where the $L_\mu$ are matrices satisfying (48). Thus the problem of finding the possible equations for elementary particles reduces to the problem of finding the possible non-completely-reducible representations of type (44) with $M^{(1)}_{\mu\nu} = M^{(2)}_{\mu\nu}$.


[1] Iu. M. Shirokov, J. Exptl. Theoret. Phys. (U.S.S.R.) **33**, 861 (1957), Soviet Phys. JETP **6**, 664 (1958).

[2] Iu. M. Shirokov, J. Exptl. Theoret. Phys. (U.S.S.R.) **33**, 1196 (1957), Soviet Phys. JETP, this issue, p. 919.

[3] E. P. Wigner, Ann. of Math. 40, 149 (1939).

[4] L. S. Pontriagin, Непрерывные группы (Continuous Groups), 2nd ed., Moscow, GITTL, 1954. (See also the English translation of the 1st edition: Topological Groups, Princeton University Press, 1946.)

[5] I. M. Gel'fand and A. M. Naimark, Journ. of Phys. (U.S.S.R.) **10**, 93 (1946); M. A. Naimark, Usp. Mat. Nauk 9, 19 (1954), (Translation in Amer. Math. Soc. Translations, Ser. 2, Vol. 6, 1957.)

[6] F. D. Murnaghan, Theory of Group Representations, Johns Hopkins Press, 1938.

[7] I. M. Gel'fand and A. M. Iaglom, J. Exptl. Theoret. Phys. (U.S.S.R.) **18**, 703 (1948); H. J. Bhabha, Revs. Mod. Phys. **21**, 451 (1949).


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# *EQUATIONS FOR THE GREEN'S FUNCTIONS OF A SYSTEM OF FUNDAMENTAL PARTICLES*

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Green's functions for fundamental particles are introduced. On the basis of Lagrangians describing all strong interactions of mesons and baryons, closed systems of equations for the Green's functions are obtained in variational derivatives with respect to the external currents, in both three-dimensional and four-dimensional isotopic spin space.

THE scheme of Gell-Mann[1] for the description of heavy mesons and hyperons is well confirmed by the experimental data. On the basis of this scheme d'Espagnat and Prentki,[2,3] Salam,[4] Matthews and Salam,[5] and others have constructed Lagrangians that describe all the strong interactions of the fundamental particles.

The purpose of the present work is to obtain a complete system of equations for the Green's functions of the fundamental particles.

## 1. THE INTERACTION LAGRANGIAN. THE GREEN'S FUNCTIONS

Let us consider all the strong interactions of mesons and baryons. Let the spinors $\Lambda(x)$, $\Sigma(x)$, $\Xi(x)$, and $N(x)$ describe $\Lambda$, $\Sigma$, and $\Xi$ hyperons and nucleons, and let the pseudoscalar $\varphi(x)$ and the scalar $k_1(x)$ describe $\pi$ and K mesons, respectively. Furthermore we assume that in the isotopic spin space $\Lambda$ is a scalar, $\varphi = \begin{pmatrix}\varphi_1\\ \varphi_2\\ \varphi_3\end{pmatrix}$ and $\Sigma = \begin{pmatrix}\Sigma_1\\ \Sigma_2\\ \Sigma_3\end{pmatrix}$ are pseudovectors, $N = \begin{pmatrix}p\\ n\end{pmatrix}$ and $k_1 = \begin{pmatrix}k^+\\ k^0\end{pmatrix}$ are spinors of the first kind, and $\Xi = \begin{pmatrix} \Xi^0 \\ \Xi^- \end{pmatrix}$ are spinors of the second kind.[2]

On the basis of Ref. 4 we write the interaction Lagrangian in the following form:

