We note that additional lowering of q and t can occur as a result of the nonuniformity of the illumination of the spot, temporal pulsations of the flux, and many other factors (for example, as already indicated in [3], the air resistance, whichleessens the role of adiabatic cooling of the expanding vapor, shortens the "flash" time).

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[1]. Yu.P. Raizer, Usp. Fiz. Nauk 87, 29 (1965) [Sov. Phys.-Usp. 8, 650 (1966)].
[2] G.G. Vilenskaya and I.V. Nemchinov, Dokl. Akad. Nauk SSSR 186, 1948 (1969) [Sov. Phys.-Dokl. 14, 560 (1969)].
[3] G.G. Vilenskaya and I.V. Nemchinov, Prikl. Nat. Teor. Fiz. 3 (1969).
[4] Ya.N. Gnoevoi, A.I. Petrukhin, Yu.E. Pleshanov, and V.A. Sulyaev, ZhETF Pis. Red. 11, 440 (1970) [this issue, page 297].
[5] G.S. Romanov and K.L. Stepanov, Zh. Prikl. Spektr. 8, 753 (1968).
[6] E.G. Popov, ZhETF Pis. Red. 9, 176 (1969) [JETP Lett. 9, 102 (1969)].
[7] D.W. Gregg and S.I. Thomas, J. Appl. Phys., 37, 2787 (1966).
[8] Yu.V. Afanas'ev, N.G. Basov, O.N. Krokhin, N.V. Morachevskii, and G.V. Sklizkov, Zh. Tekh. Fiz. 39, 894 (1969) [Sov. Phys.-Tech. Phys. 14, 669 (1969)].

DIAGONAL AND NONDIAGONAL ELECTROMAGNETIC INTERACTIONS IN COLLIDING-BEAM EXPERIMENTS

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Gell-Mann et al. have advanced arguments [1] indicating the possibility of an appreciable physical difference between diagonal and nondiagonal interaction of weak currents. In [2] there was discussed a generalization of [1], including electromagnetism in such a way that the total symmetry of the diagonal interactions of hadron currents appears only after combining the contributions from both weak and electromagnetic interactions.

We consider here certain physical consequences of the proposed spearation into "diagonal" and "nondiagonal" interactions, in the case of interactions of leptonic electromagnetic currents, and note that the discovery of the effect of diagonalization, if it exists and is general, can be expected not only in neutrino experiments [1] but also in high-energy colliding-beam experiments now in progress, provided "violations" of quantum electrodynamics are observed.

We postulate that besides the coupling between the lepton and hadron parts of the total electromagnetic current with the massless proton field (we omit the vector indices of the currents and fields)[1],

$$\mathcal{L}^{em} = e j^{em} A = e(j_\ell^{em} + j_h^{em})A, \tag{1}$$

where

$$j_\ell^{em} = j_e^{em} + j_\mu^{em} = \bar{e}\gamma_\alpha e + \bar{\mu}\gamma_\alpha \mu, \tag{2}$$

[1] The possible contribution to the current j^{em} from the charged W-bosons and other possible types of new particles will not be considered explicitly here.

$$j_h^{em} = j_3^V + \frac{1}{\sqrt{3}} j_8^V \ , \tag{3}$$

and j_3^V and j_8^V are the components of the unitary octet of vector hadron currents, the different parts of the electromagnetic current are also connected with heavy neutral vector bosons V_1, V_2, and V_3 in the following manner[2]:

$$\mathcal{L}^{(\ell h)} = e(j_\ell^{em} - j_h^{em}) V_1 , \tag{4}$$

$$\mathcal{L}^{(38)} = \sqrt{2}e\left(j_3^V - \frac{1}{\sqrt{3}} j_8^V\right) V_2 , \tag{5}$$

$$\mathcal{L}^{(e\mu)} = \sqrt{2}e(j_e^{em} - j_\mu^{em}) V_3 \ . \tag{6}$$

All the V_i bosons have the same mass M, which is preferably set equal to the mass of the intermediate vector bosons of the weak interactions [2]. The summary effect of interactions (1) - (6) in the e^2 approximation leads to the following effective current-current interactions:

