объединенный
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исследований
дубна

E2-90-291

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B AND D MESON DECAYS WITH TAKING INTO ACCOUNT CONFINEMENT OF LIGHT QUARKS

Submitted to "Ядерная физика"

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1990

1. Introduction

The study of the leptonic and semileptonic decays of the B and D mesons can help to determine the Cabibbo-Kabayashi-Maskawa matrix elements [1]. The main theoretical problem consists in calculation of weak-current matrix elements between the initial heavy meson and the final light hadrons and leptons from first principles. Therefore, various phenomenological models have been suggested to describe these processes.

The leptonic decay constants of the B(D)-mesons have been calculated by using QCD sum rules [2]-[6], lattice QCD [7,8], nonrelativistic potential model [9] and QCD-inspired relativistic one [10]. There are no experimental data on these constants but they enter into the expressions defining the $B^0 - \bar{B}^0$ ($D^0 - \bar{D}^0$)-mixing that has been measured in [11]. The theoretical predictions are rather vague (see, Table 2) with the results varying within a factor of two or so.

The semileptonic B_{l_3} and D_{l_3} weak decays are characterized by two form factors: $f_+(t)$ and $f_-(t)$ where t is a square of lepton pair momentum. The form factor $f_+(t)$ defines both the decay widths and the shapes of lepton spectrum. Many theoretical works are devoted to calculation of this form factor [13]-[18]. M.Wirbel et al. [13] have expressed this form factor in terms of relativistic bound state wave functions for which they took the solutions of a relativistic oscillator potential. C.A.Dominguez and N.Paver [14,15] have calculated the B_{l_3} and D_{l_3} form factors using QCD sum rules for a two-point function involving vector currents. The calculation of $f_+(0)$ has been performed in the lattice QCD [16]. The phenomenological analysis of the semileptonic decays of heavy mesons has been done in [17] using the vector dominance model and current algebra methods. In Table 3 we give the estimates of $f_+(0)$ obtained in the approaches discussed above.

In the papers [18]-[19] we have developed the Quark Confinement Model (QCM) based on some assumptions about the hadronization and confinement of light quarks. By assuming hadrons to be colourless excitations of quark-gluon interactions, the transition to hadron variables in the QCD functional is proceeds as in [20]. The hadron interactions are described by quark diagrams averaged over vacuum gluon backgrounds.

The confinement hypothesis means that this averaging leads to that quarks do not appear in the observable hadron spectrum.

Here, we give the extension of the QCM for applying to heavy quark physics. It is based on that heavy quarks interact weakly with vacuum background fields, for example, instantons [21], and therefore, they can be considered as the static Dirac particles with large constituent masses. At the same time, interactions of the light quarks are defined by the confinement forces.

In the framework of this approach, we will calculate the pseudoscalar decay constants and the form factors of D_{l_3} and B_{l_3} decays.

2. QCM: light and heavy quarks

In the QCM, hadron interactions are described by the quark diagrams, e.g., the quark loops in the case of light mesons, see, Fig.1. The transitions of hadrons into quarks and vice versa are given by the interaction Lagrangian

$$L_H(x) = g_H H(x) J_H(x), \tag{1}$$

where H is a hadron field and J_H is the corresponding quark current. The coupling constant g_H is defined by the so-called compositeness condition [18] which means that the renormalization constant of hadron wave function is equal to zero

$$Z_H = 1 + \frac{3g_H^2}{(2\pi)^2}\tilde{\Pi}'_H(m_H^2) = 0, \tag{2}$$

where $\tilde{\Pi}'_H$ is the derivative of the mass operator.

The following assumption is about the confinement of light quarks. It has been proposed that the averaging over vacuum background fields B_{vac} of the quark diagrams can be changed to the one-multiple integral

$$\int d\sigma_{vac} tr[\Gamma_1 S(x_1 x_2|B_{vac})...\Gamma_n S(x_n x_1|B_{vac})] \to$$
$$\to \int d\sigma_v tr[\Gamma_1 S_v(x_1 - x_2)...\Gamma_n S_v(x_n - x_1)]. \tag{3}$$

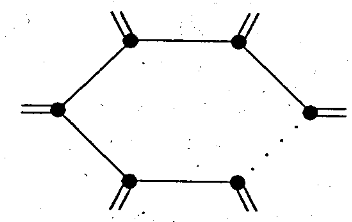

Fig.1. Light quark loop.