$$L(x) = g_1 : \overline{N}^{\mathrm{T}}(x)\gamma_5\tau^l\varphi^l(x)N(x) : + g_2 : \overline{\Lambda}(x)\gamma_5\varphi^l(x)\Sigma^l(x) + \overline{\Sigma}^l(x)\varphi^l(x)\gamma_5\Lambda(x) : + g_3\frac{1}{2i}\,\mathrm{Tr}\,(\tau^i\tau^k\tau^l) : \overline{\Sigma}^i(x)\gamma_5\varphi^k(x)\Sigma^l(x) :$$
$$+ g_4 : \overline{\Xi}^{\mathrm{T}}(x)\gamma_5\tau^l\varphi^l(x)\Xi(x) : + g_5 : \overline{N}^{\mathrm{T}}(x)\theta(x)\Lambda(x) + \overline{\Lambda}(x)\theta^{*\mathrm{T}}(x)N(x) : + g_6 : \overline{N}^{\mathrm{T}}(x)\tau^l\Sigma^l(x)\theta(x) + \theta^{*\mathrm{T}}(x)\overline{\Sigma}^l(x)\tau^l N(x) :$$
$$+ g_7 : \overline{\Xi}^{\mathrm{T}}(x)\tau_2\theta^*(x)\Lambda(x) + \overline{\Lambda}(x)\theta^{\mathrm{T}}(x)\tau_2\Xi(x) : + g_8 : \overline{\Xi}^{\mathrm{T}}(x)\tau_2\tau^l\Sigma^l(x)\theta^*(x) + \theta^{\mathrm{T}}(x)\tau^l\overline{\Sigma}^l(x)\tau_2\Xi(x) :, \tag{1}$$

where $\overline{\Psi} = \Psi^+\gamma_4$, the sign $^{\mathrm{T}}$ means transposition in the isotopic spin space, $*$ means the complex conjugate, and the matrices $\gamma$ are those of Feynman; $\theta$ and $\theta^*$ are constructed from $k_1 = \begin{pmatrix} k^+ \\ k^0 \end{pmatrix}$ and $\tilde{k}_1 = \begin{pmatrix} \tilde{k}^0 \\ \tilde{k}^- \end{pmatrix}$.[3] The summation over Latin indices is taken from 1 to 3, that over Greek indices from 1 to 4. The sign Sp means that the trace of the Dirac matrices is to be taken, and Tr means the trace of the isotopic spin matrices.

Let us also add to the Lagrangian (1) terms containing external currents, $I^l(x)$ for the $\pi$-meson field, and $\eta(x)$ and $\eta^*(x)$ for the K-meson field, namely the terms

$$L'(x) = I^l(x)\varphi^l(x) + \theta^{\mathrm{T}*}(x)\eta(x) + \eta^{*\mathrm{T}}(x)\theta(x). \tag{2}$$

Besides the ordinary Green's functions

$$G_N(x, y) = i\,\langle T\{N(x)\overline{N}^{\mathrm{T}}(y)S\}\rangle_0/\langle S\rangle_0 \tag{3}$$

and so on, let us introduce generalized Green's functions in which the external lines belong to different particles, namely

$$G_{N\Lambda}(x, y) = i\,\langle T\{N(x)\overline{\Lambda}(y)S\}\rangle_0/\langle S\rangle_0 \tag{4}$$

and so on.

The variational derivatives of these generalized Green's functions with respect to the external fields determine the cross-sections for the corresponding processes. For example, the transition amplitude for the process $\pi^- + p \rightarrow \Lambda + K_0$ is proportional to[6]

$$\int_{C_1} dp_1^0 \int_{C_2} dp_2^0\, \overline{U}(\mathbf{p}_2)\left\{\frac{\delta^2 G_{\Lambda N}(-p_1, -p_2)}{\delta\Phi^*(-k_1)\delta\Theta(k_2)}\right\}_{\Phi=\Theta=0} U(\mathbf{p}_1), \tag{5}$$

where the integration with respect to $p_1^0$ and $p_2^0$ is carried out along closed contours enclosing the points $p_1 = [\mathbf{p}_1^2 + m_N^2]^{\frac{1}{2}}$ and $p_2 = [\mathbf{p}_2^2 + m_\Lambda^2]^{\frac{1}{2}}$ and $\overline{U} = U^+\gamma_4$ and $U$ are spinor functions. The variational derivatives are taken with respect to the external fields, which we define as follows:

$$\Phi^l(x) = \langle T\{\varphi^l(x)S\}\rangle_0/\langle S\rangle_0, \tag{6}$$
$$\Theta(x) = \langle T\{\theta(x)S\}\rangle_0/\langle S\rangle_0\,. \tag{6'}$$

