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MIRROR FERMIONS, J/ψ PARTICLES, KOLAR-MINE EVENTS AND NEUTRINO ANOMALY *

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ABSTRACT

The role of colour and charm and heavy mirror fermions (suggested earlier in the context of a unification scheme) is explored in interpreting the J/ψ particles, the Kolar-mine events and the neutrino-antineutrino anomaly.

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1. In 1972 we proposed [1] a unified gauge theory of weak, electromagnetic and strong interactions based on a fundamental 16-fold fermion multiplet F which combines the four known leptons $(\nu_e, e^-, \mu^-, \nu_\mu)$ with three quartets of red, yellow and blue quarks (p,n,λ,χ). All "low-energy" phenomena could be described by the minimal anomaly-free non-abelian gauge symmetry [2] $SU_L(2) \times SU_R(2) \times SU(4)'_{L+R}$.

Since the kinetic-energy term for the sixteen fundamental fields permits of a symmetry group [3] as large as SU(32), on purely theoretical grounds there is no reason why the full symmetry SU(32) - or any of its natural subgroups [4], e.g. $SU_L(4) \times SU_R(4) \times SU_L(4)' \times SU_R(4)'$ - should not have been gauged, the relevant gauge fields and their physical effects manifesting themselves at energies higher still. There would however be one important change; to secure freedom from anomalies, one must supplement the basic set of sixteen fermions F, by a mirror set F', the two sets F and F' being coupled with opposite chiral projections to the same gauge bosons. The gauge theory would then be invariant under the mirror transformation $F_L \to F'_R$ and $F_R \to F'_L$. This suggestion was made in Refs.3 and 4, where we assumed that F' is heavy and that normal matter is composed of F only.

With the discovery of new J/ψ matter, it is natural to consider the possibility that these particles reflect one or more of the new quantum numbers (colour, charm and mirror), excitations of charm and/or mirror being permissible at present energies if the corresponding quarks lie around 1 to 2 GeV above the normal (p,n,λ) quarks. In this note we wish to examine possible assignments of these quantum numbers to J/ψ's, the relevance of Kolar-mine events [5] either as decaying integer-charge quarks or as heavy leptons contained in F' and the possible manifestation of the mirror-quantum number in ν-$\bar\nu$ scattering.

2. The strong symmetry: The two fermionic multiplets F and F' may be displayed by the 4×4 arrays:

$$F_{L,R} = \begin{bmatrix} p_a & p_b & p_c & p_d = \nu_e \\ n_a & n_b & n_c & n_d = e^- \\ \lambda_a & \lambda_b & \lambda_c & \lambda_d = \mu^- \\ \chi_a & \chi_b & \chi_c & \chi_d = \nu_\mu \end{bmatrix}_{L,R} ; \quad F'_{L,R} = \begin{bmatrix} p'_a & p'_b & p'_c & p'_d = E^0 \\ n'_a & n'_b & n'_c & n'_d = E^- \\ \lambda'_a & \lambda'_b & \lambda'_c & \lambda'_d = M^- \\ \chi'_a & \chi'_b & \chi'_c & \chi'_d = M_0 \end{bmatrix}_{L,R} \quad (1)$$

χ denotes charm; p' is mirror to p and E^{o} and M^{o} are heavy leptons. To simplify discussion, gauge[6] $\mathcal{G} = SU(2)_L \times SU(2)_R \times SU(4)'_L \times SU(4)'_R$, for which $F'_R \sim F_L = (2+2,1,\bar{4},1)$ and $F'_L \sim F_R = (1,2+2,1,\bar{4})$. The anomaly-free strong gauge Lagrangian generated by $SU(4)'_L \times SU(4)'_R$ is:

$$\mathcal{L}_S = \frac{f}{2}\left[\vec{V}_1 \cdot (\bar{F}_L \vec{\lambda}_c F_L + \bar{F}'_R \vec{\lambda}_c F'_R)\right] + (V_1 \to V_2, L \leftrightarrow R). \quad (2)$$

