This has been added # 3477 Glaser

LETTERE AL NUOVO CIMENTO VOL. 12, N. 3 18 Gennaio 1975

# Are the Weak Neutral Currents an Electromagnetic Effect? (*) (**)

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(ricevuto il 17 Ottobre 1974)

1. – The recent neutrino-nucleon scattering experiments opened a new field of physics by demonstrating the existence of weak neutral currents (ref. (1)). The data are generally interpreted with the theory proposed by SALAM (ref. (2)) and WEINBERG (ref. (3)). Indeed that scheme furnishes an elegant escape to the old problem of the perturbative treatment of the nonrenormalizable Fermi couplings. That motivation is also the basis of numerous other attempts (ref. (4)). If the Nature is really like this theory suggests, we are obviously faced with a big mutation of QED. Indeed that scheme unifies the elementary photon field, whose couplings conserve $C$ and $P$, with other elementary boson fields whose couplings violate $C$ and $P$ maximally. Furthermore their masses are so big that QED, and even hadron physics, appear as a superficial aspect of a new underground world, that we are not close to see.

The object of this note is to call attention to the fact that the new revolution of QED which seems thus to begin might not necessarily be that which most people believe. Having heard so many philosophical arguments on the problem posed by these experiments and their interpretation, let us, before entering into the technical points, clarify the positions. Apart the obvious interest of having new forces for exploring the physical world, that which is mostly questioned by theoricians in these experiments and their interpretation is the problem of renormalizability.

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(*) This work has been supported in part by the Institut National de la Physique Nucléaire et de la Physique des Particules and by the Commissariat à l'Energie Atomique.

(**) A preliminary version of this letter circulated as internal report under the title *On the interpretation of the weak neutral current experiments*, LPC (January 1974). That note was refused for publication in *Phys. Lett.* Its main results were also communicated at *The Conference on Physics at Ultra-High Energies, London, Sept. 1974.*

(1) F. J. HASERT *et al.*: *Phys. Lett.*, **46** B, 138 (1973).

(2) A. SALAM and J. WARD: *Phys. Lett.*, **13**, 168 (1964).

(3) S. WEINBERG: *Phys. Rev. Lett.*, **19**, 1264 (1969).

(4) For a comprehensible and exhaustive review of these theories see C. H. LLEWELLYN SMITH: preprint CERN TH 1710.

(5) B. JOUVET: *Nuovo Cimento*, **38**, 951 (1965). The limits of the $\nu_\mu$-$\mathcal{N}$ neutral interaction used in this paper are now known to be erroneous.

(6) B. JOUVET: *Solid State Physics, Nuclear Physics and Particle Physics*, edited by SAADEVRA (New York, N. Y., 1968).

The Salam-Weinberg scheme and its variants furnish a solution of the Fermi-interaction renormalization in perturbation theory. They do not, however, solve the problem of the renormalization constants in renormalizable theories: but on this point most people do not care and even often believe that these constants simply do not exist physically, because they are divergent in perturbation theory.

The explanation, prediction and utilization (ref. (5), ref. (6) p. 142) of the phenomena which one observes now and those we shall review later disagree precisely on these two ideas. First of all we do not believe that the renormalizability in perturbation theory is a physical criterion: the existence of the gravitation field is a heavy counter-example of such a criterion. We also believe that the renormalization constants, though infinite when computed with perturbation methods, are useful physically existing objects. We think that by deleting them we perhaps make the same error as that which was made before the discovery of the Lamb schift when we did not believe in the existence of vacuum polarization effects, because they were already infinite! We explained in detail elsewhere (ref. (6), p. 204) how the treatment of the Fermi coupling, by mean of which one could possibly unify the weak interactions with the composite photon and hadron theories, will become possible if the difficult problem of computing consistently the $Z_3$-type renormalization constants of the renormalizable theories can be solved. This has not been done as yet. Only the use of the various representations of the renormalization groups has recently thrown a new light on the obstacle to surmount: we gave examples of finite renormalization constants $Z_3(\alpha)$ of the photon field which agree with all the known properties of that function, but in that cases the divergences only result from the unlegitimate use of perturbation theory, which spoils a delicate built-in cut-off mechanism (ref. (7)). Though this is a possible direction towards the future solution of the $Z_3$-problem, it cannot be excluded too that some other force, foreign to the pure QED (the gravitation for instance), be in reality the cause of the necessary cut-off mechanism.

