$

$$\begin{aligned} \Pi^{p \to p\rho^0} &= g_{\rho\bar{u}u} \left\langle \bar{u}u \left| p\bar{p} \right| 0 \right\rangle + g_{\rho\bar{d}d} \left\langle \bar{d}d \left| p\bar{p} \right| 0 \right\rangle \\ &= \sqrt{2}\Pi_1(u,u,d) - \frac{1}{\sqrt{2}}\Pi_2(u,u,d) \ . \end{aligned} \tag{18}$$

Coupling constants of ρ^0 meson to the neutron and Ξ baryons,

$$
\begin{aligned}
\Pi^{n\to n\rho^0} &= \frac{1}{\sqrt{2}}\Pi_2(d,d,u) - \sqrt{2}\Pi_1(d,d,u)\ , \\
\Pi^{\Xi^0\to\Xi^0\rho^0} &= \frac{1}{\sqrt{2}}\Pi_2(s,s,u)\ , \\
\Pi^{\Xi^-\to\Xi^-\rho^0} &= -\frac{1}{\sqrt{2}}\Pi_2(s,s,d)\ . \qquad (19)
\end{aligned}
$$

The couplings of ρ^0 meson with baryons in terms of two invariant functions $\Pi_1(u,d,s)$ and $\Pi_2(u,d,s)$.

Now derive similar relations for the charged ρ meson. The matrix element $\left\langle \bar{d}d \left| \Sigma^0 \bar{\Sigma}^0 \right| 0 \right\rangle$ d quarks from the Σ^0 and $\bar{\Sigma}^0$ form the final $\bar{d}d$ and the other u and s quarks are the spectators. In the matrix element $\left\langle \bar{u}d \left| \Sigma^+ \bar{\Sigma}^0 \right| 0 \right\rangle$, d quark from Σ^0 and u quark from Σ^+ form the state $\bar{u}d$ and the other u and s quarks, similar to the previous case, are the spectators. Therefore, one can expect that these matrix elements should be proportional, and indeed, calculations confirm that, i.e.,

$$\begin{aligned} \Pi^{\Sigma^0 \to \Sigma^+ \rho^-} &= \left\langle \bar{u}d \left| \Sigma^+ \bar{\Sigma}^0 \right| 0 \right\rangle = -\sqrt{2} \left\langle \bar{d}d \left| \Sigma^0 \bar{\Sigma}^0 \right| 0 \right\rangle \\ &= -\sqrt{2}\Pi_1'(u,d,s) = -\sqrt{2}\Pi_1(d,u,s) \; . \end{aligned} \tag{20}$$

Exchange $u \leftrightarrow d$, we get

$$\Pi^{\Sigma^0 \to \Sigma^- \rho^+} = \left\langle \bar{d}u \left| \Sigma^- \bar{\Sigma}^0 \right| 0 \right\rangle = \sqrt{2} \left\langle \bar{u}u \left| \Sigma^0 \bar{\Sigma}^0 \right| 0 \right\rangle = \sqrt{2}\Pi_1(u,d,s) \ . \tag{21}$$

Similar calculations for the Ξ baryons,

$$\begin{aligned} \Pi^{\Xi^0 \to \Xi^- \rho^+} &= \left\langle \bar{d}u \left| \Xi^- \bar{\Xi}^0 \right| 0 \right\rangle = -\sqrt{2} \left\langle \bar{u}u \left| \Xi^0 \bar{\Xi}^0 \right| 0 \right\rangle = \Pi_2(s,s,u) \ , \\ \Pi^{\Xi^- \to \Xi^0 \rho^-} &= \left\langle \bar{u}d \left| \Xi^0 \bar{\Xi}^- \right| 0 \right\rangle = -\sqrt{2} \left\langle \bar{d}d \left| \Xi^0 \bar{\Xi}^0 \right| 0 \right\rangle = \Pi_2(s,s,d) \ . \end{aligned} \tag{22}$$

The correlation functions involving the ρ and K^* mesons

$$
\begin{aligned}
\Pi^{\Sigma^- \to \Sigma^0 \rho^-} &= \sqrt{2}\Pi_1(u,d,s)~, \\
\Pi^{\Sigma^+ \to \Sigma^0 \rho^+} &= \sqrt{2}\Pi_1'(u,d,s) = -\sqrt{2}\Pi_1(d,u,s)~, \\
\Pi^{\Sigma^- \to n K^{*-}} &= -\Pi_2(d,d,s)~, \\
\Pi^{p \to \Sigma^+ K^{*0}} &= -\Pi_2(u,u,d)~, \\
\Pi^{\Sigma^+ \to p \bar{K}^{*0}} &= -\Pi_2(u,u,s)~, \\
\Pi^{n \to \Sigma^- K^{*+}} &= -\Pi_2(d,d,s)~. \qquad (23)
\end{aligned}
$$

The correlation functions involving a single Λ baryon appear together with correlation functions involving a Σ^0 baryon. It is impossible to separate them using only Π_1 and Π_2. To separate the correlation functions involving the Λ and Σ^0 baryons, one more independent function

$$\Pi_3(u,d,s) = -\Pi^{\Sigma^0 \to \Xi^- K^{*+}} = -\left\langle u\bar{s} \left| \Xi^- \bar{\Sigma}^0 \right| 0 \right\rangle . \qquad (24)$$

Similar way ω, ϕ couplings can be obtained.