Here

$$S_v(x_1 - x_2) = \int \frac{d^4p}{(2\pi)^4 i} e^{-ip(x_1-x_2)} \frac{1}{v\Lambda_q - \hat{p}}.$$

The parameter Λ_q characterizes the confinement range. In other words, the averaging over B_{vac} effectively leads to the smearing of quark masses $m_q = v\Lambda_q$ with the measure $d\sigma_v$. The measure $d\sigma_v$ is defined as

$$\int \frac{d\sigma_v}{v - z} = G(z) = a(-z^2) + zb(-z^2). \tag{4}$$

The function $G(z)$ called the confinement function is an entire analytical function which decreases faster than any degree of z in an Euclidean direction $z^2 \to -\infty$. This requirement provides the absence of the singularities corresponding to quark productions in the physical matrix elements and makes all diagrams to be finite. $G(z)$ is a universal function, i.e., is independent on colour and flavour. In other words, the function $G(z)$ is unique for all quark diagrams defining the hadron interaction at low energies. The choice of $G(z)$ is one of the model assumptions. However, as calculations have showed, only integral characteristics of the function $G(z)$ are important for the description of low-energy physics [18,19] and the choice of its shape is motivated by the convenience of calculations. Some restrictions on the shapes $a(u)$ and $b(u)$ can be obtained from the condition of correspondence of the QCM-predictions to the well-established low-energy approaches as chiral theory, vector dominance model etc. for small external momenta.

To demonstrate this correspondence, let us consider the main low-energy physical values. The interaction Lagrangian is chosen as

$$L_H = \frac{g_\pi}{\sqrt{2}}\bar{q}\hat{\pi}i\gamma^5 q + \frac{g_\rho}{\sqrt{2}}\bar{q}\hat{\rho}_\mu\gamma^\mu q + \frac{g_\omega}{\sqrt{2}}\bar{q}\hat{\omega}_\mu\gamma^\mu q\,, \tag{5}$$

where $\hat{\pi} = \pi^i\tau^i$, $\hat{\rho}_\mu = \rho^i_\mu\tau^i$. Electroweak interactions are introduced in a standard manner. The quark diagrams describing physical processes are calculated according to confinement ansatz (3) (for details see [18,19]). The relations between the physical values obtained in the limits of zero hadron masses are shown in Table 1. The notation is $B_0 = \int\limits_0^\infty du b(u)$, $A_0 = \int\limits_0^\infty du a(u)$. One can see, if the following conditions are valid

$$a(0) = b(0) = 1; \qquad -a'(0) = 1; \qquad a''(0) = 2;$$
$$A_0 = B_0 = 2; \qquad \Lambda_q = 236\,Mev \tag{6}$$

the well-known low-energy relations are reproduced. It is to be remarked that the numerical value of the parameter Λ_q = 236Mev turns out to coincide with the constituent mass of a light quark. Further, we will use the simplest shape of the functions $a(u)$ and $b(u)$ satisfying the conditions (6):

$$a(u) = (1 - a_1 u + a_2 u^2) exp\{-[(a_2 - 1) + \frac{(1 - a_1^2)}{2}]u^2 - (1 - a_1)u\};$$
$$b(u) = exp\{-u^2 + b_1 u\}. \tag{7}$$

Here, $b_1 = 1.18$ and the parameters a_1 and a_2 are connected with each other by the condition $A_0 = 2$. The best agreement with experimental data is achieved at $a_1 = 1.5$ and $a_2 = 2.675$. The numerical results obtained with taking into account the physical hadron masses are shown in Table 1.

The calculations of numerous low-energy effects of the meson-meson and meson-baryon interactions performed in the QCM [19] have showed that the model allows one to describe with quite a good accuracy both the static hadron characteristics as decay widths, magnetic moments etc., and more sophisticated ones as form factors, phase shifts, etc.