Here λ_c's act on colour indices (a,b,c,d). Spontaneous symmetry breaking can be arranged[2),4)] such that the two octets of vector and axial-vector gauge eigenstates ($V_1 \pm V_2$) pertaining to $SU(3)'_L \times SU(3)'_R$ are relatively light ($\approx$ 3 to 10 GeV), while the remaining (X_V and X_A), which couple quarks and leptons, are heavy. The important feature of this theory (with both F and F') is the invariance of the effective strong Lagrangian for the larger global symmetry $U(8)_L \times U(8)_R \times SU(3)'$, where $U(8)_{L,R}$ act over the space of eight valency indices $[(p,n,\lambda,\chi) + (p',n',\lambda',\chi')]_{L,R}$. This global $U(8)_L \times U(8)_R$ is broken by quark-mass terms (see later). Assuming that mass splittings between (p',n',λ') are relatively small, the mirror global symmetries, $SU(2)_M$, $SU(3)_M$, would be good symmetries of hadrons in addition to the familiar SU(2) and SU(3). There is, however, no reason why some members of F' (e.g. p' and n') could not be lighter than the charmed quark χ. We will allow such possibilities in the interpretation of J/ψ.

3. J/ψ particles: The presently attained value[7)] of $R = 5.9 \pm 0.9$ at $E_{CM} = 7.4$ GeV and the lack of increase of K/π ratio in e^+e^- annihilation appear to exclude the hypothesis that the three J/ψ particles (which we shall call $\psi_1(3.1), \psi_2(3.7)$ and $\psi_3(4.1)$) are all charm-anticharm $\bar{\chi}\chi$ composites. Depending on relative masses of χ,p',n',λ' and χ' and of colour octet states, a number of possibilities arise. Note, however, that in any case the two lowest states (ψ_1 and ψ_2) must both be assigned either to colour, or to mirror, or to charm. (This is because $\psi_2 \to \psi_1 + \pi + \pi$.) A few typical possibilities are:

a) Colour and charm excited[8)] (but not mirror). ψ_1 and ψ_2 are colour; ψ_1 in particular being a member of the colour gauge octet, while ψ_3 is $\bar{\chi}\chi$ composite. Naive parton model will give[9)] $R = 6$. (ψ_3 as $\bar{\chi}\chi$ composite has the merit that the large partial width $\approx$ 250 MeV is accounted for by assuming that its decay into normal hadrons is suppressed by the normal Zweig factor appropriate to $\phi \to \rho + \pi$ decay. Also, in this case, the charm composites $D(=\bar{p}\chi$ and $\bar{n}\chi)$ and $F(=\bar{\lambda}\chi)$ could be relatively massive $\approx$ 3.2 BeV and thus not produced until E_{CM} exceeds 6.4 GeV. This could be one possible explanation of lack of increase of K/π ratio below 6.4 GeV. (However, see Sec.5.)

b) Mirror and charm excited (but not colour). Assign ψ_1 and ψ_2 to mirror[10)]; in particular assume ψ_1 is the mirror ρ (ρ_M); $\psi_1 = (\bar{p}'p' - \bar{n}'n')/\sqrt{2}$ while ψ_2 is its radial excitation[11)]. If mirror I-spin (I_M) defined in the (p',n') space is a good quantum number (except for electromagnetism), this could account for the extreme narrowness of ψ_1, through a normal Zweig rule suppression (10^{-2}), as observed in $\phi \to \rho + \pi$ decay, allied with the factor α from electromagnetism. A mirror ω ($\omega_M = (\bar{p}'p' + \bar{n}'n')/\sqrt{2}$) nearly degenerate with ρ_M would be expected to exist[12)] with a production cross-section (in e^+e^- experiment) a factor 9 lower than for ρ_M (analogous to ω:ρ situation). However, its width - suppressed only through the normal Zweig rule (but not through electromagnetism) - would be considerably larger than that of ρ_M^0, making it harder to detect.

If colour is not yet excited, ψ_3 may be associated with charm-anticharm $\bar{\chi}\chi$ composite as in Case a). (R = 5 assuming excitations of p,n,λ,χ,p' and n'.) If colour is excited, ψ_3 could be a member of the colour gauge octet. In this case (unless ψ_3 is a superposition of two resonant states[13)]) its broadness would be attributed to the strong decay $\psi_3(4.1) \to \pi(\text{colour}) + \text{pions}$.