Until this problem receive a solution, the point of view we take here is the conventional one: namely we admit, as it has always been done with success, particularly in the $\pi$-e decay calculation, that with regard to the effective low-energy Fermi interactions one is justified to compute any process by considering only the first-order terms in the renormalized Fermi constant.

This means that the higher-order terms are either strongly damped by the e.m. and mesons forces, or even entirely suppressed. That last strange cancellation mechanism can indeed likely occur when the photon and hadrons are the dynamical bound states resulting from a fundamental scheme of Fermi-type couplings between the leptons and quarks, as it occurs in the, at present academic, neutrino-electron $g_F J_\nu^\sigma \cdot J_e^\sigma$ vector-coupling theory of the composite photon (*). In that model the composite photon is constructed by treating the $S$-matrix to all orders in $g_F$, whereas the neutrino charge radius turns out to be exactly given by the first-order graphs in $g_F$, clothed however by all the composite-photon radiative corrections.

**2.** – With this points of view neutral weak interactions of the neutrinos with hadrons, with strength comparable with $g_F$, are generated, as explained in detail in ref. (5), by the following mechanism:

*a*) We admit the existence of *local* Fermi interaction between the $V-A$ charged-lepton (e, respectively $\mu$) currents and the neutral-lepton ($\nu_e$, respectively $\nu_\mu$)

(7) B. Jouvet: *Rev. Braz. Fis.*, **3**, 345 (1973); *Ren-group representation and the GML and C.S. equations for the photon propagator*, ICTP preprint IC/74/12 (in press in *Nuovo Cimento*).

(*) See in ref. (6) ref. (3) and notes (17,18).

currents. In the Feynman-Gell-Mann–Marshak–Sudarshan hypothesis the renormalized coupling constants are $g_{V,A}^{\nu_\mu-\mu} = g_{V,A}^{\nu_e-e} = \pm g_F$. Then the effective neutral interaction of the $\nu_\mu$ with hadrons (electrons) given by the graph of Fig. 1, where only the vector part of the Fermi interaction is involved, is equal to

$$(1)\qquad -\frac{g_V^{\nu_\mu-\mu}}{\sqrt{2}}\, q^2 B(q^2, \alpha, \mu)\cdot(e^2/q^2)\, d_r(q^2, \alpha)\cdot\left[(\bar{\nu}_\mu\gamma_\sigma(1+\gamma_5)\nu_\mu)\cdot J_h^{\sigma,\mathrm{e.m.}} (\text{or } J_e^\sigma)\right],$$

where $J_h^{\sigma,\mathrm{e.m.}}(J_e^\sigma)$ is the e.m. current of hadrons (electrons), $q^2B(q^2, \alpha, \mu)$ the ***unsubtracted*** gauge-invariant vectorial vacuum polarization loop of muons and $d_r(q^2, \alpha)$ the

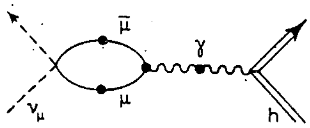


**Fig. 1. – Graph of the neutral interaction of the $\nu_\mu$ with hadrons.**

renormalized clothing function of the photon. $B(q^2, \alpha, \mu)$ diverges logarithmically in perturbation theory and therefore cannot presently be computed consistently. Only $B(q^2, \alpha, \mu) - B(0, \alpha, \mu)$ can be calculated with reliability.