- All possible strong coupling constants of the octet vector mesons with the octet baryons in terms of three independent invariant functions without using the flavor symmetry.
- The invariant function $\Pi_3(u,d,s)$ can be split into symmetric and antisymmetric parts with respect to the exchange of d and s quarks as:

  $$\Pi_3(u,d,s) = \Pi_3^{sym}(u,d,s) + \Pi_3^{asym}(u,d,s)\ .$$

  The symmetric part, Π_3^{sym}, can be expressed in terms of Π_1 and Π_2 as

  $$\Pi_3^{sym}(u,d,s) = \frac{1}{\sqrt{2}}\Big[\Pi_1(u,d,s) + \Pi_1(u,s,d) - \Pi_2(s,d,u)\Big]\ .$$

- $\Pi_3^{asym}(u,d,s)$, vanishes in the $SU(3)_f$ limit, hence only two invariant functions Π_1 and Π_2 are relevant and they correspond to $\mathcal{F}$ and $\mathcal{D} - \mathcal{F}$ couplings.

- For calculation these three invariant functions. The correlation functions responsible for the transitions $\Sigma^0 \to \Sigma^0 \rho^0$, $\Sigma^0 \to \Sigma^0 \phi$ and $\Sigma^0 \to \Xi^- K^{*+}$
- In deep Euclidean region, $-p_1^2 \to \infty$, $-p_2^2 \to \infty$, the correlation function can be evaluated using OPE.

- We use the he matrix elements $\langle V(q)\,|\bar{q}(x)\Gamma q(0)|\,0\rangle$ and $\langle V(q)\,|\bar{q}(x)G_{\mu\nu}q(0)|\,0\rangle$ Up to twist–4 accuracy.
- the light quark propagator

$$
\begin{aligned}
S_q(x) &= \frac{i\not{x}}{2\pi^2x^4} - \frac{m_q}{4\pi^2x^2} - \frac{\langle\bar{q}q\rangle}{12}\left(1-\frac{im_q}{4}\not{x}\right) - \frac{x^2}{192}m_0^2\,\langle\bar{q}q\rangle\left(1-\frac{im_q}{6}\not{x}\right) \\
&- ig_s\int_0^1 du\left\{\frac{\not{x}}{16\pi^2x^2}G_{\mu\nu}(ux)\sigma^{\mu\nu} - ux^\mu G_{\mu\nu}(ux)\gamma^\nu\frac{i}{4\pi^2x^2}\right. \\
&- \left.\frac{im_q}{32\pi^2}G_{\mu\nu}(ux)\sigma^{\mu\nu}\left[\ln\left(\frac{-x^2\Lambda^2}{4}\right)+2\gamma_E\right]\right\}, \qquad (25)
\end{aligned}
$$

Equating both representations of correlation function and separating coefficients of Lorentz structures $\not p \not\varepsilon \not q$ and $\not p(\varepsilon \cdot p)$ and applying Borel transformation to both side of the correlation functions on the variables p^2 and $(p+q)^2$ in order to suppress the contributions of the higher states and continuum , we get the sum rules for the corresponding vector meson baryon couplings. For a given transition $B_1 \to B_2 V$, once the Borel transformed and continuum subtracted coefficient functions Π^{f_1} and $\Pi^{f_1+f_2}$ are obtained, the sum rules for the electric and magnetic type couplings are obtained as

$$f_1 = \frac{1}{\lambda_{B_1}\lambda_{B_2}} e^{-\frac{m_1^2}{M_1^2}-\frac{m_2^2}{M_2^2}-\frac{m_V^2}{M_1^2+M_2^2}} \Pi^{f_1}$$

$$f_1+f_2 = \frac{1}{\lambda_{B_1}\lambda_{B_2}} e^{-\frac{m_1^2}{M_1^2}-\frac{m_2^2}{M_2^2}-\frac{m_V^2}{M_1^2+M_2^2}} \Pi^{f_1+f_2}$$

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The interaction Lagrangean of DOV in $SU(3)_f$ symmetry

$$\mathcal{L}_{int} = g \varepsilon_{ijk} \bar{O}^j_\ell D^{mk\ell} V^i_m + h.c. \, , \qquad (26)$$

correlation function,

$$\Pi^{D\to OV}_\mu = i \int d^4x e^{ipx} \left\langle V(q) \left| T\left\{ \eta(x) \bar{\eta}_\mu(0) \right\} \right| 0 \right\rangle \, , \qquad (27)$$

$$\Pi_\mu^{D\to OV}(p,q) = \frac{\langle 0 \left|\eta\right| O(p_2)\rangle \langle O(p_2)V(q)|D(p_1)\rangle}{p_2^2-m_2^2} \frac{\langle D(p_1)\left|\bar{\eta}_\mu\right| 0\rangle}{p_1^2-m_1^2} + \cdots , \tag{28}$$