All these possibilities would have their decisive tests in the discovery (or non-appearance) of associated composites carrying the new quantum numbers. Besides the well-known charmed F and D states, full mirror excitation would require the existence of thirty-two mixed ($\bar{q}q'$) and ($\bar{q}'q$) composite states (with spins 0,1). Examples of these are:

$$\begin{array}{l} \bar{p}p',\ \bar{n}p',\ \bar{\lambda}p' = G^0, G^+, H^+ , \\ \bar{p}n',\ \bar{n}n',\ \bar{\lambda}n' = N^-, N^0, P^0 . \end{array} \quad (3)$$

Note that the decays of the lowest-lying mixed composites arise only through weak interactions[14)] (see later).

4. <u>Kolar-mine events</u>: The recently reported Kolar-mine events [5] appear to suggest the existence of new massive objects ($m \approx 2$-5 GeV) which decay with lifetimes between 10^{-3} to 10^{-6} sec. on the one hand and 10^{-9} sec. on the other, depending on whether they are produced in the upper atmosphere [15] or in the rock through cosmic ray neutrino interactions (a suggestion due to the experimenters themselves). Within the present model it is natural to ascribe these events either to decaying neutral heavy leptons E^0 (or M^0) in the mirror multiplet or to decaying integral-charge quarks.

All quarks in our model decay into leptons - the fundamental mechanism [2] for such decays being the mixing of weak gauge bosons W with the very massive gauge mesons (X-mesons) which couple quarks to leptons ($q \to W + q \to X + q \to (\ell + \bar{q}) + q$). There are a number of selection rules for such decays in our basic model, as a consequence of which red quarks have relatively long lives ($\sim 10^{-5}$ to 10^{-9} secs. for $m_q \sim 2 - 5$ GeV) while blue and yellow quarks are shorter-lived ($\approx 10^{-9}$ to 10^{-13} secs.). One may envisage the Kolar events to be $\nu + N \to q + \bar{q} + \mu^- + N$ followed by quark decays to leptons (and possibly pions) with lifetimes $\approx 10^{-9}$ secs.

Alternatively, if the new objects were produced in the upper atmosphere, a possible interpretation could be the production of charged heavy leptons via $\gamma \to E^+ + E^-$ followed by normal weak decays of $E^\pm (E^- \to E^0 + e^- + \bar{\nu}_e$, or $E^- \to E^0 + \pi^-)$. Unlike other possibly <u>ad hoc</u> schemes, the important point about our model unifying baryons and leptons is that <u>all</u> heavy leptons (just like all quarks) are naturally unstable, no individual lepton number L_e, L_μ, L_E, L_M being absolutely conserved. E^0, for example, would decay through the chain:

$$E^0 \to X^0 + p'^0_a \to (\mu^- + \bar{\lambda}_a^+) + p'^0_a = \mu^- + H^+ ,$$

which is followed by a rapid weak decay of H^+. (This of course assumes $m_{E^0} > m_{H^+}$.) (With the effective strength [2] for X interaction $\approx 10^{-9}$ GeV^{-2}, we estimate $\tau_{E^0} \approx 10^{-4}$ sec. if $m_{E^0} \approx 2.2$ GeV and $m_{H^+} \approx 1.8$ GeV.) Note the pair production of $E^+ + E^-$ will contribute one unit to the experimental value of R, if $E_{CM} > 2m_{E^-}$. Thus one (among other) explanation of the rise in the SPEAR cross-section between 4.6 and 5 GeV, might be the opening of $(E^+ + E^-)$ channel.

We conclude this section with the general remark that, on the basis of lifetime estimates only, decaying integer-charge quarks and heavy charged leptons are hard to distinguish. However, when production cross-sections are considered, there is the distinction that neutral heavy leptons are produced

through weak interactions only, which may easily be distinguished from the more copious quark production possibly $\approx 10^{-33} - 10^{-32}$ cm^2. More important is the distinction that slow and long-lived ($\tau \geq 10^{-10}$ sec.) quarks (not being absorbed by normal hadronic matter) should scatter against nuclei with cross-sections $\approx 10^{-27}$ cm^2; something unattainable for heavy leptons.

