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x) In this connection, one should as well mention the theoretically possible states $2N2\bar{N}$ /11/ and the baryon systems 2NN /12/ having been not *searched for as yet. (Some of the data* /13/ may be considered as giving evidence in favour of the quasinuclear mesons $2N2\bar{N}$).

BILOCAL FUNCTIONAL APPROACH TO DYNAMICAL SYMMETRY-BREAKING

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Let us consider an Abelian gauge theory of massless fermions("quarks") ψ interacting with a massless neutral vector ("gluon") field A_μ. The generating functional of all Green's functions including the disconnected ones, is given by the pathintegral

$$Z(J,\eta,\bar{\eta}) = N\int DA_\mu D\psi D\bar{\psi}\, \delta[\partial_\mu A_\mu] \times$$
$$\times \exp\Big\{ i\int d^4x \big[\bar{\psi} i\hat{\partial}\psi - \tfrac{1}{4}F_{\mu\nu}^2 + g\bar{\psi}\hat{A}\psi + J_\mu A_\mu + \bar{\psi}\eta + \bar{\eta}\psi \big]\Big\} \qquad (1)$$
$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu \,, \quad \hat{A} = \gamma_\mu A_\mu$$

Here J^μ, $\bar{\eta}$, η are the external sources of the fields $A_\mu, \psi, \bar{\psi}$ and N is a normalization factor chosen such that $Z(0,0,0) = 1$. Note that the Lagrangian appearing in eq. (1) is invariant under chiral transformations $\psi \to \exp(i\gamma_5\lambda)\psi$. If we first integrate over A_μ we get a factor with the exponent ($\psi, \bar{\psi}$ are anticommuting Grassman variables)

$$\frac{i}{2}g^2\int d^4x_1 d^4y_1 d^4x_2 d^4y_2 \big[\bar{\psi}_{\alpha_1}(x_1)\psi_{\beta_1}(y_1)\big] K_{(\alpha_1\beta_1;\alpha_2\beta_2)}(x_1y_1;x_2y_2) \times \big[\bar{\psi}_{\alpha_2}(x_2)\psi_{\beta_2}(y_2)\big] \qquad (2)$$
$$\equiv \frac{i}{2}g^2\, tr\big[(\bar{\psi}\times\psi)K(\bar{\psi}\times\psi)\big]$$

where

$$K_{(\alpha_1\beta_1,\alpha_2\beta_2)}(x_1y_1;x_2y_2) = (\gamma_\mu)_{\alpha_1\beta_2} D_{\mu\nu}(x_1-x_2)(\gamma_\nu)_{\alpha_2\beta_1} \times \delta(x_1-y_2)\delta(y_1-x_2) \qquad (3)$$

Here $D_{\mu\nu}(x)$ is the propagator of a massless vector meson in the transverse Landau gauge (see ref. /1/ for its definition). We now linearize eq. (2) by a (bilocal) Gauss integration x)

x) In ref. /2/ an analogous technique has been used for a nonrelativistic system of interacting fermions and bosons.

$$\exp \frac{i}{2} g^2 tr [(\bar{q} \times q) K (\bar{q} \times q)] = [\det K^{-1}]^{1/2} \times \int \mathcal{D}\chi(x,y) \exp \{ -\frac{i}{2} tr\, \chi K^{-1} \chi - i \bar{q}_a q_b g \chi_{ab} \}_{a \equiv (\alpha, x)} \quad (4)$$

Performing the integration over the quark field and using eq. (4) the generating functional (1) reads finally

$$Z(J, \bar{\eta}, \eta) = N' \int \mathcal{D}\chi\, e^{iS(\chi)} Z(J, \bar{\eta}, \eta | \chi) \quad (5)$$

with

$$S(\chi) = tr [-\frac{1}{2} \chi K^{-1} \chi - i \ln (1 + g G_0 \chi)]$$

$$Z(J, \bar{\eta}, \eta | \chi) = \exp [-\frac{i}{2} J_\mu \cdot \mathcal{D}_{\mu\nu} \cdot J_\nu + i \bar{\eta} G(g\chi - g\hat{A}_{ext}) \eta + tr \ln (1 - g G(g\chi) \hat{A}_{ext})] \quad (6)$$

The Green's functions $G(g\chi - g\hat{A}_{ext})$ and G_0 are defined as follows $i\hat{\partial}_x G_0(x-y) = -\delta(x-y)$ and

$$(i\hat{\partial}_x + g\hat{A}_{ext}) G(x,y|g\chi - g\hat{A}_{ext}) - g \int d^4z\, \chi(x,z) \times G(z,y|g\chi - g\hat{A}_{ext}) = -\delta(x-y) \quad (7)$$

where $\hat{A}_{ext}$ is the external field associated to J_μ.

The functional $S(\chi)$ that appears as a weight factor in the functional integral (5) may be naturally interpreted as the effective action of the bilocal field $\chi(x,y)$. The "classical" field M is then determined from the action principle by

$$g \frac{\delta S(\chi)}{\delta \chi} \Big|_{g\chi = M} = -K^{-1} M - i g^2 G^T(M) = 0 \quad (8)$$

or, multiplying from the left by K,

$$M_{\alpha\beta}(x,y) = -i g^2 \mathcal{D}_{\mu\nu}(x-y) [\gamma_\mu G(x,y|M) \gamma_\nu]_{\alpha\beta} \quad (9)$$

Here $G(x,y|M)$ is given by an equation like eq. (7) but without the term $g\hat{A}_{ext}$. This equation and eq. (9) do not involve the external sources. It is therefore natural to assume translational invariance of the solutions, i.e. $M(x,y) = M(x-y)$ and $G(x,y|M) = G(x-y|M)$. Eq. (9) is just the Schwinger-Dyson gap equation for the quark propagator in the lowest non-trivial approximation of perturbation theory. It was years ago the starting point of the finite QED of Baker, Johnson and Willey /3/ who have shown that it admits a nontrivial γ_5-symmetry violating solution.