Using the Lorentz invariance, the $\langle O(p_2)V(q)|D(p_1)\rangle$ is parametrized in terms of three form factors g_1, g_2 and g_3 as follows

$$\langle O(p_2)V(q)|D(p_1)\rangle = \bar{u}(p_2)\Big\{g_1(q_\alpha \not\varepsilon - \varepsilon_\alpha \not q)\gamma_5 + g_2[(p\cdot\varepsilon)q_\alpha - (P\cdot q)\varepsilon_\alpha]\gamma_5 + g_3[(q\cdot\varepsilon)q_\alpha - q^2\varepsilon_\alpha]\gamma_5\Big\}u_\alpha(p_1) , \tag{29}$$

where $P=(p_1+p_2)/2$. The vector meson is on shell problems

- Contributions from 1/2 states $\langle 0 \left| \eta_\mu \right| 1/2(p) \rangle \sim (\alpha \gamma_\mu - \beta p_\mu)$
- Not all Lorentz structures are independent
- Ordering procedure $\gamma_\mu \not{\varepsilon} \not{q} \not{p} \gamma_5$

phenomenological part of the correlation function

$$
\begin{aligned}
\Pi_\mu = & \frac{\lambda_0 \lambda_D}{[m_1 - (p+q)^2]} \frac{1}{(m_2^2 - p^2)} \Big[g_1 (m_1 + m_2) \not\varepsilon \not p \gamma_5 q_\mu \\
& - g_2 \not q \not p \gamma_5 (p \cdot \varepsilon) q_\mu + g_3 q^2 \not q \not p \gamma_5 \varepsilon_\mu \\
& + \text{other structures} \Big] . \qquad (30)
\end{aligned}
$$

The structures $\not\varepsilon \not p \gamma_5 q_\mu$, $\not q \not p \gamma_5 (p \cdot \varepsilon) q_\mu$ and $\not q \not p \gamma_5 \varepsilon_\mu$ do not contain contributions from $J^P = \frac{1}{2}^-$ states

Relations among the invariant functions for the structures $\not\varepsilon \not p \gamma_5 q_\mu$, $\not q \not p \gamma_5 (p \cdot \varepsilon) q_\mu$ and $\not q \not p \gamma_5 \varepsilon_\mu$. The relations between the invariant functions are structure independent, while their explicit terms are structure dependent.

- Steps similar OOV case

- Example $\Delta^+ \to p\rho^0$ transition. $\Delta^+ = \Sigma^{*+}(s \to d)$ and $p = -\Sigma^+(s \to d)$,

$$\begin{aligned}
\Pi^{\Delta^+ \to p\rho^0} &= -\left(g_{\rho^0 uu} \left\langle \bar{u}u \left| \Sigma^+ \bar{\Sigma}^{*+} \right| 0 \right\rangle \right)(s \to d) \\
&- \left(g_{\rho^0 ss} \left\langle \bar{s}s \left| \Sigma^+ \bar{\Sigma}^{*+} \right| 0 \right\rangle \right)(s \to d) \\
&= \sqrt{2}\Pi_1(u,u,d) - \frac{1}{\sqrt{2}}\Pi_2(u,u,d) \, . \qquad (31)
\end{aligned}$$

$$\Pi^{\Delta^0 \to n\rho^0} = \sqrt{2}\Pi_1(d,d,u) - \frac{1}{\sqrt{2}}\Pi_2(d,d,u) \, . \qquad (32)$$

$$\begin{aligned}
\Pi^{\Xi^{*0} \to \Xi^0\rho^0} &= \frac{1}{\sqrt{2}}\Pi_2(s,s,u) \, , \\
\Pi^{\Xi^{*-} \to \Xi^-\rho^0} &= \frac{1}{\sqrt{2}}\Pi_2(s,s,d) \, . \qquad (33)
\end{aligned}$$

for charged ρ meson:

$$\Pi^{\Sigma^{*0}\to\Sigma^+\rho^-} = \left\langle \bar{u}d \left| \Sigma^+\bar{\Sigma}^{*0} \right| 0 \right\rangle = -\sqrt{2} \left\langle \bar{d}d \left| \Sigma^0\bar{\Sigma}^{*0} \right| 0 \right\rangle = -\sqrt{2}\Pi_1(d,u,s) \ . \quad (34)$$

Making the exchange $u \leftrightarrow d$ in the above expression, we obtain,

$$\Pi^{\Sigma^{*0}\to\Sigma^-\rho^+} = \left\langle \bar{d}u \left| \Sigma^-\bar{\Sigma}^{*0} \right| 0 \right\rangle = \sqrt{2} \left\langle \bar{u}u \left| \Sigma^0\bar{\Sigma}^{*0} \right| 0 \right\rangle = \sqrt{2}\Pi_1(u,d,s) \ . \quad (35)$$

Couplings involving K^*, ω and ϕ with DO can be obtained in the similar way

- The coupling constants of DOV can qualitatively be understood from a simple *diquark+quark* picture the Hermitian conjugate channel, $O + V \to D$. Denote O as $O(q_1 q_2, q_3)$ where $q_1 q_2$ forms the diquark and q_3 is a single quark. In a reaction, for example $p\rho^+ \to \Delta^{++}$, the single q_3 (in this case d) is the V–absorbing quark, and therefore, this reaction is described by Π_{q_3} (in our notation Π_2). In the reaction $n\rho^+ \to \Delta^+$, the V–absorbing quark is from the diquark (here dd), and this reaction is described by, let us say, Π_1.
- For the reactions of Δ decays with the participation of ρ^0, both functions Π_1 and Π_2 contribute. Obviously, only Π_1 and Π_2 contribute to the reactions $\Sigma^* \to \Sigma\rho^0$ and $\Xi^* \to \Xi\rho^0$, respectively. Similar situation take place for the reactions involving ω and ϕ mesons.

Relation between Π_1 and Π_2

$$\Pi_2(u,d,s) = -\Pi_1(s,u,d) - \Pi_1(s,d,u)\ .$$

Main result. All coupling constants DOV can be written in terms of only one invariant function without using the $SU(3)_f$ flavor symmetry.