5. <u>Fermi-mass matrix, the weak gauges</u>: Now we exhibit certain new complexions in the weak gauge interactions which arise due to the presence of both F and F' and point out, in particular, their implications in ν-$\bar{\nu}$ scatterings. Splitting $F_{L,R}$ and $F'_{L,R}$ into valency doublets $F_{1L,R} = \begin{pmatrix} p \\ n \end{pmatrix}_{L,R}$ and $F_{2L,R} = \begin{pmatrix} \chi \\ \lambda \end{pmatrix}_{L,R}$ and similarly $F'_{1L,R}$ and $F'_{2L,R}$, the Fermi-mass terms would take the form:

$$\mathcal{L}_{mass} = \sum_{i,j=1}^{2} \Big[a_{ij} \bar{F}_{iL} \langle\phi\rangle F_{jR} + b_{ij} \bar{F}'_{iL} \langle\phi\rangle F'_{jR} + \epsilon_{ij} \bar{F}_{iL} F'_{jR} + \epsilon'_{ij} \bar{F}'_{iL} F_{jR} + \text{H.C.} \Big] . \tag{4}$$

Here $\langle\phi\rangle$'s are vacuum expectation values of appropriate Higgs-Kibble fields and a_{ij}, b_{ij}, ϵ_{ij}, ϵ'_{ij} are constant parameters [16]. Note that $\langle\phi\rangle$ can induce familiar Cabibbo mixings between (n_L, λ_L), (n_R, λ_R) etc., while ϵ, ϵ' terms give rise to F-F' mixing. (Note $\epsilon \neq \epsilon'$ would induce P and CP violating mass terms.) In the presence of both types of mixing, the $SU(2)_L \times SU(2)_R$ weak gauge interactions, expressed in terms of the <u>diagonal</u> Fermi fields [17], in general take the form (suppressing a,b,c colour indices):

$$\mathcal{L}_W = \frac{g}{2} \sum_{i=1}^{2} \Big[\bar{F}_{iL}(\Theta) \vec{\tau} F_{iL}(\Theta) + \bar{F}'_{iR}(\Theta) \vec{\tau} F'_{iR}(\Theta) \Big] \cdot \vec{W}_1 + (\text{Leptonic Terms}) + (L \leftrightarrow R,\ W_1 \to W_2) \tag{5}$$

where $F_{iL,R}(\Theta)$ and $F'_{iL,R}(\Theta)$ are the rotated doublets, in general involving familiar Cabibbo angles $(\theta_{L,R})$ and eight angles $(\phi, \xi, \delta, \eta)_{L,R}$ specific to F-F' mixing between $(p, p')_{L,R}$ $(n_c, n'_c)_{L,R}$, ... We shall refer to these as "skewness" angles. (For example, after diagonalization, $p \to p \cos\phi + p' \sin\phi$ and $p' \to -p \sin\phi + p' \cos\phi$, etc., c denotes Cabibbo rotated fields.) In the limit of all skewness angles $\to 0$, we recover the "normal" theory with no special effects appearing due to the presence of mirror. However, F-F' mixing can give rise to intriguing possibilities; two models are listed below (where, for simplicity, all left skewness angles are set equal to zero).

Model I: Allow skewness angles ϕ_R and η_R to be nearly maximal[18) (i.e. $p_R \rightarrow p'_R$ and $\chi_R \leftrightarrow \chi'_R$), the $\vec{W}_1$ and $\vec{W}_2$ gauge boson couplings are:

$$\vec{W}_1 \cdot \left[-\begin{pmatrix} p \\ n_c \end{pmatrix}_L + \begin{pmatrix} \chi \\ \lambda_c \end{pmatrix}_L + \begin{pmatrix} p \\ n'_c \end{pmatrix}_R + \begin{pmatrix} \chi \\ \lambda'_c \end{pmatrix}_R \right] + \vec{W}_2 \cdot \left[\begin{pmatrix} p' \\ n_c \end{pmatrix}_R + \begin{pmatrix} \chi' \\ \lambda_c \end{pmatrix}_R + \begin{pmatrix} p' \\ n'_c \end{pmatrix}_L + \begin{pmatrix} \chi' \\ \lambda'_c \end{pmatrix}_L \right] \qquad (6)$$