*b*) The unknown constant $B(0, \alpha, \mu)$ enters in the expression for $Z_3$

$$(2)\qquad Z_3 = 1 - L - H\,, \qquad L \equiv \sum_{\text{leptons}} \zeta_l, \qquad H \equiv \sum_{\text{hadrons}} \zeta_h\,, \qquad \zeta_i = e^2 B(0, \alpha, i)\,.$$

We estimated in ref. (5) that $H \approx 2\alpha/3$, in agreement with latter results (ref. (8)), and concluded therefore that if the photon is a composite particle, which implies (ref. (9)) that $Z_3(\alpha) = 0$, or if $Z_3$ differs notably from unity, the hadron's contribution to $Z_3$ is negligible as compared to that of the charged leptons. It follows that the measurement of the $\nu_\mu$ (respectively $\nu_e$) neutral interactions with the hadrons, or with e (respectively $\mu$), allows to determine $g_V^{\nu_\mu-\mu}\cdot\zeta_\mu$ (respectively $g_V^{\nu_e-e}\cdot\zeta_e$) and therefore $Z_3$, if the constants $g_V^{\nu_l-l}$ are known and if there does not exist other charged leptons than e and $\mu$.

The present data on $e^-e^+$ annihilation, if their interpretation is correct, seem however to indicate that $H$, though still of the order of $\alpha$, may turn out to be much bigger, giving to the hadrons more importance in the future understanding of the photon structure.

*c*) Let us admit now that $Z_3 = 0$ and that the e and $\mu$ are the only existing charged leptons. Let us suppose furthermore that the functions $B(0, \alpha, \mathrm{e})$ and $B(0, \alpha, \mu)$, which are certainly not exactly equal if their finiteness results from the mechanism explained in ref. (7), are however not very different, so that

$$B(0, \alpha, \mu)/B(0, \alpha, \mathrm{e}) \approx 1\,.$$

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(8) N. M. Kroll, T. D. Lee and B. Zumino: *Phys. Rev.*, **157**, 1376 (1967); G. J. Gounaris: *Phys. Rev.*, **181**, 2077 (1969); E. Etim and P. Picchi: *Lett. Nuovo Cimento*, **4**, 368 (1970).

(9) B. Jouvet: *Nuovo Cimento*, **5**, 1 (1957). For a review of this question see also ref. (6) and K. Hayashi, M. Hirayama, T. Muta, N. Seto and T. Shirafuji: *Forsch. Phys.*, **15**, 625 (1967); H. Osborn: *Ann. of Phys.*, **47**, 351 (1968).

Then $\zeta_\mu \approx \frac{1}{2}$, and in formula (1)

$$e^2 B(q^2, \alpha, \mu) \approx \frac{1}{2} + 0\left(\frac{\alpha}{3\pi} \log \frac{q^2}{\mu^2}\right)$$

when $q^2$ is not exceedingly high. Thus if there exist couplings of the type mentioned in 2*a*), QED alone suffices in order to produce weak neutral neutrino-hadron interactions of the order of magnitude of the usual charged ones.

*d*) This electromagnetic effect is however very paradoxical because the two principal characteristic properties of QED are masked (*): the long-range behaviour (photon pole) is killed by the $q^2$-term of the e.m. form factor of the null-charge neutrino, like in the e.m. electron-neutron interaction.

The usual strength ($\sim \alpha$) of the long-range e.m. interaction is replaced by a strength which is related to the zero distance of QED, governed by the $Z_3$-renormalization constant. This strength is here chosen to be the maximal one by the photon compositeness hypothesis.

It results that the trace of the e.m. origine of this neutral current has to be searched either in the $q^2$-dependent fine effects contained in the e.m. functions $B(q^2, \alpha, \mu)$ — — $B(\theta, \alpha, \mu)$ and $d_r(q^2, \alpha)$ and more easily, at present, in the other known characteristics of the photon, contained in the photon-hadron effective coupling. Indeed the neutral-hadron current is the *e.m. current* characterized by the properties of

*a*) being pure vectorial $V$,

*b*) conserving $C$ and $P$,

*c*) conserving strangeness $\Delta S = 0$,

*d*) being such that $\Delta T = 0$ and 1.