Let us now calculate corrections to the symmetry breaking solution of eq. (9) by expanding the integrand of eq. (5) around the "classical" solution $M(x-y)$. If we shift

$$g\chi(x,y) = M(x-y) + g\phi(x,y) \quad (10)$$

we obtain

$$Z(J, \bar{\eta}, \eta) = \bar{N} \int \mathcal{D}\phi\, e^{-\frac{i}{2} tr\, \phi S^{(2)}(M) \phi} [e^{iS_{int}(\phi)} \times Z(J, \bar{\eta}, \eta | M + g\phi)] \quad (11)$$

with

$$S_{int}(\phi) = i \sum_{n=3}^{\infty} \frac{(-g)^n}{n} tr [G(M)\phi]^n \quad (12)$$

$$S^{(2)}_{(\alpha_1\beta_1;\alpha_2\beta_2)}(M) = K^{-1}_{(\alpha_1\beta_1\alpha_3\beta_3)} [\delta_{(\alpha_3\beta_3;\alpha_2\beta_2)} - i g^2 K_{(\alpha_3\beta_3,\kappa\varepsilon)} G_{\varepsilon\alpha_2}(M) G_{\beta_2\kappa}(M)]$$

Moreover, we define the propagator $\mathcal{D}^{\phi}_{(\alpha\beta;\gamma\delta)}(xy;x'y')$ of the bilocal field $\phi_{\alpha\beta}(x,y)$ by

$$\mathcal{D}^{\phi}_{(\alpha\beta;\gamma\delta)}(xy;x'y') \equiv i \langle \phi_{\alpha\beta}(x,y) \phi_{\gamma\delta}(x'y') \rangle_\phi = [S^{(2)}(M)]^{-1}_{(\alpha\beta;\gamma\delta)}(xy;x'y') \quad (13)$$

where $\langle \ldots \rangle_\phi$ means a functional average with the weight factor $\exp -\frac{i}{2} tr\, \phi S^{(2)}(M) \phi$ (a normalization factor is suppressed). Using a Wick theorem we may also evaluate the functional averages of higher order products of bilocal fields. We computated the two-particle Green's functions G, Δ of the quarks and vector gluons defined by

$$G_{\alpha\beta}(x,y) = \frac{1}{iZ} \frac{\delta}{\delta \eta_\beta(y)} \frac{\delta Z}{\delta \bar{\eta}_\alpha(x)} \Big|_{\eta = \bar{\eta} = 0}; \quad \Delta_{\mu\nu} = i \frac{\delta}{\delta J_\nu(y)} \frac{\delta \ln Z}{\delta J_\mu(x)} \Big|_{\eta = \bar{\eta} = 0}$$

In fig.1 and 2 we give the graphical expression of the bilocal propagator and of different terms in the expansion of the pathintegrals for G and Δ. The dashed lines represent the bilocal propagator. On the right-hand side the associated classes of Feynman diagrams are shown.

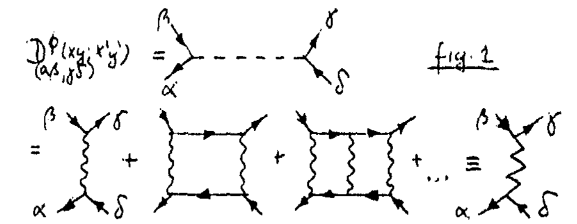

fig. 1

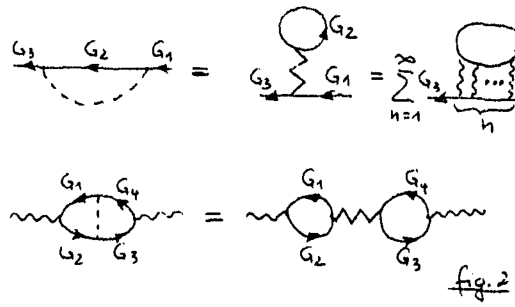

fig. 2

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Note Added

H.Kleinert has informed us that he has obtained similar results using bilocal techniques /4/ (see also the contributions tothis conference).

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HADRONIZATION OF QUARK THEORIES AND BILOCAL QED

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There are two approaches to strong interactions: Colored quark gluon theory (QCD) and the dual model. Either approach is powerful where the other has its weaknesses. In QCD, currents, their light cone properties, and their conservation laws (CVC,PCAC) can be studied without much effect. The spectrum, on the other hand, is very hard to calculate/1/. The opposite holds for dual models. Here the spectrum is obvious while proper currents have not yet been constructed.

Much work could be saved if the two approaches were, in fact, equivalent. Then one or the other could be used depending on whether long or short-range questions are to be answered.

We have been able to establish an equivalence of this type /2,3/ for the simplified situation where gluons are color singlets with an arbitrary mass μ. Since quarks may have several flavours, this theory might be called quantum flavour dynamics (QFD). Using functional methods, we have transformed QFD into an equivalent bilocal field theory whose bare quanta propagate and interact just like hadrons in dual diagrams (only the dynamical property of duality itself is missing due to the absence of colour). Photons interact with hadrons via a current field identity. The bare quanta are quark-antiquark bound states as they arise from ladder exchange of gluons.

Since QFD contains a spontaneously broken chiral symmetry it gives naturally rise to massless π, K, etc.,mesons. The small physical masses of these mesons are obtained by introducing a small bare mass term.

In the limit of a large gluon mass, hadronised QFD simplifies considerably. The bilocal fields become local and describe π, ρ, σ, A, mesons in the standard σ model