Outline

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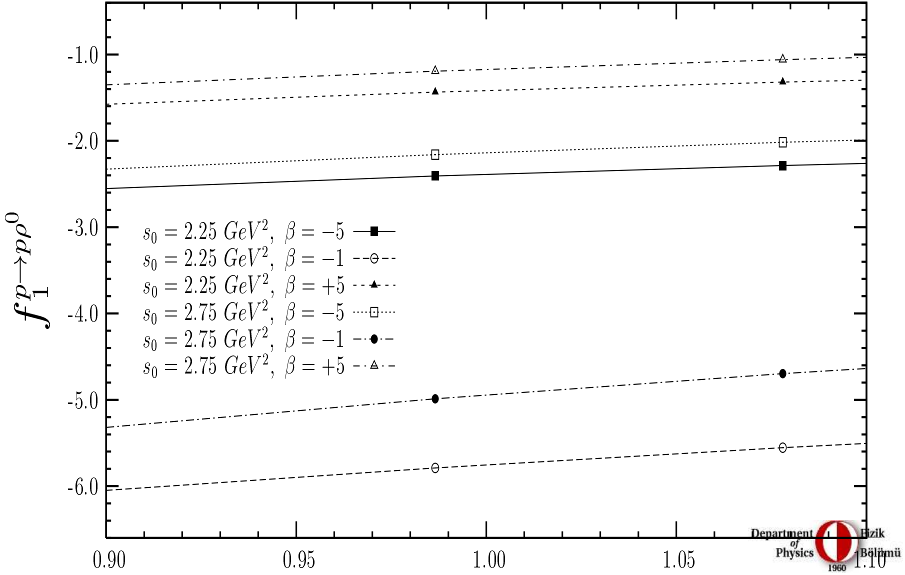
- Three parameters: M^2, s_0, β
- $s_0 = (m_B + 0.5)^2$
- Upper bound of M^2. Higher states+cont.$< 1/2$ of total result
- lower bound of M^2 highest order of $1/M^2 < (1/4)$ of highest order of M^2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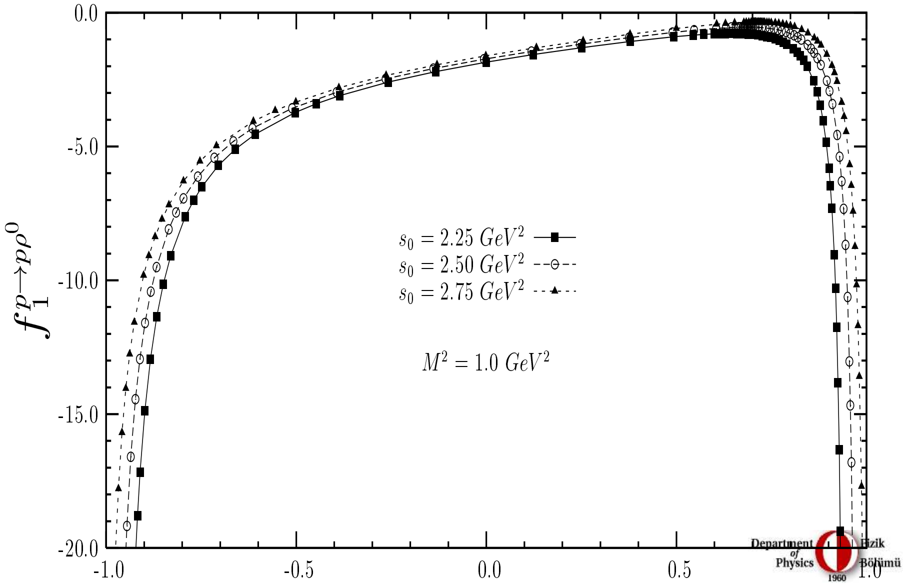
-2.0
-3.0
-4.0
-5.0
-6.0
0.90
0.95
1.00
1.05
1.10
$f_1^{p\to p\rho^0}$
$s_0 = 2.25\ GeV^2,\ \beta = -5$
$s_0 = 2.25\ GeV^2,\ \beta = -1$
$s_0 = 2.25\ GeV^2,\ \beta = +5$
$s_0 = 2.75\ GeV^2,\ \beta = -5$
$s_0 = 2.75\ GeV^2,\ \beta = -1$
$s_0 = 2.75\ GeV^2,\ \beta = +5$