In addition to the familiar weak interactions generated by the lighter $\vec{W}_1$ mesons, the following new features arise:

a) Above threshold for production of heavy mesonic $n'\bar{p}$, $n'\bar{n}$ and baryonic ($n'qq$) composites (relevant for x small), the right current $\bar{n}'\gamma_\mu(1 + i\gamma_5)p$ coupled to W_1^- gives rise to a y-independent term to anti-neutrino scattering cross-section $d^2\sigma(\bar{\nu} + N \rightarrow \mu^+ + X)/dx\,dy$ within a parton model context, without making an analogous contribution to neutrino scattering. This, together with the contribution from the familiar V-A current $\bar{p}\gamma_\mu(1 - i\gamma_5)n$ (which leads to distributions proportional to $f(x)$ and $f(x)\,(1-y)^2$ for ν and $\bar{\nu}$, respectively), gives a simple explanation of the observed anomaly[19) in $(\nu,\bar{\nu})$ charged current scattering processes. These show that for small $x < 0.1$, both ν and $\bar{\nu}$ distributions are nearly independent of y, contrary to the expectations from the simple (V-A) theory.

b) The neutral weak boson Z^0 in the present theory is coupled to the following hadronic current in the (p,n) space: $J_\mu^{Z^0}(p,n) = -(1/2)(\bar{p}\gamma_\mu p - \bar{n}\gamma_\mu\gamma_5 n)$. This violates parity and has vector $I = 0, 1$ and axial $I = 0,1$ pieces.

c) If χ is heavier than mirror λ', D and F particles could decay into $(\lambda'\bar{p})$ and $(\lambda'\bar{\lambda})$ composites plus pions (in addition to the familiar $(K\pi)$ and $(K\bar{K})$ decays).

Model II: An alternative model for weak interactions, which could arise from Eq.(5), is:

$$\vec{W}_1 \cdot \left[\begin{pmatrix} p \\ n_c \end{pmatrix}_L + \begin{pmatrix} \chi \\ \lambda_c \end{pmatrix}_L + \begin{pmatrix} p \\ n'_c \end{pmatrix}_R + \begin{pmatrix} \chi \\ n \end{pmatrix}_R \right] + \vec{W}_2 \cdot \left[\begin{pmatrix} p' \\ \lambda \end{pmatrix}_R + \begin{pmatrix} \chi' \\ \lambda'_c \end{pmatrix}_R + \begin{pmatrix} p' \\ n'_c \end{pmatrix}_L + \begin{pmatrix} \chi' \\ \lambda'_c \end{pmatrix}_L \right]. \qquad (7)$$

Besides explaining $\nu,\bar{\nu}$ anomaly[20) (see above), this complexion for weak currents provides an attractive new term for the effective $|\Delta S| = 1$ non-leptonic interaction[21) $G_F \cos\theta_L (\bar{n}\gamma_\mu(1 + i\gamma_5)\chi)(\bar{\chi}\gamma_\mu(1 - i\gamma_5)\lambda)$ in addition to the familiar term $G_F \cos\theta_L \sin\theta_L (\bar{n}\gamma_\mu(1 - i\gamma_5)p)(\bar{p}\gamma_\mu(1 - i\gamma_5)\lambda)$. This term is pure $\Delta I = \frac{1}{2}$ and is not suppressed[22) by Cabibbo factor $\sin\theta_L$.

Note that the neutral current coupled to Z^0 in this model is pure $I = 1$ vector $(\bar{p}\gamma_\mu p - \bar{n}\gamma_\mu n)$.

A choice between Models I and II can be made by examining the decay modes of charmed D and F particles. Model II (but not Model I) permits their decay into pions at rates comparable to $K\pi$ or $K\bar{K}$ decays.

To conclude, it is conceivable that $\nu,\bar{\nu}$ scattering anomaly may already be providing direct evidence for mirror[3),4) - one single concept which appears to combine a number of disparate ideas (heavier quarks, four heavy leptons plus a natural explanation of $\nu,\bar{\nu}$ anomaly through a mirror helicity interchange).

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2) J.C. Pati and Abdus Salam, Phys. Rev. D10, 275 (1974).

3) J.C. Pati, Abdus Salam and J. Strathdee, Nuovo Cimento 26, 72 (1975). If neutrinos are massless, the group might be SU(34).

4) J.C. Pati and Abdus Salam, Phys. Rev. D11, 1137 (1975) (see Addendum p.1149). Invited talk by J.C. Pati, Proceedings of the second Orbis Scientiae Coral Gables, Florida, January 1975 (to appear).