Table 1. Main fit.

Process	$m_H = 0$	Physical masses	Expt.
$P \to P$	$g_P = 2\pi\sqrt{\frac{2}{3B_0}}$		
$V \to V$	$g_V = 2\pi\sqrt{\frac{1}{B_0}}$		
$\pi \to \mu\nu$	$f_\pi \equiv \sqrt{2}F_\pi = \frac{2\Lambda_q}{g_\pi}\frac{A_0}{B_0}$	$130 Mev$	$132 Mev$
$\rho \to \gamma$	$g_{\rho\gamma} = \frac{1}{2\pi}\sqrt{\frac{B_0}{2}}$	0.18	0.20
$\pi^0 \to \gamma\gamma$	$g_{\pi\gamma\gamma} = \frac{a(0)}{4\pi^2 F_\pi}$	$0.276\ Gev^{-1}$	$0.276\ Gev^{-1}$
$\omega \to \pi\gamma$	$g_{\omega\pi\gamma} = 3\pi g_{\pi\gamma\gamma}\sqrt{\frac{2}{B_0}}$	$2.12\ Gev^{-1}$	$2.54\ Gev^{-1}$
$\rho \to \pi\pi$	$g_{\rho\pi\pi} = \frac{1}{g_{\rho\gamma}} = 2\pi\sqrt{\frac{2}{B_0}}$	6.5	6.1
$\gamma \to 3\pi$	$g_{\gamma 3\pi} = \frac{-a'(0)}{4\pi^2 F_\pi^3}$		
5π-vertex	$g_{5\pi} = \frac{1}{80\pi^2 F_\pi^5}\frac{a''(0)}{2}$		
Anomaly Ward identity	$p_\alpha T_5^{\alpha\mu\nu} = 2\Lambda_q T_5^{\mu\nu}\frac{b(0)}{[-a'(0)]} - \frac{i}{2\pi^2}\epsilon^{\mu\nu q_1 q_2}\frac{b(0)a(0)}{[-a'(0)]}$		

It is clear that additional physical ideas are needed for applying the QCM to heavy quark physics.It has known that heavy quarks weakly interact with vacuum gluon fields, e.g. instantons [21]. Therefore, we can adopt the following picture for describing the processes with heavy and light quarks. The interaction of light quarks is completely defined by the confinement mechanism whereas a heavy quark is considered as an ordinary Dirac particle with a large mass. According to this notion, we propose the following ansatz for averaging quark diagrams containing the heavy quark propogator (see, Fig.2):

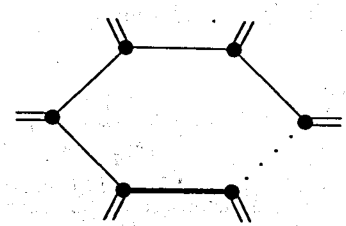

Fig.2. Light and heavy quark loop.

$$\int d\sigma_{vac} tr[\Gamma_1 S(x_1 x_2|B_{vac})...\Gamma_n S^{heavy}(x_n x_1|B_{vac})] \to$$
$$\to \int d\sigma_v tr[\Gamma_1 S_v(x_1 - x_2)...\Gamma_n S^{heavy}(x_n - x_1)], \quad (8)$$

where

$$S^{heavy}(x) = \int \frac{d^4p}{(2\pi)^4 i} e^{-ipx} \frac{1}{M_Q - \hat{p}}.$$

Here, M_Q is a constituent mass of heavy quark. In other words, it is suggested that a heavy quark is described by an ordinary free propagator with mass M_Q.

It is to be emphasized that the ansatz (8) provides confinement of both a heavy quark and a light one, i.e., absence of imaginary parts corresponding to quark productions.