1) Regularized effective electromagnetic interaction

$$\mathcal{L}_{eff}^{em} = e^2 j_\alpha^{em} j_\beta^{em} \Delta_{\alpha\beta}^\gamma , \tag{7}$$

where $\Delta^\gamma_{\alpha\beta}$ is the effective photon propagator,

$$\Delta_{\alpha\beta}^\gamma = \left(\frac{1}{q^2} - \frac{1}{q^2 + M^2}\right) \delta_{\alpha\beta} \ . \tag{8}$$

2) Diagonal interaction of neutral hadron currents

$$\mathcal{L}_{\text{diag}}^h = 4e^2 (j_{3\alpha}^V j_{3\beta}^V + \frac{1}{3} j_{8\alpha}^V j_{8\beta}^V) \Delta_{\alpha\beta}^D , \tag{9}$$

where $\Delta_{\alpha\beta}^D$ is equal to the propagator of the vector boson with mass M,

$$\Delta_{\alpha\beta}^D = (\delta_{\alpha\beta} + q_\alpha q_\beta / M^2)(q^2 + M^2)^{-1} . \tag{10}$$

3) Diagonal lepton interaction

$$\mathcal{L}_{\text{diag}}^\ell = 4e^2 [(\bar{e}\gamma_\alpha e)(\bar{e}\gamma_\beta e) + (\bar{\mu}\gamma_\alpha \mu)(\bar{\mu}\gamma_\beta \mu)] \Delta_{\alpha\beta}^D \ . \tag{11}$$

It follows from (7) - (11) that the essential difference between the effective propagators for the diagonal and nondiagonal current-current interactions pertains, possibly, not to weak interactions only [1], but is a more general physical phenomenon. It is possible to isolate in this manner the singularities of the ordinary electromagnetic interaction, which are responsible for the known divergences (with the exception of the polarization of vacuum), and to localize them only in the diagonal interactions (9) and (11). On the other hand, a complete analysis of the latter is apparently meaningful only at same level with the diagonal interactions of the weak currents. This reveals,

[2] The currents in (4) - (6) have the common property that their conservation is violated only by weak interactions.

possibly, a deep connection between the problem of divergences in electrodynamics and the problem of the connection between electromagnetism and weak interactions[3]. We shall consider here only lepton interactions.

It is seen from (7) and (11) that the effective propagator of the diagonal electromagnetic lepton interactions ($ee \to ee$ and $\mu\mu \to \mu\mu$) is given by

$$-\left(\frac{1}{q^2} + \frac{n}{q^2 + M^2}\right) \delta_{\alpha\beta}, \tag{12}$$

where n = +3, whereas the effective propagator of nondiagonal electromagnetic lepton interactions ($ee \to \mu\mu$) is given by (8).

The diagonal interactions contribute to the anomalous magnetic moment of the leptons. If it is naively assumed that they are responsible for the discrepancy between the theoretical and experimental values of (g - 2) for the muon, then the CERN data [3] and (12) would lead at n = +3 to the estimate $M \simeq (6.8^{+3.4}_{-1.3})$ GeV. But in any case we get $M \gtrsim 5$ GeV.

If the mass of the vector boson M is not very large, then these predictions can be verified in the future in experiments with colliding electron-positron beams. The ratio of the cross section of the nondiagonal reaction

$$e^- + e^+ \to \mu^- + \mu^+ \tag{13}$$

in the present model to its value in ordinary quantum electrodynamics does not depend on the angle and equals

$$r_1 = (1 - \epsilon^2)^{-2}, \tag{14}$$

where $\varepsilon = E_{cms}/M$ is the ratio of the total energy in the c.m.s. to the mass of the intermediate boson. For example, at M - 8 GeV and E_{cms} = 2 GeV, the ratio (14) is equal to ~1.13. On the other hand, it is easy to find by direct calculation that the ratio of the cross section of the diagonal reaction $e^- + e^+ \to e^- + e^+$, which follows from the given model, to its value in the usual quantum electrodynamics depends on the angle; for example, if the c.m.s. scattering angle is $\theta = \pi/2$, the ratio is[4]

$$r_2 = [(2 + (n+1)\epsilon^2)^2 + n^2\epsilon^4(1 - \epsilon^2)^{-2}](2 + \epsilon^2)^{-2}. \tag{15}$$