5) M.R. Krisna Murty et al., Tata Institute of Fundamental Research preprint (CR-MUNU-1, 1975).

6) The two "effective" constants g and f appearing in weak and strong gauging of $\mathcal{G} = SU_L(2) \times SU_R(2) \times SU_L(4)' \times SU_R(4)'$, reflect the passage from the higher unifying symmetries SU(32) or $SU(16)_L \times SU(16)_R$ (with one constant) down to $\mathcal{G}$, through finite renormalization effects.

7) G. Feldman, Report of SPEAR results at Palermo International Conference (June 1975).

8) J.C. Pati and Abdus Salam, Phys. Rev. Letters 34, 613 (1975); University of Maryland Technical Report No. 75-056 (Feb. 1975, unpublished).

9) The contribution of colour to R and to ep scattering in the context of a gauge theory based on integer-charge quarks and massive gluons is being examined. Below threshold for colour production, F (as well as F') quarks would of course act as if they carry the familiar fractional charges (see the case $\alpha = \beta = 0$ in Ref.2), even if their true (full) charges were integral.

10) J/ψ particles have been interpreted as composites of three new heavy coloured quark triplets by R.M. Barnett (Harvard preprint) and H. Harari (SLAC-PUB-1568). Barnett's new quarks exhibit V+A and V-A weak interactions; these are naturally comprised within our F' (Refs.3 and 4). Harari uses V-A only; in this respect and in the classification symmetry adopted by him there are crucial differences between his and our model.

11) This is analogous to Barnett's assignment (Ref.10) for ψ_1 and ψ_2 (who, however, uses, in our notation, (χ, n') rather than (p', n') quarks). The explanation for extreme narrowness of ψ_1 is due to Barnett.

12) Note the dominant mechanism $\rho_M^0 \to \omega_M^0 \to$ hadrons for ρ_M^0 decays is G parity conserving.

13) For example, ψ_3 may be a narrow colour gluon superposing with a relatively broad $\bar{\chi}\chi$.

14) Details of such decays will be considered in a longer paper.

15) This is a suggestion due to A. De Rújula, H. Georgi and S.L. Glashow (Harvard preprint), who interpret these objects as heavy leptons.

16) See Ref.2 for effective emergence of approximate SU(3). Note with $a_{ij} = 0$; $b_{ij} \neq 0$ and $\epsilon_{ij} = \epsilon'_{ij} \neq 0$, the masses of F may be derived from the masses of F' in a "natural" symmetry manner.

17) For convenience, we use the same notation for the diagonal fields as in Eq.(1). Note, given F-F' mixing, (μ, ν_μ) could start life from F', (E^-, E^0) originating from F.

18) The effects are proportional to $\sin^2\phi_R$.

19) Fermi-Lab results reported by D. Cline and C. Rubbia at Palermo International Conference (June 1975).

20) In this case (in contrast to Model I) the V+A $(\bar{\chi}\gamma_\mu(1 + i\gamma_5)n)$-current gives a $(1 - y)^2$ contribution to neutrino scattering; the net contributions to ν and $\bar{\nu}$ being thus identical (above threshold for production of n' and χ-composites).

21) This type of interaction was first suggested by R.N. Mohapatra (Phys. Rev. D6, 2023 (1972)) in the context of CP violation. Its $\Delta I = \frac{1}{2}$ character has recently been noted in a preprint by A. De Rújula, H. Georgi and S.L. Glashow; other merits of this non-leptonic interaction have been noted by P. Minkowski and H. Fritzsch (preprint). (We learnt of these works during the process of writing this paper; private communications by R.N. Mohapatra and H. Fritzsch.)

22) This, by itself, does not constitute evidence for Model II, since there exists a satisfactory explanation of $\Delta I = \frac{1}{2}$ rule and octet enhancement within the framework of asymptotic freedom (M. Gaillard and B.W. Lee, Phys. Rev Letters 33, 108 (1974); G. Altarelli and L. Maiani, Phys. Letters 52, 351 (1974)), together with arguments based on three-colour model and current algebra (J.C. Pati and C.H. Woo, Phys. Rev. D3, 2920 (1971)).