0.0
-5.0
-10.0
-15.0
-20.0
-1.0
-0.5
0.0
0.5
1.0
$f_1^{p\to p\rho^0}$
$s_0 = 2.25\ GeV^2$
$s_0 = 2.50\ GeV^2$
$s_0 = 2.75\ GeV^2$
$M^2 = 1.0\ GeV^2$
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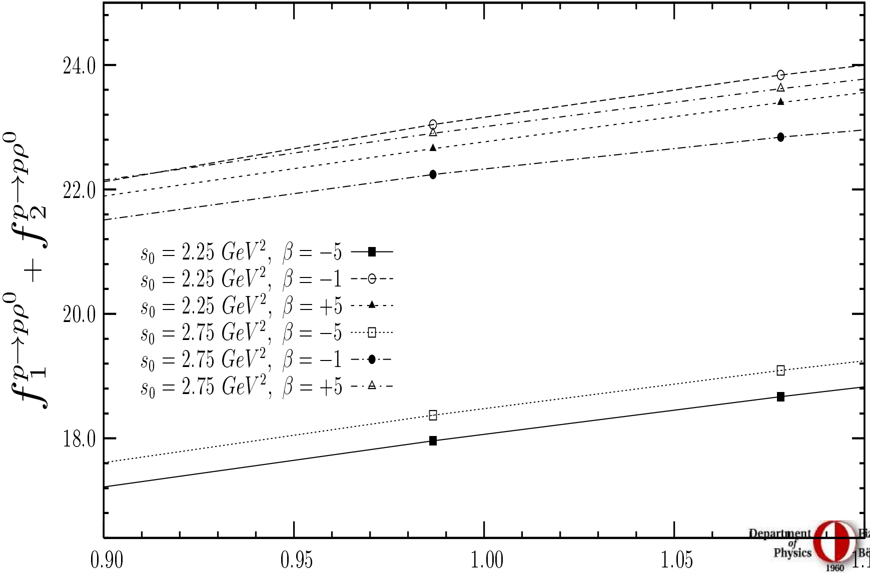
1960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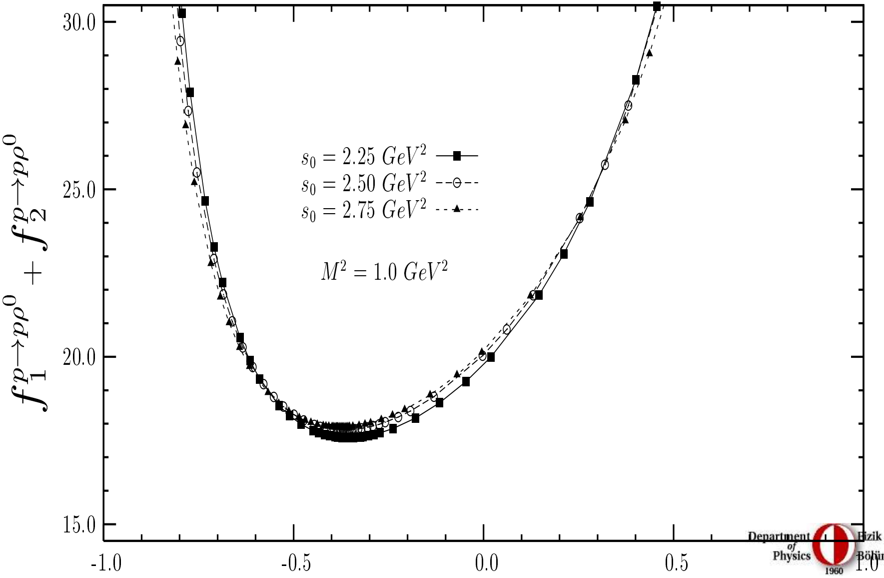
22.0
20.0
18.0
0.90
0.95
1.00
1.05
1.10
$f_1^{p\to p\rho^0} + f_2^{p\to p\rho^0}$
$s_0 = 2.25\ GeV^2,\ \beta = -5$
$s_0 = 2.25\ GeV^2,\ \beta = -1$
$s_0 = 2.25\ GeV^2,\ \beta = +5$
$s_0 = 2.75\ GeV^2,\ \beta = -5$
$s_0 = 2.75\ GeV^2,\ \beta = -1$
$s_0 = 2.75\ GeV^2,\ \beta = +5$


$f_1^{p\to p\rho^0} + f_2^{p\to p\rho^0}$
$s_0 = 2.25\ GeV^2$
$s_0 = 2.50\ GeV^2$
$s_0 = 2.75\ GeV^2$
$M^2 = 1.0\ GeV^2$
30.0
25.0
20.0
15.0
-1.0
-0.5
0.0
0.5
1.0

f_1 channel	General current Result	General current $SU(3)_f$	Ioffe current Result	Ioffe current $SU(3)_f$	QSR
$f_1^{p\to p\rho^0}$	-2.5 ± 1.1	-1.7	-5.9 ± 1.3	-6.4	2.5 ± 0.2
$f_1^{p\to p\omega}$	-8.9 ± 1.5	-10.3	-8.2 ± 0.4	-9.6	18 ± 8
$f_1^{\Xi^0\to\Xi^0\rho^0}$	-4.2 ± 2.1	-4.3	-2.0 ± 0.2	-1.6	—
$f_1^{\Sigma^0\to\Lambda\rho^0}$	1.9 ± 0.7	1.5	-3.0 ± 0.5	-2.8	—
$f_1^{\Lambda\to\Sigma^+\rho^-}$	1.9 ± 0.7	1.5	-2.8 ± 0.6	-2.8	—
$f_1^{\Sigma^+\to\Sigma^0\rho^+}$	7.2 ± 1.2	6.0	8.5 ± 0.8	8.0	—
$f_1^{\Sigma^+\to\Lambda\rho^+}$	2.0 ± 0.6	1.5	-2.8 ± 0.6	-2.8	—
$f_1^{p\to\Lambda K^{*+}}$	5.1 ± 1.8	4.4	7.4 ± 0.8	8.3	—
$f_1^{\Sigma^-\to nK^{*-}}$	6.6 ± 1.8	6.1	1.7 ± 0.4	2.3	—