3. Leptonic and semileptonic decays of B and D mesons

The Lagrangian describing the strong interactions of heavy mesons ($H = B, D, B^*, D^*$) with quarks is written as

$$\begin{aligned} L_I &= g_B[B^0(\bar{b}i\gamma^5 d) + B^-(\bar{b}i\gamma^5 u)] + g_D[D^0(\bar{u}i\gamma^5 c) + D^-(\bar{d}i\gamma^5 c)] + \\ &+ g_B^*[B_\mu^{*0}(\bar{b}\gamma^\mu d) + B_\mu^{*-}(\bar{b}\gamma^\mu u)] + g_D^*[D_\mu^{*0}(\bar{u}\gamma^\mu c) + D_\mu^{*-}(\bar{d}\gamma^\mu c)]. \quad (9) \end{aligned}$$

The coupling constants $g_{H(H^*)}$ are determined from the compositeness condition (2) where the mass operator $\tilde{\Pi}(p^2)$ is defined by the diagram, Fig.3a, and is written in the following form:

$$\begin{aligned} \Pi_{HH}(p^2) &= \int \frac{d^4k}{4\pi^2 i} \int d\sigma_v tr[i\gamma^5 \frac{1}{v\Lambda_q - \hat{k}} i\gamma^5 \frac{1}{M_Q - (\hat{k} + \hat{p})}] = \quad (10) \\ &= -\Lambda_q^2 \int \frac{d^4k}{\pi^2 i} \frac{[za(-k^2) - k(k+p)b(-k^2)]}{z^2 - (k+p)^2}. \end{aligned}$$

Here, $z = M_Q/\Lambda_q$.

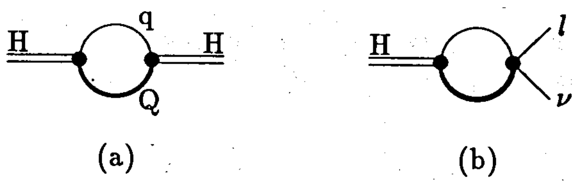

Fig.3. Diagrams describing (a) mass operator and (b) leptonic decay of heavy mesons.

Using the formula

$$\int \frac{d^4k}{\pi^2 i} \frac{f(-k^2)}{z^2 - (k+p)^2} = \int_0^\infty du f(u) C(u, p^2),$$

$$C(u, x) = \frac{[\sqrt{(u + z^2 - x)^2 + 4ux} - (u + z^2 - x)]}{2x},$$

one can obtain

$$\Pi_{HH}(p^2) = -\Lambda_q^2 I_{HH}(\frac{p^2}{\Lambda_q}), \quad (11)$$

$$I_{HH}(x) = \frac{1}{2}\int_0^\infty du u b(u) + \int_0^\infty du C(u, x)\{za(u) + \frac{1}{2}(x - z^2 + u)b(u)\}.$$

Substituting (11) into (2) we have the following expression for the coupling constant g_H

$$g_H = \frac{2\pi}{\sqrt{3}} \frac{1}{\sqrt{I'_{HH}(\mu_H^2)}}, \quad (12)$$

where

$$\begin{aligned} I'_{HH}(\mu_H^2) &= \int_0^\infty du\{za(u) C'_{\mu_H^2}(u, \mu_H^2) + \\ &+ \frac{1}{2} b(u)[C(u, \mu_H^2) + (u - z^2 + \mu_H^2) C'_{\mu_H^2}(u, \mu_H^2)]\}, \end{aligned}$$

$$\mu_H^2 = m_H^2/\Lambda_q^2.$$

The leptonic weak decay $H \to l\nu$ is defined by the diagram, Fig.3b. The invariant matrix element is written as

$$M(H \to l\nu) = G V_{qQ} f_H \bar{l}\hat{p}(1-\gamma^5)\nu\,, \qquad (13)$$

where V_{qQ} is the CKM-matrix element and

$$f_H = \Lambda_q \frac{3 g_H}{(2\pi)^2} I_H(\mu_H^2), \qquad (14)$$

$$\begin{aligned} I_H(x) \;&=\; \int\limits_0^\infty du\{zb(u)\frac{[u-(u+z^2-x)C(u,x)]}{2x} - \\ &- \; a(u)\frac{[u-(u+z^2+x)C(u,x)]}{2x}\}. \end{aligned}$$

The numerical results are shown in Table 2. One can see, our predictions are closer to the results of [10]. The value of the decay constant f_H being dependent on heavy quark mass is changed within 20%.