## 2. THE COMPLETE SYSTEM OF EQUATIONS FOR THE GREEN'S FUNCTIONS

In the derivation of the equations for the Green's functions we use the generalization given by N. N. Bogoliubov of Wick's theorem on the development of T-products of field operators. We assume that the spinors describing different fields anticommute. Confining ourselves to the strong interactions given by Eq. (1), we find the following system of equations for the Green's functions in variational derivatives with respect to the external currents:

$$\left\{-i\gamma_\mu\frac{\partial}{\partial x_\mu} + m_N - g_1\gamma_5\tau^l\left(\Phi^l(x) - i\frac{\delta}{\delta I^l(x)}\right)\right\}G_N(x, y) = \delta(x - y)$$
$$- g_5\left(\Theta(x) - i\frac{\delta}{\delta\eta^{*\mathrm{T}}(x)}\right)G_{\Lambda N}(x, y) - g_6\tau^l\left(\Theta(x) - i\frac{\delta}{\delta\eta^{*\mathrm{T}}(x)}\right)G_{\Sigma N}^l(x, y)\,; \tag{7}$$

$$\left\{-i\gamma_\mu \frac{\partial}{\partial x_\mu} + m_\Xi - g_4\gamma_5\tau^l\left(\Phi^l(x) - i\frac{\delta}{\delta I^l(x)}\right)\right\} G_\Xi(x, y) = \delta(x-y)$$
$$- g_7\tau_2\left(\Theta^*(x) + i\frac{\delta}{\delta\eta^{\mathrm{T}}(x)}\right) G_{\Lambda\Xi}(x, y) - g_8\tau_2\tau^l\left(\Theta^*(x) + i\frac{\delta}{\delta\eta^{\mathrm{T}}(x)}\right) G^l_{\Sigma\Xi}(x, y); \qquad (8)$$

$$\left\{\left(-i\gamma_\mu \frac{\partial}{\partial x_\mu} + m_\Sigma\right)\delta_{il} - \frac{g_3}{2i}\mathrm{Tr}\,(\tau^i\tau^m\tau^l)\,\gamma_5\left(\Phi^m(x) - i\frac{\delta}{\delta I^m(x)}\right)\right\} G^{lk}_\Sigma(x, y) = \delta(x-y) + g_2\gamma_5\left(\Phi^i(x) - i\frac{\delta}{\delta I^i(x)}\right) G^k_{\Lambda\Sigma}(x, y)$$
$$- g_6\left(\Theta^{*\mathrm{T}}(x) + i\frac{\delta}{\delta\eta(x)}\right)\tau^i G^k_{N\Sigma}(x, y) - g_8\left(\Theta^{\mathrm{T}}(x) - i\frac{\delta}{\delta\eta^*(x)}\right)\tau^i\tau_2 G^k_{\Xi\Sigma}(x, y); \qquad (9)$$

$$\left\{-i\gamma_\mu \frac{\partial}{\partial x_\mu} + m_\Lambda\right\} G_\Lambda(x, y) = \delta(x-y) + g_2\gamma_5\left(\Phi^l(x) - i\frac{\delta}{\delta I^l(x)}\right) G^l_{\Sigma\Lambda}(x, y)$$
$$+ \left(\Theta^{*\mathrm{T}}(x) + i\frac{\delta}{\delta\eta(x)}\right)[g_5 G_{N\Lambda}(x, y) + g_7\tau_2 G_{\Xi\Lambda}(x, y)]; \qquad (10)$$

$$\left\{-i\gamma_\mu \frac{\partial}{\partial x_\mu} + m_N - g_1\gamma_5\tau^l\left(\Phi^l(x) - i\frac{\delta}{\delta I^l(x)}\right)\right\} G_{N\Lambda}(x, y)$$
$$= g_5\left(\Theta(x) - i\frac{\delta}{\delta\eta^{*\mathrm{T}}(x)}\right) G_\Lambda(x, y) + g_6\tau^l\left(\Theta(x) - i\frac{\delta}{\delta\eta^{*\mathrm{T}}(x)}\right) G^l_{\Sigma\Lambda}(x, y)]; \qquad (11)$$

$$\left\{-i\gamma_\mu \frac{\partial}{\partial x_\mu} + m_N - g_1\gamma_5\tau^k\left(\Phi^k(x) - i\frac{\delta}{\delta I^k(x)}\right)\right\} G^l_{N\Sigma}(x, y)$$
$$= g_5\left(\Theta(x) - i\frac{\delta}{\delta\eta^{*\mathrm{T}}(x)}\right) G^l_{\Lambda\Sigma}(x, y) + g_6\tau^k\left(\Theta(x) - i\frac{\delta}{\delta\eta^{*\mathrm{T}}(x)}\right) G^{kl}_\Sigma(x, y); \qquad (12)$$

