Weak nucleon form factors in a modified vector-dominance model

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A modification of the vector-dominance model at small distances, based on the idea of dynamically factorizable quarks, is proposed. Weak nucleon form factors devoid of the free parameters are obtained. A comparison with the experimental data shows a good agreement.

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Investigation of elastic neutrino reactions in the channels of charged and neutral currents has recently generated an increasing interest. The fact is that this class of interactions gives important information on the static properties of a nucleon, as a unit, in contrast to deep inelastic processes that probe its "hyperfine" structure. A more complete information on these properties can be obtained by studying the nucleon form factors derived from measurements of the Q^2 dependence of scattering cross sections. A low probability of occurrence of elastic neutrino events greatly complicates the determination of their kinematic characteristics. In view of this, the available data on this problem until now have been confined to the results obtained by two groups.[1,2] However, the physics research programs of many accelerator laboratories include the measurements of $\nu N \to \mu N$; νN. Thus, we can expect new data in the near future. It is undoubtedly also important to theoretically analyze in greater detail the weak nucleon form factors (NFF). The frequently assumed dipole behavior, confirmed experimentally rather well, has not been justified theoretically. The status of vector dominance (VD) in this sense is exactly opposite. It agrees poorly with the experiment, but has a theoretical justification. The latter, however, has to be re-examined. Skachkov *et al.*[3] successfully modified the VD for electromagnetic interactions. In this paper we examine the possibility of modifying VD for weak interactions from the viewpoint of the dynamic model of factorizing quarks (DMFQ).[4] The need for modification of the classical VD can be prceived from the quark structure in a nucleon. Let us consider a geometric picture[5] in which the rms radius of a nucleon $\langle R^2 \rangle$ is comprised of the

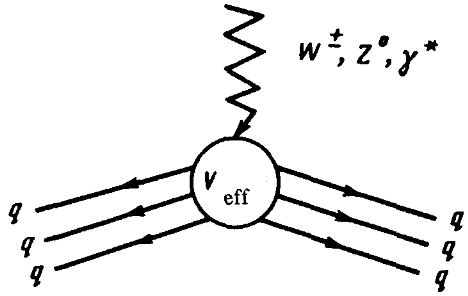

FIG. 1

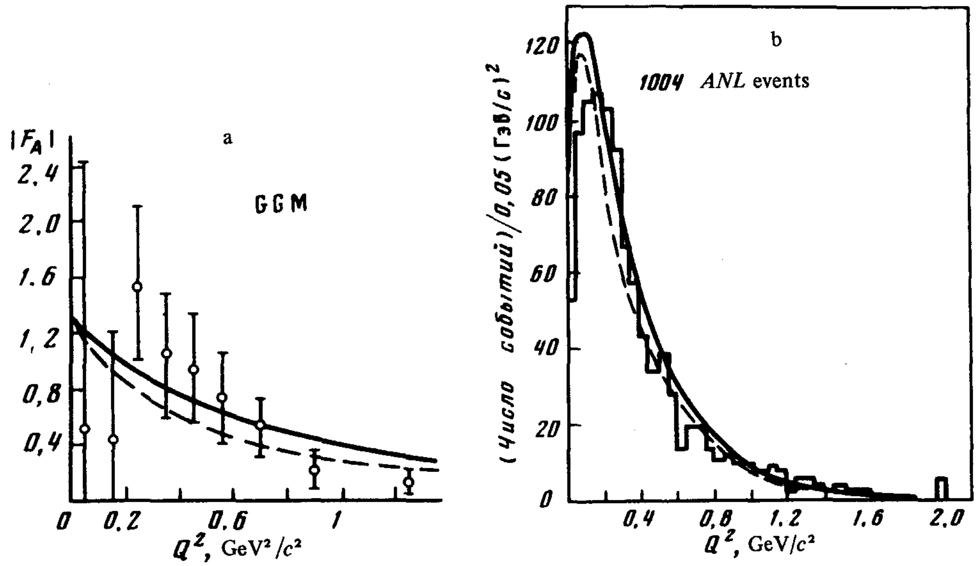

FIG. 2. Experimental data: (a) GGMPS (Ref. 1); (b) ANL (Ref. 2). The solid lines represent the predictions of the modified VD and the dashed lines denote the predictions of the dipole formula $F_V^{(c)}(Q^2) = [1+(Q^2/m_V^2)]^{-2}$, $F_A^{(c)}(Q^2) = \{1.23/[1+(Q^2/m_A^2)]^2\}$, $m_V = 0.84$ GeV, $m_A = 0.98$ GeV.