In particular, when n = +3, and $\varepsilon = 1/4$, we get $r_2 \simeq 1.2$. When $\varepsilon^2 \ll 1$, the ratios (14) and (15) tend to unity. When $\varepsilon^2 \gg 1$ we have $r_1 \simeq 1/\varepsilon^4 \to 0$ and $r_2 \to 16$; the limiting ratio $r_1/r_2 \to 1/16\varepsilon^4$ does not depend on the angle[5].

What is the physical meaning of separating the current-current interactions into diagonal and nondiagonal ones? It is possible that the true basis for such a separation is the condition of restoration of the postulated

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[3] The diagonal hadron interaction (9) complements in [2] the diagonal interactions of weak hadron currents to form an isotropically invarient expression, leading to elimination of the divergences for the mass differences of the isomultiplet components.

[4] The ratio (14) for the reaction (13) coincides with the expression given by Lee, in the theory with indefinite metric, but the corresponding relations of the type (15) for diagonal reactions are appreciably different.

[5] Allowance for the charged W bosons might change somewhat the estimates for the diagonal reactions (possibly n = +7 in lieu of n = +3 in (12) and (15), but would not change the form of the interaction (7) and (8) or the estimate (14) for nondiagonal reactions.

symmetry [2]. From this point of view, the separation, predicted by the present model, of the lepton interactions into diagonal and nondiagonal ones is in fact a concrete formulation of the problem as applied to an experiment involving the lepton symmetry. The existence of the aforementioned diagonalization effect for interactions of electrons and muons, namely the different character of the energy and angular dependence of the deviations from ordinary quantum electrodynamics for (eeee) and (eeμμ) processes at high energies, respectively, would signify that the e-currents and the μ-currents are "different currents" and that the electron and muon are of an essentially different nature. The absence of such an effect would possibly signify only that there exists a unified leptonic electromagnetic current, and that the electron and muon are particles of the same type. In the latter case, both processes could be "diagonal," with an effective propagator of the type (12) (at n = +1 or n = +3). The ratio (14) would have to be replaced in this case (for ee → μμ) by

$$r_1 = [1 - n\epsilon^2(q - \epsilon^2)^{-1}]^2, \tag{16}$$

and vanishes at $\varepsilon^2 = 1/(n + 1)$. The only possible nondiagonal interactions would be hadron-lepton processes, for example $e^-e^+ \to \pi^-\pi^+$ and others [2].

In conclusion we note that particular interest attaches to the possibility of experimentally verifying, in high-energy colliding-beam experiments, the hypothesis [5] that there exists an axial pseudo-electric interaction, under the condition that the boson mass is not very large, M << 100 GeV. It is easily seen that this hypothesis leads to a separation of the electromagnetic processes into diagonal and nondiagonal ones with respect to the particle helicity (this is the consequence of the gauge-invariance conditions employed above and of the relation $(VV + AA) = \frac{1}{2}[(V - A)(V - A) + (V + A)(V + A)]$). A convincing experimental confirmation of this idea would be the observation of an essential difference between the cross sections for the reactions of high-energy particles with identical and opposite helicities, for example $e^-_L e^-_L \to e^-_L e^-_L$ and $e^-_L e^-_R \to e^-_L e^-_R$, or $e^-_L e^+_R \to e^-_L e^+_R$ and $e^-_L e^+_L \to e^-_L e^+_L$.

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[1] M. Gell-Mann et al., Phys. Rev. 179, 1518 (1969).
[2] E.M. Lipmanov, Yad. Fiz. 11, 648 (1970) [Sov. J. Nuc. Phys. 11, No. 3 (1970)].
[3] J. Bailey et al., Phys. Lett. B28, 287 (1968).
[4] T.D. Lee, Topical Conf. on Weak Inter., CERN, 1969.
[5] E.M. Lipmanov, Zh. Eksp. Teor. Fiz. 50, 1309 (1966) [Sov. Phys.-JETP 23, 869 (1966)].