$$\left\{-i\gamma_\mu \frac{\partial}{\partial x_\mu} + m_\Lambda\right\} G^l_{\Lambda\Sigma}(x, y) = g_2\gamma_5\left(\Phi^k(x) - i\frac{\delta}{\delta I^k(x)}\right) G^{kl}_\Sigma(x, y) + g_5\left(\Theta^{*\mathrm{T}}(x) + i\frac{\delta}{\delta\eta(x)}\right) G^l_{N\Sigma}(x, y)$$
$$- g_7\left(\Theta^{\mathrm{T}}(x) - i\frac{\delta}{\delta\eta^*(x)}\right)\tau_2 G^l_{\Xi\Sigma}(x, y); \qquad (13)$$

$$\left\{-i\gamma_\mu \frac{\partial}{\partial x_\mu} + m_\Xi - g_4\gamma_5\tau^l\left(\Phi^l(x) - i\frac{\delta}{\delta I^l(x)}\right)\right\} G_{\Xi\Lambda}(x, y)$$
$$= g_7\tau_2\left(\Theta^*(x) + i\frac{\delta}{\delta\eta^{\mathrm{T}}(x)}\right) G_\Lambda(x, y) + g_8\tau_2\tau^l\left(\Theta^*(x) + i\frac{\delta}{\delta\eta^{\mathrm{T}}(x)}\right) G^l_{\Sigma\Lambda}(x, y); \qquad (14)$$

$$\left\{-i\gamma_\mu \frac{\partial}{\partial x_\mu} + m_\Xi - g_4\gamma_5\tau^k\left(\Phi^k(x) - i\frac{\delta}{\delta I^k(x)}\right)\right\} G^l_{\Xi\Sigma}(x, y)$$
$$= g_7\tau_2\left(\Theta^*(x) + i\frac{\delta}{\delta\eta^{\mathrm{T}}(x)}\right) G^l_{\Lambda\Sigma}(x, y) + g_8\tau_2\tau^k\left(\Theta^*(x) + i\frac{\delta}{\delta\eta^{\mathrm{T}}(x)}\right) G^{k,l}_\Sigma(x, y); \qquad (15)$$

$$(\Box - \mu_\pi^2)\,\Phi^l(x) = -I^l(x) + ig_1\,\mathrm{Sp}\,\mathrm{Tr}\,\gamma_5\tau^l G_N(x, x) - ig_2\,\mathrm{Sp}\,\mathrm{Tr}\,\gamma_5 G^l_{\Sigma\Lambda}(x, x) - ig_2\,\mathrm{Sp}\,\mathrm{Tr}\,\gamma_5 G^l_{\Lambda\Sigma}(x, x)$$
$$- \frac{g_3}{2}\,\mathrm{Tr}\,(\tau^i\tau^l\tau^k)\,\mathrm{Sp}\,\mathrm{Tr}\,\gamma_5 G^{ki}_\Sigma(x, x) - ig_4\,\mathrm{Sp}\,\mathrm{Tr}\,\gamma_5\tau^l G_\Xi(x, x); \qquad (16)$$

$$(\Box - \mu_K^2)\Theta(x) = -\eta(x) - ig_5\,\mathrm{Sp}\,G_{N\Lambda}(x, x) - ig_6\,\mathrm{Sp}\,\tau^l G^l_{N\Sigma}(x, x) - ig_7\,\mathrm{Sp}\,\tau_2 G^{(\mathrm{T})}_{\Lambda\Xi}(x, x) + ig_8\,\mathrm{Sp}\,\tau_2\tau^l G^{l(\mathrm{T})}_{\Sigma\Xi}(x, x). \qquad (17)$$

The equations for $G_{\Lambda N}(x, y)$, $G^l_{\Sigma\Xi}(x, y)$, $G^l_{\Sigma\Lambda}(x, y)$, $G_{\Lambda\Xi}(x, y)$, and $G^l_{\Sigma\Xi}(x, y)$ are analogous to Eqs. (11), (12), (13), (14), and (15). It is not hard to obtain them if we apply the appropriate operators acting from the right on the variable y; for example, we find the equation for $G_{\Lambda N}(x, y)$ in the form

$$G_{\Lambda N}(x, y)\left\{i\gamma_\mu \frac{\overleftarrow{\partial}}{\partial y_\mu} + m_N - g_1\gamma_5\tau^l\left(\Phi^l(y) - i\frac{\delta}{\delta I^l(y)}\right)\right\} = \left(\Theta^{*\mathrm{T}}(y) + i\frac{\delta}{\delta\eta(y)}\right)[g_5 G_\Lambda(x, y) + g_6\tau^l G^l_{\Lambda\Sigma}(x, y)]. \qquad (11')$$