Table: The values of the electric coupling constants for various

f_1 channel	General current Result	General current $SU(3)_f$	Ioffe current Result	Ioffe current $SU(3)_f$	QSR
$f_1^{\Xi^0\to\Sigma^+K^{*-}}$	-2.3 ± 1.7	-2.4	-10.0 ± 1.8	-9.1	—
$f_1^{\Xi^-\to\Lambda K^{*-}}$	-5.9 ± 0.7	-5.8	-6.2 ± 0.4	-5.5	—
$f_1^{\Sigma^0\to\Xi^0 K^{*0}}$	1.6 ± 1.0	1.7	7.1 ± 1.3	6.4	—
$f_1^{\Lambda\to\Xi^0 K^{*0}}$	-6.0 ± 0.7	-5.9	-6.2 ± 0.2	-5.5	—
$f_1^{n\to\Sigma^0 K^{*0}}$	-4.0 ± 0.7	-4.3	-1.5 ± 0.3	-1.6	—
$f_1^{\Lambda\to\Lambda\omega}$	-7.1 ± 1.1	-7.7	-4.8 ± 0.2	-4.8	—
$f_1^{\Xi^0\to\Xi^0\phi}$	-9.5 ± 2.5	-8.5	-13.5 ± 1.6	-11.3	—
$f_1^{\Lambda\to\Lambda\phi}$	-5.3 ± 1.5	-3.6	-8.0 ± 1.0	-6.8	—
$f_1^{\Sigma^0\to\Sigma^0\phi}$	-6.0 ± 0.8	-6.1	-0.25 ± 0.50	-2.3	—

Table: The values of the electric coupling constants for various

(f_1+f_2) channel	General current Result	General current $SU(3)_f$	Ioffe current Result	Ioffe current $SU(3)_f$	QSR
$(f_1+f_2)^{p\to p\rho^0}$	19.7±2.8	21.4	22.7±1.3	24.7	21.6 ± 6.6
$(f_1+f_2)^{p\to p\omega}$	14.5±2.6	15.0	21.2±1.2	25.7	$32.4 \pm 14.$
$(f_1+f_2)^{\Xi^0\to\Xi^0\rho^0}$	−2.8±1.6	−3.2	−0.24±0.24	0.5	—
$(f_1+f_2)^{\Sigma^0\to\Lambda\rho^0}$	13.8±2.7	14.2	15.1±0.9	14.0	—
$(f_1+f_2)^{\Lambda\to\Sigma^+\rho^-}$	14.3±2.9	14.2	15.1±0.8	14.0	—
$(f_1+f_2)^{\Sigma^+\to\Sigma^0\rho^+}$	−17.8±2.2	−18.2	−27.9±1.8	−25.2	—
$(f_1+f_2)^{\Sigma^+\to\Lambda\rho^+}$	14.3±2.9	14.2	15.1±0.8	14.0	—
$(f_1+f_2)^{p\to\Lambda K^{*+}}$	−22.9±4.2	−22.9	−27.3±1.5	−28.8	—
$(f_1+f_2)^{\Sigma^-\to nK^{*-}}$	3.8±2.8	4.5	−0.79±0.05	−0.7	—

Table: The values of the magnetic coupling constants for various channels

(f_1+f_2) channel	General current		Ioffe current		QSR
	Result	$SU(3)_f$	Result	$SU(3)_f$	
$(f_1+f_2)^{\Xi^0\to\Sigma^+K^{*-}}$	33.8±4.9	30.3	41.3±2.4	34.9	—
$(f_1+f_2)^{\Xi^-\to\Lambda K^{*-}}$	11.6±2.9	8.7	17.9±1.0	14.8	—
$(f_1+f_2)^{\Sigma^0\to\Xi^0K^{*0}}$	−24.6±4.8	−21.4	−29.2±1.7	−24.7	—
$(f_1+f_2)^{\Lambda\to\Xi^0K^{*0}}$	11.1±2.6	8.7	15.0±1.0	14.8	—
$(f_1+f_2)^{n\to\Sigma^0K^{*0}}$	−2.8±1.8	−3.2	0.56±0.04	0.5	—
$(f_1+f_2)^{\Lambda\to\Lambda\omega}$	1.6±0.6	1.8	7.1±0.5	9.1	—
$(f_1+f_2)^{\Xi^0\to\Xi^0\phi}$	22.8±6.4	25.7	37.7±2.5	35.6	—
$(f_1+f_2)^{\Lambda\to\Lambda\phi}$	19.3±5.0	18.7	22.0±1.4	23.5	—
$(f_1+f_2)^{\Sigma^0\to\Sigma^0\phi}$	−3.5±2.5	4.5	0.81±0.05	0.7	—

Table: The values of the magnetic coupling constants for various channels

For the coupling f_1: substantial difference for channels.
$p \to \Sigma^+ K^{*0}$, $\Xi^0 \to \Sigma^0 \bar{K}^{*0}$, $\Sigma^- \to n K^{*-}$, $n \to p\rho^-$, $\Xi^0 \to \Sigma^- K^{*-}$, $\Sigma^0 \to \Xi^0 K^{*0}$ channels for the general case, differ considerably from the prediction of the Ioffe current. Especially, the difference between the predictions of the above–mentioned currents for the $\Sigma^0 \to \Sigma^0 \phi$ transition is worth mentioning. While the Ioffe current predicts $f_1 \simeq 0$, the general current case predicts $f_1 \simeq -5$. The sign of f_1 for the $\Sigma^0 \to \Lambda\rho^0$, $\Sigma^+ \to \Lambda\rho^+$, transitions differ from those predicted by the Ioffe current.