Table 2. Leptonic decay constants $f_H(H = D.B)$.

References	f_D, Mev	f_B, Mev
M.Suzuki [9]	117 ± 14	75 ± 9
E.Shuryak [2]	220	140
V.Chernyak [3]	160	90
V.Aliev et al. [4]	170	130
C.A.Dominguez et al. [5]	224 ± 26	145-211
S.Narison [6]	173 ± 16	182 ± 18
C.Bernard et al. [7]	$174 \pm 26 \pm 46$	$105 \pm 17 \pm 30$
P.Cea et al. [10]	182	231
QCM ($M_c = 1.4 \pm .1$, $M_b = 4.5 \pm .1$)	142 ± 20	174 ± 20

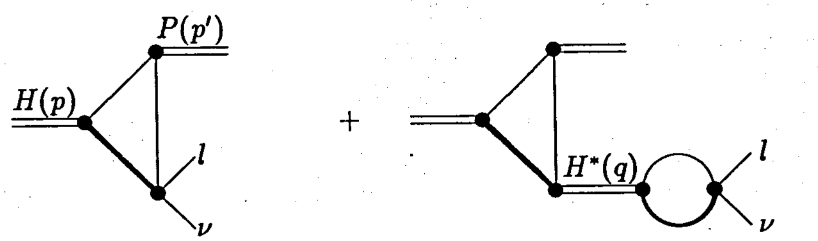

Fig.4. Diagrams describing semileptonic decay of B and D mesons.

The semileptonic weak decay $H \to Pe\nu (P = K, \pi)$ is defined by the diagram in Fig.4. After cumbersome calculations we have the following expression for the matrix element:

$$M(H \to Pe\nu) = \frac{G}{\sqrt{2}} V_{qQ}(\bar{l}O^\mu \nu_l)[(p+p')^\mu f_+(t) + q^\mu f_-(t)]\,, \qquad (15)$$

where $q = p - p'$, $t = q^2$. The weak form factors $f_\pm(t)$ are written as

$$\begin{aligned} f_+(t) \;&=\; \frac{3 g_H g_P}{(2\pi)^2} I^+_{PPV}(p^2,p'^2,t)\frac{I^{(1)}_{VV}(m_V^2)}{[I^{(1)}_{VV}(m_V^2) - I^{(1)}_{VV}(t)]}, \qquad (16) \\ f_-(t) \;&=\; f_+(t)\frac{1}{[I^{(1)}_{VV}(m_V^2) - I^{(1)}_{VV}(t) - tI^{(2)}_{VV}(t)]} \\ &* \;\; \{(p^2 - p'^2) + [I^{(1)}_{VV}(m_V^2) - I^{(1)}_{VV}(t)]\frac{I^-_{PPV}(p^2,p'^2,t)}{I^+_{PPV}(p^2,p'^2,t)}\}. \end{aligned}$$

The structure integrals $I^\pm_{PPV}$ and $I^{1,2}_{VV}$ are shown in Appendix.
The decay width is calculated by the standard formula:

$$\Gamma(H \to Pe\nu) = \frac{G}{192\pi^3}\frac{|V_{qQ}|^2}{m_H^3}\int\limits_0^{t_-} |f_+(t)|^2[(t-t_+)(t-t_-)]^{\frac{3}{2}}, \qquad (17)$$

where $t_\pm = (m_H \pm m_P)^2$.

The special interest in our approach is a consideration of the decay $B \to De\nu$ (see, Fig.5) because two heavy quarks come to the

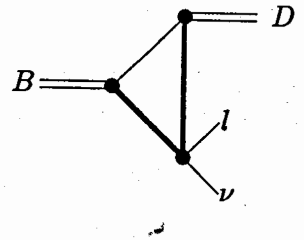

Fig.5. Diagrams describing decay $B \to Dl\nu$

quark loop. It this case, the threshold singularities corresponding to production of b and c quarks may appear at $t \geq (M_b + M_c)^2$. But due to the kinematics of the decay this threshold cannot be reached because $t_{max} = (m_B - m_D)^2 < (M_b + M_c)^2$. Therefore, we calculate the amplitude of this decay according to our ansatz (3) using the free quark propagators for heavy quarks.