suppression region of quarks $\langle r_A^2 \rangle$, which is determined by the wave function of their bound state, and the size of the vector meson cloud $\langle r_A^2 \rangle$ of each quark. Thus, an approximate estimate gives: $\langle R^2 \rangle = \langle r_A^2 \rangle + \langle r_V^2 \rangle$. It follows from this that $F = F_A F_{\rm VD}$, where F is the NFF and F_A and $F_{\rm VD}$ are the form factors corresponding to the distribution of the "charge" that forms the regions $\langle r_A^2 \rangle$ and $\langle r_V^2 \rangle$, respectively. We assume that F_A can be described by the DMFQ. According to it, the incident particle ($W^{\pm}, Z^0, \gamma^*$) excites an effective potential $V_{\rm eff}(r)$ in the nucleon, on the basis of which the quasi-independent scattering of the constituent quarks occurs (Fig. 1). In the DMFQ $V_{\rm eff}(r)$ is given in the relativistic configuration representation (RCR), (Ref. 6).[1] Like in Refs. 3 and 4, we chose $V_{\rm eff}(r) = \delta(r)/4\pi r^2$; thus, we obtain for the scattering amplitude of a g_i quark

$$g_i(Q\ ) = \frac{y_i}{\sinh y_i}, \qquad y_i = \mathrm{Ar}\cosh(1 + Q_i^2/2m^2). \tag{1}$$

Here Q_i^2 is the momentum transfer per quark of mass m (for simplicity, we assume that $m = M/3$ and $Q_i = Q/3$, where M is the nucleon mass and Q is the total momentum transfer). As shown in Ref. 4, the NFF is proportional in this case to the produce of the scattering amplitudes g_i of quarks and $V_{\rm eff}$. Thus, $F_A(Q^2) = g_i^3(Q^2)$. Turning to the VD part of the NFF, we limit ourselves to the contribution of the lightest mesons: vectors ρ-meson contribution to the vector NFF $F_V^{(c)}$ and axial A_1-meson contribution to the axial NFF-$F_A^{(c)}$. Finally, we obtain

$$F_{V,A}^{(c)}(Q^2) = g_i^3(Q^2)\frac{G_{V,A}}{1 + Q^2/m^2_{\rho,A_1}}, \quad m_\rho = 770 \text{ MeV}, \quad m_{A_1} = \sqrt{2}\, m_\rho \tag{2}$$

On the basis of conservation of the vector current (CVC) and also $G_p^E = G_p^M/\mu_p = G_n^M/\mu_n$ in the electromagnetic interactions, we determine the NFF of the weak magnetism: $F_M^{(c)} = (\mu_p - \mu_n)F_V^{(c)}, \mu_p = 1.79$, where $\mu_n = -1.91$ are the anomalous magnetic moments of the proton and neutron, respectively. The CVC also specifies the vector coupling constant $C_V = 1$. The axial constant $C_A = 1.23$ was determined from the nuclear β decay. We emphasize the important property of the quark scattering amplitude $g_i(Q^2)_{Q^2\to 0}\to 1$, i.e., the g_i^3 factor does not distort the normalizations of the form factors. Therefore, Eqs. (2) and (3) do not have free parameters. Equations (2) and (3) are compared with the experimental data[1,2] in Fig. 2, in which the results of the dipole formula are also shown. From the viewpoint of authenticity of description, we cannot uniquely choose one of the curves. To do this, we need new, more accurate data. Judging from the given facts, however, the experimental evidence does not favor the dipole formula. In particular, this pertains to the region $0 \leqslant Q_N^2 \leqslant 0.5$ GeV.

Turning to the NFF $F_{V,M,A}^{(N)}$ for a weak neutral current J_μ^N, we use the result of the Weinberg-Salam model: $J_\mu^N = J_\mu^{(3)\mu} - 2\sin^2\theta_W J_\mu^{\rm em}$, where θ_W is the Weinberg angle and $J_\mu^{(3)}$ and $J_\mu^{\rm em}$ are the isovector and electro-magnetic currents. Using CVC, we find

$$F_{V,M}^{(N)}(Q^2) = \frac{1}{2}F_{V,M}^{(c)}(Q^2) - 2\sin^2\theta_W F_{1,2}^{em}(Q^2),$$

$$F_A^{(N)}(Q^2) = \frac{1}{2}F_A^{(c)}(Q^2). \tag{3}$$

Knowing the NFF for weak, charged, and electromagnetic currents, we obtain the predictions of the modified VD in the neutral-current channel. Since the systematic data for $\nu N \to \nu N$ at present are not available, Eq. (3) has only a forecasting nature.

In conclusion, we note that if $g_i(Q^2)$ is interpreted as the form factor of a quark of radius $\langle r_i^2\rangle \approx 1/m_i^2$, we can expand the geometric picture presented above,[5] assuming that $\langle r_A^2\rangle = 3\langle r_i^2\rangle$. Thus, Eq. (2) follows from the relation $\langle R^2\rangle = 3\langle r_i^2\rangle + \langle r_V^2\rangle$.

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[1)] RCR is related to momentum space by the Fourier transformation which uses the relativistic Shapiro functions $[(P_0 - \mathbf{r}\cdot\mathbf{n})/m]^{-1-irm}$ (Ref. 7) that realize the unitary, irreducible, infinite-dimensional representations of the Lorentz group, instead of the nonrelativistic plane waves $\exp(i\mathbf{kr})$.

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