For the coupling $f_1 + f_2$: Except the $\Xi^0 \to \Xi^0 \rho^0$, $\Sigma^+ \to \Sigma^0 \rho^+$, $\Sigma^- \to nK^{*-}$, $\Xi^0 \to \Xi^0 \phi$, $n \to \Sigma^0 K^{*0}$, $p \to \Sigma^+ K^{*0}$, $\Lambda \to \Lambda\omega$ and $\Sigma^0 \to \Sigma^0 \phi$ transitions, our predictions for the general current is in good agreement with the predictions of Ioffe current. These discrepancies between the coupling constants obtained using the general form of the baryon current and the Ioffe current can be explained as follows. For many channels the value $\beta = -1$ lies outside the stability region of β, as a result of which considerable differences appear between the predictions of the above–mentioned baryon currents, making the predictions less reliable.

In the Tables, we have also presented in the columns labeled $SU(3)_f$. The $SU(3)_f$ fits central values of $\mathcal{F} = -3.0 \pm 0.5$, $\mathcal{D} = 1.3 \pm 0.6$ and $\mathcal{F} = -4.2 \pm 0.7$, $\mathcal{D} = -2.7 \pm 1.0$ for the general and Ioffe current. For the central values, $\alpha_E = 1.6$ and $\alpha_E = 0.61$, respectively, both of which deviates from VDM model prediction $\alpha_E = 1$ considerably.

In Table–2, the $SU(3)_f$ fit value corresponds to $\mathcal{F} = 9.2 \pm 1.0$, $\mathcal{D} = 12.4 \pm 1.4$ and $\mathcal{F} = 12.7 \pm 1.8$, $\mathcal{D} = 12.2 \pm 1.8$ for the general form of the baryon current and $\beta = -1$ baryon current, respectively. For the α_M value of the magnetic type coupling, these predictions yield $\alpha_M = 0.43$ and $\alpha_M = 0.85$, respectively

Outline

1. Introduction
2. Sum rules for the coupling constants of baryon-baryon-meson
   - vector mesons-octet-octet baryons
   - vector mesons- decuplet–octet baryons
3. Numerical results of the coupling constants
   - vector mesons- octet–octet baryons
   - vector mesons- decuplet–octet baryons

g_1 channel	General current		Ioffe current	
	Result	$SU(3)_f$	Result	$SU(3)_f$
$g_1^{\Sigma^{*+}\to\Sigma^+\rho^0}$	-5.6 ± 1.6	-5.7	-7.8 ± 0.5	-7.8
$g_1^{\Delta^0\to p\rho^-}$	9.1 ± 2.9	8	12.2 ± 0.8	11
$g_1^{\Xi^{*0}\to\Xi^0\rho^0}$	-5.5 ± 1.5	-5.7	-7.2 ± 0.3	-7.8
$g_1^{\Sigma^{*-}\to\Lambda\rho^-}$	-10 ± 3	-9.8	-13.5 ± 0.7	-13.5
$g_1^{\Delta^+\to\Sigma^0K^{*+}}$	-13.1 ± 4.1	-11.3	-18.4 ± 1.4	-15.6
$g_1^{\Sigma^{*+}\to\Xi^0K^{*+}}$	8.9 ± 2.5	8	12 ± 0.5	11
$g_1^{\Sigma^{*+}\to p\bar{K}^{*0}}$	-9.5 ± 2.7	-8	-12.4 ± 0.9	-11

Table: The values of the coupling constant g_1 for various channels.

$g_1$channel	General current		Ioffe current	
	Result	$SU(3)_f$	Result	$SU(3)_f$
$g_1^{\Omega^- \to \Xi^0 K^{*-}}$	-14 ± 4	-13.9	-18.8 ± 1.4	-19.1
$g_1^{\Xi^{*0} \to \Sigma^+ K^{*-}}$	-8.6 ± 2.5	-8	-11.6 ± 0.9	-11
$g_1^{\Xi^{*0} \to \Lambda \bar{K}^{*0}}$	10.8 ± 3.0	9.8	14.1 ± 0.9	13.5
$g_1^{\Sigma^{*+} \to \Sigma^+ \omega}$	-5.1 ± 1.4	-5.7	-6.9 ± 0.4	-7.8
$g_1^{\Xi^{*0} \to \Xi^0 \omega}$	-4.9 ± 1.3	-5.7	-6.5 ± 0.5	-7.8
$g_1^{\Sigma^{*+} \to \Sigma^+ \phi}$	8.0 ± 2.8	8	11.6 ± 0.7	11
$g_1^{\Xi^{*0} \to \Xi^0 \phi}$	7.1 ± 1.9	8	10.9 ± 0.8	11

Table: The values of the coupling constant g_1 for various channels.

$g_2$channel	General current		Ioffe current	
	Result	$SU(3)_f$	Result	$SU(3)_f$
$g_2^{\Sigma^{*+}\to\Sigma^+\rho^0}$	-2.3 ± 1	-2.3	-3.6 ± 0.6	-3.8
$g_2^{\Delta^0\to p\rho^-}$	3.3 ± 1.5	3.2	5.3 ± 1.0	5.4
$g_2^{\Xi^{*0}\to\Xi^0\rho^0}$	-2.2 ± 1	-2.3	-3.4 ± 0.5	-3.8
$g_2^{\Sigma^{*-}\to\Lambda\rho^-}$	-4 ± 1.7	-3.9	-6.3 ± 1.2	-6.6
$g_2^{\Delta^+\to\Sigma^0K^{*+}}$	-16.4 ± 6	-4.5	-27.3 ± 7.3	-7.6
$g_2^{\Sigma^{*+}\to\Xi^0K^{*+}}$	11.1 ± 3	3.2	16.9 ± 3.5	5.4
$g_2^{\Sigma^{*+}\to p\bar{K}^{*0}}$	-10.8 ± 4.8	-3.2	-17.9 ± 4.7	-5.4