3. — *a*) It is known that neutral currents satisfy the criterion *c*). The H.P.W. FNAL experiment (ref. ([10])) indicates that $\sigma^N_{\nu_\mu}/\sigma^N_{\bar{\nu}_\mu} = 1 \pm 0.2$ which is consistent with criterion *b*). (A different ratio has also been given from Gargamelle experiment (ref. ([11])) which, being theory dependent, cannot be used here.) On the criterion *d*) the data are presently contradictory and nothing is known on the criterion *a*).

*b*) Using (ref. ([10])) $R_{\bar{\nu}_\mu} = 0.32 \pm 0.09$ and $\sigma^c_{\bar{\nu}_\mu} = (0.28 \pm 0.01) E_{\text{GeV}} \cdot 10^{-38}\,\text{cm}^2$ and the deep inelastic formula in which the Callan-Gross relation is admitted, one gets

$$y_\mu = g_V^{\nu_\mu - \mu} \zeta_\mu / g_F = 0.77 \pm 0.13\,, \tag{3}$$

this value being up to 1.15 bigger if $\int x F_1 \, dx$ is decreased to its null lower bound. This value is also consistent with the bound $y_\mu \leqslant 0.8$ one obtains from the three $\bar{\nu}_\mu e \to \bar{\nu}_\mu e$ observed events (ref. ([12])). Thus if the hypothesis of 2*a*) is right, $\zeta_\mu = 0.77 \pm 0.13$,

(*) We are grateful to Prof. T. D. LEE for a suggestive criticism on this paradoxical situation.

([10]) B. AUBERT, A. BENVENUTI, D. CLINE, W. T. FORD, R. IMLAY, T. Y. LING, A. K. KANN, F. MESSING, J. PILCHER, D. D. REEDER, C. RUBBIA, R. STEFANSKI and L. SULAK: *Phys. Rev. Lett.*, **32**, 1457 (1974).

([11]) F. J. HASERT *et al.*: *International Conference on High-Energy Physics, London, 1974.*

([12]) F. J. HASERT *et al.*: *Phys. Lett.*, **46** B, 121 (1973); R. MUSSET: private communication (1974).

and therefore $Z_3 + \zeta_e + H = 0.23 \pm 0.13$, which fixes bounds on $Z_3$, $\zeta_e$ and $H$. In consequence $\sigma_{\nu_e - h}$ should be sensibly smaller than $\sigma_{\nu_\mu - h}$.

The experimental demonstration that $g_V^{\nu_\mu - \mu} = g_F$ could be done by measuring $\nu_\mu$-$\mu$ or $\nu_e$-e interactions which are governed by the coupling

$$\frac{g_F}{\sqrt{2}} (\bar{\nu}_l \gamma_\sigma (1 + \gamma_5) \nu_l) \{V(1 - \zeta_l) - A\}_l \,, \qquad l = \mu, e \,.$$

*c*) The strong dissymetry between $\zeta_\mu$ and $\zeta_e$ demonstrates the failure of the hypothesis that one can consistently compute $Z_3$ *in perturbation theory*, if the theory possesses a (built-in or extra) cut-off, since the value of $A$ necessary for explaining $\zeta_\mu$ entails then that $\zeta_\mu \approx \zeta_e$ and $Z_3 < 0$. A qualitative interpretation of the dissymetry can be given in terms of the renormalization group kernel properties (ref. (7)) in which the built-in cut-off is relatively low and the main contributions to $\zeta_l$ come from the slowly converging asymptotic behaviour.

The big value of $\zeta_\mu$ excludes of course the existence of elementary $W^\pm$-mesons, though there might exist composite resonances in the charged channel.