The functions $G^{(\mathrm{T})}_{\Xi\Lambda}(x, y) = i\langle T\{\Xi^{\mathrm{T}}(x)\Lambda(y)S\}\rangle_0/\langle S\rangle_0$, $G^{(\mathrm{T})}_{\Lambda\Xi}(x, y)$, $G^{l(\mathrm{T})}_{\Xi\Sigma}(x, y)$, and $G^{l(\mathrm{T})}_{\Sigma\Xi}(x, y)$ satisfy equations obtained from Eqs. (14) and (15) by carrying out transpositions in the isotopic spin space.

The system of equations (7) — (17) is a closed one. This system of equations is exact; it does not involve any approximations.

The system (7) — (17) must be supplemented if in addition to the scalar $\theta$ mesons there are also pseudoscalar $\tau$ mesons. Some of the equations are considerably changed in case the hyperons (for example $\Sigma$) turn out to have spin greater than $\frac{1}{2}$.

It is easy to obtain from the complete system of equations (7) — (17) the partial closed system essential to the treatment of any given concrete process, if one confines oneself to part of the terms of the Lagrangian (1).

## 3. THE EQUATIONS FOR THE GREEN'S FUNCTIONS IN THE FOUR-DIMENSIONAL ISOTOPIC SPIN SPACE

The system of equations (7) — (17) for the Green's functions not only is very cumbersome, but also contains eight independent interaction constants. To reduce the number of coupling constants, Matthews and Salam[5] have formally expressed all the strong interactions in a four-dimensional isotopic spin space, without making any essential change in the d'Espagnat-Prenkti formulation of the Gell-Mann scheme. We shall use the interaction Lagrangian obtained in Ref. 5 to find the equations for the Green's functions in a compact form containing only three independent coupling constants.

For this purpose we introduce the following isotopic spinors

$$\Psi = \begin{pmatrix} N \\ \Xi \end{pmatrix}, \quad \mathscr{K} = \begin{pmatrix} \theta \\ \tilde{\theta} \end{pmatrix}$$

and tensors
$$\Sigma_{\mu\nu} = \begin{pmatrix} \Lambda & -i\Sigma_3 & i\Sigma_2 & 0 \\ i\Sigma_3 & \Lambda & -i\Sigma_1 & 0 \\ -i\Sigma_2 & i\Sigma_1 & \Lambda & 0 \\ 0 & 0 & 0 & \Lambda \end{pmatrix},$$

$$\pi_{\mu\nu} = \begin{pmatrix} 0 & -i\varphi_3 & i\varphi_2 & 0 \\ i\varphi_3 & 0 & -i\varphi_1 & 0 \\ -i\varphi_2 & i\varphi_1 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix},$$

where $\theta = \begin{pmatrix} \theta_1 \\ \theta_2 \end{pmatrix}$, $\tilde{\theta} = \begin{pmatrix} \theta_2^* \\ \theta_1^* \end{pmatrix}$.

We write the interaction Lagrangian in the form

$$L(x) = \frac{f_1}{2} : \overline{\Psi}^{\mathrm{T}}(x)\,\Gamma_4\Gamma_\mu\Gamma_\nu\mathscr{K}(x)\,\Sigma_{\mu\nu}(x) + \overline{\Sigma}_{\nu\mu}(x)\,\mathscr{K}^{*\mathrm{T}}(x)\,\Gamma_\nu\Gamma_\mu\Gamma_4\Psi(x) : + \frac{f_2}{2} : \overline{\Psi}^{\mathrm{T}}(x)\,\Gamma_4\Gamma_\mu\Gamma_\nu\gamma_5\Psi(x) : \pi_{\mu\nu}(x)$$
$$+ \frac{f_3}{2}\,\mathrm{Sp}\,\gamma_\mu\gamma_\nu\gamma_\rho\gamma_\sigma\gamma_\alpha\gamma_\beta : \overline{\Sigma}_{\mu\nu}(x)\,\gamma_5\Sigma_{\rho\sigma}(x)\,\pi_{\alpha\beta}(x) : + \frac{1}{2} I_{\mu\nu}(x)\,\pi_{\mu\nu}(x) + H^{*\mathrm{T}}(x)\,\mathscr{K}(x) + \mathscr{K}^{*\mathrm{T}}(x)\,H(x). \tag{18}$$