The numerical results for $f_+(0)$ are shown in Table 3. We give results for both zero masses of final light mesons and physical ones. The values of $f_+(0)$ obtained in our approach are larger than other estimates. Our results are closer to the predictions of [15].

The values $\Gamma/|V|^2$ are shown in Table 4. Using the available experimental data

$$\Gamma(D^0 \to Ke\nu) = (6.5 \pm 1.1)10^{-14} Gev [24]$$

$$\Gamma(B^0 \to De\nu) = (4.9 \pm 1.6)10^{-14} Gev [26]$$

we estimate the $|V_{cs}|$ and $|V_{cb}|$. The results are in Table 4.

Table 3. Weak form factors at zero momentum.

References	$D\pi$	DK	$B\pi$	BD
[17]	0.77 ± 0.04	0.77 ± 0.04		
[13]	0.69-0.78	0.76-0.82	0.33-0.39	0.7
[14,15]	0.75 ± 0.05	0.75 ± 0.05	0.4 ± 0.1	
[23]	0.72	0.72	0.3-0.4	
[25]				$1. \pm 0.2$
UCLA [16]	0.63 ± 0.15	0.75 ± 0.20		
ELC [16]	0.70 ± 0.20	0.74 ± 0.17		
QCM:				
$m_{\pi,K} = 0$	0.89 ± 0.03	0.89 ± 0.03	0.65 ± 0.03	0.95 ± 0.15
phys. $m_{\pi,K}$	0.90 ± 0.03	1.00 ± 0.05	0.65 ± 0.03	0.95 ± 0.15

Table 4. Widths of semileptonic decays.

Ref.	$D\pi$	DK	$B\pi$	BD
	$\frac{\Gamma}{\lvert V\rvert^2} 10^{-14} Gev$		$\frac{\Gamma}{\lvert V\rvert^2} 10^{-12} Gev$	
[15]	9.4-13.9	5.4-7.5 $\lvert V\rvert_{cs} =$ $0.92 - 0.96$	4.2-6.6	5.3-5.4 $\lvert V_{cb}\rvert =$ 0.042 ± 0.008
[16,17]	11.3 ± 0.6	7.0 ± 0.5 $\lvert V_{cs}\rvert =$ 0.96 ± 0.12	9.5 ± 3.0	
[25]				9.2 ± 1.8 $\lvert V_{cb}\rvert =$ 0.034 ± 0.008
QCM: $m_{\pi,K} = 0$	12.2 ± 0.6	8.0 ± 0.3 $\lvert V_{cs}\rvert =$ 0.9 ± 0.08	16.6 ± 2.0	8.9 ± 1.6
phys. $m_{\pi,K}$	15.2 ± 0.6	11.0 ± 0.5 $\lvert V_{cs}\rvert =$ 0.076 ± 0.01	16.6 ± 2.0	$\lvert V_{cb}\rvert =$ 0.035 ± 0.008

5. Conclusion

We have developed the scheme based on the confinement hypothesis of light quarks and factorization of heavy ones which allows one to calculate hadron matrix elements from unique point of view. The leptonic decay constants, semileptonic form factors and decay widths of heavy mesons are calculated. Our results are in agreement with other approaches and available experimental data. In future, we are planning to consider the $B^0 - \bar{B}^0$ ($D^0 - \bar{D}^0$)-mixing and nonleptonic decays of heavy mesons in the framework of our approach.

Acknowledgements

We would like to thank G.V.Efimov and S.B.Gerasimov for many interesting discussions.