Table: The values of the coupling constant g_2 for various channels.

g_2 channel	General current		Ioffe current	
	Result	$SU(3)_f$	Result	$SU(3)_f$
$g_2^{\Omega^- \to \Xi^0 K^{*-}}$	-17.3 ± 6	-5.5	-27.7 ± 6.0	-9.4
$g_2^{\Xi^{*0} \to \Sigma^+ K^{*-}}$	-6.3 ± 4.0	-3.2	-16.1 ± 3.4	-5.4
$g_2^{\Xi^{*0} \to \Lambda \bar{K}^{*0}}$	12.4 ± 4.8	3.9	19.2 ± 3.9	6.6
$g_2^{\Sigma^{*+} \to \Sigma^+ \omega}$	-2.0 ± 0.7	-2.3	-3.2 ± 0.6	-3.8
$g_2^{\Xi^{*0} \to \Xi^0 \omega}$	-1.9 ± 0.6	-2.3	-3.0 ± 0.4	-3.8
$g_2^{\Sigma^{*+} \to \Sigma^+ \phi}$	4.4 ± 1.8	3.2	7.2 ± 1.5	5.4
$g_2^{\Xi^{*0} \to \Xi^0 \phi}$	4.2 ± 2	3.2	6.7 ± 1.1	5.4

Table: The values of the coupling constant g_2 for various channels.

$g_3$channel	General current		Ioffe current	
	Result	$SU(3)_f$	Result	$SU(3)_f$
$g_3^{\Omega^- \to \Xi^0 K^{*-}}$	33.5 ± 3	31.5	31.4 ± 2.4	45.7
$g_3^{\Xi^{*0} \to \Sigma^+ K^{*-}}$	17.3 ± 0.7	18.2	16.5 ± 1.4	26.4
$g_3^{\Xi^{*0} \to \Lambda \bar{K}^{*0}}$	-36.5 ± 8.2	-22.3	-45.5 ± 1.7	-32.3
$g_3^{\Sigma^{*+} \to \Sigma^+ \omega}$	23.9 ± 6.5	12.9	27.9 ± 2.1	18.7
$g_3^{\Xi^{*0} \to \Xi^0 \omega}$	19.1 ± 4.3	12.9	23.9 ± 1.3	18.7
$g_3^{\Sigma^{*+} \to \Sigma^+ \phi}$	-24.2 ± 6.2	-18.2	-31.7 ± 2.1	-26.4
$g_3^{\Xi^{*0} \to \Xi^0 \phi}$	-16.2 ± 3.8	-18.2	-33.2 ± 1.7	-26.4

Table: The values of the coupling constant g_3 for various channels.

g_3 channel	General current		Ioffe current	
	Result	$SU(3)_f$	Result	$SU(3)_f$
$g_3^{\Sigma^{*+}\to\Sigma^+\rho^0}$	31.4 ± 3.5	12.9	27.4 ± 1.8	18.7
$g_3^{\Delta^0\to p\rho^-}$	-33.5 ± 3.1	-18.2	-35.2 ± 2.6	-26.4
$g_3^{\Xi^{*0}\to\Xi^0\rho^0}$	16.2 ± 3.8	12.9	27.9 ± 1.6	18.7
$g_3^{\Sigma^{*-}\to\Lambda\rho^-}$	36.5 ± 8.5	22.3	45.7 ± 2.6	32.3
$g_3^{\Delta^+\to\Sigma^0K^{*+}}$	22.6 ± 2.4	25.7	19.6 ± 1.9	37.3
$g_3^{\Sigma^{*+}\to\Xi^0K^{*+}}$	-17.5 ± 2.3	-18.2	-17.3 ± 1.8	-26.4
$g_3^{\Sigma^{*+}\to p\bar{K}^{*0}}$	14.6 ± 1.7	18.2	12.6 ± 2.6	26.4

Table: The values of the coupling constant g_3 for various channels.

- The coupling constant g_1. Good agreement between the predictions of the general current and the Ioffe current for the octet baryons.
- In the case of the coupling constant g_2, there are considerable discrepancies between the predictions of the general current and Ioffe current for the octet baryons for the $\Sigma^{*+} \to \Xi^0 K^{*+}$, $\Omega^- \to \Xi^0 K^{*-}$, $\Delta^+ \to \Sigma^0 K^{*+}$, $\Delta^{++} \to \Sigma^+ K^{*+}$, $\Xi^{*0} \to \Lambda \bar{K}^{*0}$, $\Delta^- \to \Sigma^- \bar{K}^{*0}$ and $\Xi^{*0} \to \Sigma^+ K^{*-}$ channels. The characteristic property of all these channels is that they all involve the K^* meson.

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- For these channels, the relations among the coupling constants and invariant functions are also strongly violated. In the general current case all these discrepancies can be attributed to not having stable region for $\cos\theta$. For the remaining transitions the results for both cases are close to each other within the error limits.
- For the coupling constant g_3: The relations between the coupling constant g_3 and the invariant function Π_1 are strongly violated in the channels $\Sigma^{*-} \to \Lambda\rho^-$, $\Xi^{*0} \to \Xi^0\rho^0$, as well as in the channels involving ϕ meson. These discrepancies, as is the case for the g_2 coupling constant, can be attributed to the absence of the stability region g_3 with respect to the $\cos\theta$. For this reason, for the above–mentioned transitions, the predictions for the coupling constant g_3 are not reliable.

THANKS FOR YOUR ATTENTION