Here the $\Gamma$ are matrices in the four-dimensional isotopic spin space, and

$$\Gamma_\mu\Gamma_\nu + \Gamma_\nu\Gamma_\mu = \delta_{\mu\nu}, \quad \Gamma_k = \begin{pmatrix} \tau^k & 0 \\ 0 & \tau^k \end{pmatrix}, \quad \Gamma_4 = \begin{pmatrix} I & 0 \\ 0 & -I \end{pmatrix}.$$

We determine the Green's functions from

$$G(x, y) = i\langle T\{\Psi(x)\,\overline{\Psi}^{\mathrm{T}}(y)\,S\}\rangle_0 / \langle S\rangle_0 = i\frac{1}{\langle S\rangle_0}\langle T\left\{\begin{pmatrix} N(x)\,\overline{N}^{\mathrm{T}}(y) & N(x)\,\overline{\Xi}^{\mathrm{T}}(y) \\ \Xi(x)\,N^{\mathrm{T}}(y) & \Xi(x)\,\overline{\Xi}^{\mathrm{T}}(y) \end{pmatrix} S\right\}\rangle_0; \tag{19}$$

$$G_{\mu\nu;\rho\sigma}(x, y) = i\langle T\{\Sigma_{\mu\nu}(x)\,\overline{\Sigma}_{\rho\sigma}(y)\,S\}\rangle_0 / \langle S\rangle_0; \tag{20}$$

$$G^{\mu\nu}_{\Psi\Sigma}(x, y) = i\langle T\{\Psi(x)\,\overline{\Sigma}_{\mu\nu}(y)\,S\}\rangle_0 / \langle S\rangle_0; \tag{21}$$

$$G^{\mu\nu}_{\Sigma\Psi}(x, y) = i\langle T\{\Sigma_{\mu\nu}(x)\,\overline{\Psi}^{\mathrm{T}}(y)\,S\}\rangle_0 / \langle S\rangle_0; \tag{21'}$$

$$\Pi_{\mu\nu}(x) = \langle T\{\pi_{\mu\nu}(x)\,S\}\rangle_0 / \langle S\rangle_0; \tag{22}$$

$$K(x) = \langle T\{\mathcal{K}(x)S\}\rangle_0 / \langle S\rangle_0; \tag{23}$$

$$K^*(x) = \langle T\{\mathcal{K}^*(x)S\}\rangle_0 / \langle S\rangle_0. \tag{23'}$$

We obtain the complete system of equations for the Green's functions of the fundamental particles in the following form:

$$\left\{-i\gamma_{\mu'}\frac{\partial}{\partial x_{\mu'}} + M - \frac{f_2}{2}\Gamma_4\Gamma_\mu\Gamma_\nu\gamma_5\left(\Pi_{\mu\nu}(x) - 2i\frac{\delta}{\delta I_{\mu\nu}(x)}\right)\right\}G(x,y) = \delta(x-y) - \frac{f_1}{2}\Gamma_4\Gamma_\mu\Gamma_\nu\left(K(x) - i\frac{\delta}{\delta H^{*T}(x)}\right)G^{\mu\nu}_{\Sigma\Psi}(x,y); \tag{24}$$

$$\left\{-i\gamma_{\mu'}\frac{\partial}{\partial x_{\mu'}} + M - \frac{f_2}{2}\Gamma_4\Gamma_\rho\Gamma_\sigma\gamma_5\left(\Pi_{\rho\sigma}(x) - 2i\frac{\delta}{\delta I_{\rho\sigma}(x)}\right)\right\}G^{\mu\nu}_{\Psi\Sigma}(x,y) = \frac{f_1}{2}\Gamma_4\Gamma_\rho\Gamma_\sigma\left(K(x) - i\frac{\delta}{\delta H^{*T}(x)}\right)G_{\rho\sigma;\mu\nu}(x); \tag{25}$$