Appendix

The structure integrals defining the $H \to Pl\nu$-decay are

$$I^\mu(p,p') = \int \frac{d^4k}{4\pi^2 i} \int d\sigma_v tr[\gamma^\mu \frac{1}{M_Q - \hat{k} - \hat{p}} \gamma^5 \frac{1}{\Lambda_q v - \hat{k}} \gamma^5 \frac{1}{\Lambda_q v - \hat{k} - \hat{p}'}] =$$

$$= (p+p')^\mu I^+_{PPV}(\frac{p^2}{\Lambda_q^2}, \frac{p'^2}{\Lambda_q^2}, \frac{q^2}{\Lambda_q^2}) + q^\mu I^-_{PPV}(\frac{p^2}{\Lambda_q^2}, \frac{p'^2}{\Lambda_q^2}, \frac{q^2}{\Lambda_q^2})$$

$$I^+_{PPV}(p^2, p'^2, q^2) = \frac{1}{2} \int_0^1 d\alpha \{ z I_S^{a_1}(W_\alpha, P_\alpha^2) + I_0^b(W_\alpha) -$$

$$- \; z^2 I_S^{b_1}(W_\alpha, P_\alpha^2) - [(1-\alpha)p^2 + \alpha q^2] I_V^{b_1}(W_\alpha, P_\alpha^2)\},$$

$$I^-_{PPV}(p^2, p'^2, q^2) = -I_V^b(q^2) - \frac{1}{2} \int_0^1 d\alpha \{ z I_S^{a_1}(W_\alpha, P_\alpha^2) + I_0^b(W_\alpha) -$$

$$- \; z^2 I_S^{b_1}(W_\alpha, P_\alpha^2) - [(1-\alpha)p^2 + \alpha q^2 - 2\alpha p'^2] I_V^{b_1}(W_\alpha, P_\alpha^2)\}.$$

Here, $W_\alpha = \alpha(1-\alpha)p'^2$; $P_\alpha^2 = (1-\alpha)p^2 - \alpha(1-\alpha)p'^2 + \alpha q^2$.

$$I_0^b(y) = B_0 + \frac{y}{4} \int_0^1 du b(-u\frac{y}{4})\sqrt{1-u};$$

$$I_V^b(x) = \int_0^\infty du b(u) \frac{[u - (u + z^2 + x)C(u,x)]}{2x};$$

$$I_S^{a_1}(y,x) = \int_0^\infty du a(u-y) C'_u(u,x);$$

$$I_S^{b_1}(y,x) = \int_0^\infty du b(u-y) C'_u(u,x);$$

$$I_V^{b_1}(y,x) = \int_0^\infty du b(u-y) \frac{[1 - C(u,x) - (u + x + z^2)C'_u(u,x)]}{2x}.$$

The structure integrals defining the two-point vector-vector loop are

$$I_{VV}^{\mu\nu}(p) = \int \frac{d^4k}{4\pi^2 i} \int d\sigma_v tr[\gamma^\mu \frac{1}{M_Q - \hat{k} + \hat{p}} \gamma^\nu \frac{1}{\Lambda_q v - \hat{k}}] =$$

$$= g^{\mu\nu} I_{VV}^{(1)}(\frac{p^2}{\Lambda_q^2}) + \frac{p^\mu}{\Lambda_q} \frac{p^\nu}{\Lambda_q} I_{VV}^{(2)}(\frac{p^2}{\Lambda_q^2});$$

$$I_{VV}^{(1)}(x) = B_1 + z I_S^a(x) - z^2 I_S^b(x) - x I_V^b(x) + 2 I_{T1}^b(x);$$

$$I_{VV}^{(2)}(x) = I_V^b(x) + I_{T2}^b(x).$$

$$I_S^f(x) = \int_0^\infty du f(u) C(u,x);$$

$$I_V^f(x) = \int_0^\infty du f(u) \frac{[u - (u + z^2 + x)C(u,x)]}{2x};$$

$$I^f_{T1}(x) = \int_0^\infty du f(u) \frac{\{u(u+z^2-x) - [(u+z^2-x)^2 + 4ux]C(u,x)\}}{12x};$$

$$I^f_{T2}(x) = \int_0^\infty du f(u) \frac{\{-u(u+z^2+2x) + [(u+z^2+x)^2 - xz^2]C(u,x)\}}{3x^2}.$$

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Received by Publishing Department
on April 25, 1990.