$$G^{\mu\nu}_{\Sigma\Psi}(x,y)\left\{i\gamma_{\mu'}\overleftarrow{\frac{\partial}{\partial y_{\mu'}}} + M - \frac{f_2}{2}\Gamma_4\Gamma_\rho\Gamma_\sigma\gamma_5\left(\Pi_{\rho\sigma}(y) - 2i\,i\frac{\delta}{\delta I_{\rho\sigma}(y)}\right)\right\} = \frac{f_1}{2}\left(K^{*T}(y) + i\frac{\delta}{\delta H(y)}\right)\Gamma_\rho\Gamma_\sigma\Gamma_4 G_{\mu\nu;\rho\sigma}(x,y); \tag{25'}$$

$$\begin{gathered}\left\{\left(-i\gamma_{\mu'}\frac{\partial}{\partial x_{\mu'}} + M_1\right)\delta_{\alpha\beta} - \frac{f_3}{2}\,\mathrm{Sp}\,(\gamma_\pi\gamma_\tau\gamma_\alpha\gamma_\beta)\,\gamma_5\left(\Pi_{\pi\tau}(x) - 2i\frac{\delta}{\delta I_{\pi\tau}(x)}\right)\right\}G_{\alpha\beta,\rho\sigma}(x,y) \\ = 4\delta_{\rho\sigma}\delta(x-y) + 8f_1\left(K^{*T}(x) + i\frac{\delta}{\delta H(x)}\right)\Gamma_4 G^{\rho\sigma}_{\Psi\Sigma}(x,y);\end{gathered} \tag{26}$$

$$\begin{gathered}\left\{\left(-i\gamma_{\mu'}\frac{\partial}{\partial x_{\mu'}} + M_1'\right)(\Gamma_\alpha\Gamma_\beta - \delta_{\alpha\beta}) + \frac{f_3}{16}(\Gamma_m\Gamma_n - \delta_{mn})\,\mathrm{Sp}\,[(\gamma_m\gamma_n - \delta_{mn})\gamma_\pi\gamma_\tau\gamma_\alpha\gamma_\beta]\gamma_5\left(\Pi_{\pi\tau}(x) - 2i\frac{\delta}{\delta I_{\pi\tau}(x)}\right)\right\}G_{\alpha\beta;\rho\sigma}(x,y) \\ = 2(\delta_{\rho\sigma} - \Gamma_\rho\Gamma_\sigma)\,\delta(x-y) - 2f_1\Gamma_n\left(K^{*T}(x) + i\frac{\delta}{\delta H(x)}\right)\Gamma_n G^{\rho\sigma}_{\Psi\Sigma}(x,y),\end{gathered} \tag{26'}$$

$$(\square - \mu_\pi^2)\,\Pi_{mn}(x) = -I_{mn}(x) - if_2\,\mathrm{Sp}\,\mathrm{Tr}\,\Gamma_4\Gamma_m\Gamma_n\gamma_5 G(x,x) + \frac{i}{16}f_3\,\mathrm{Sp}\,\gamma_\alpha\gamma_\beta\gamma_\rho\gamma_\sigma\gamma_m\gamma_n\cdot\mathrm{Sp}\,\mathrm{Tr}\,\gamma_5 G_{\rho\sigma;\alpha\beta}(x,x); \tag{27}$$

$$(\square - \mu_K^2)\,K(x) = -H(x) - i\frac{f_1}{2}\,\mathrm{Sp}\,\Gamma_\nu\Gamma_\mu\Gamma_4 G^{\nu\mu}_{\Psi\Sigma}(x,x). \tag{28}$$

On going over from the four-dimensional to the three-dimensional isotopic spin space the system of equations (24) — (28) goes over into a system closely similar to Eqs. (7) — (17), if in the latter we express the interaction constants $g_i$ in terms of the $f_i$ by the formulas:

$$2g_5 = -2g_7 = g_6 = -g_8 = f_1, \quad g_1 = -g_4 = f_2, \quad g_3 = g_2 = f_3.$$

[1] M. Gell-Mann and A. Pais, Proceedings of Glasgow Conference on Nuclear and Meson Physics, p. 342, 1954.
[2] B. d'Espagnat and J. Prentki, Phys. Rev. 99, 328 (1955).
[3] B. d'Espagnat and J. Prentki, Phys. Rev. 102, 1684 (1956); Nuclear Physics 1, 33 (1956).
[4] A. Salam, Nuclear Physics 2, 173 (1956).
[5] P. Matthews and A. Salam, Nuclear Physics 2, 582 (1956).
[6] V. G. Solov'ev, Dissertation, Moscow State University, 1956.

Translated by W. H. Furry
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