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Comments and Addenda

The section Comments and Addenda is for short communications which are not appropriate for regular articles. It includes only the following types of communications: (1) Comments on papers previously published in **The Physical Review** *or* **Physical Review Letters**. *(2) Addenda to papers previously published in* **The Physical Review** *or* **Physical Review Letters**, *in which the additional information can be presented without the need for writing a complete article. Manuscripts intended for this section must be accompanied by a brief abstract for information-retrieval purposes. Accepted manuscripts follow the same publication schedule as articles in this journal, and page proofs are sent to authors.*

Tests of spontaneous left-right–symmetry breaking*

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Experimental limits on the strength of right-handed $(e\nu_e)$ and $(\mu\nu_\mu)$ current couplings are discussed in connection with a recent conjecture that parity nonconservation arises from spontaneous breaking of left-right symmetry.

In a recent communication, Bég *et al.*[1] discuss the interesting possibility that the weak interactions may be left-right symmetric at the Lagrangian level, parity violation arising exclusively from spontaneous breakdown of this symmetry (asymmetric vacuum generated by a symmetric Higgs potential). As a specific example they describe a $U(1)\times SU(2)_L\times SU(2)_R$ model in which (for the charged currents, say) left- and right-handed currents, identical in every respect but handedness $(\gamma_5\to\gamma_5)$, couple respectively to gauge bosons W_L and W_R. Owing to spontaneous symmetry breakdown, the physical bosons W_1 and W_2 (with generally different masses m_1 and m_2) are linear combinations of W_L and W_R:

$$W_1 = W_L\cos\zeta - W_R\sin\zeta\ ,$$

$$W_2 = W_L\sin\zeta + W_R\cos\zeta\ .$$

It is this mixing and mass splitting that induces parity violation. A purely left-handed structure of the effective interactions emerges in the limit $\zeta\to 0$, $m_2/m_1\to\infty$.

It is not easy on the symmetric-Lagrangian picture to understand why neutrinos are massless (or nearly so), but accepting that they are Bég *et al.* go on to consider the limits that are set by existing experimental data on the parameters m_2/m_1 and $\tan\zeta$. In fact, for low-energy processes they parametrize the effective interactions in general terms, without necessary commitment to the full details of any underlying model. Our modest purpose here is to call attention to an additional experimental input, not discussed in Ref. 1, that serves to somewhat tighten the limits on the parameters, and further, to consider yet another source of information whose interpretation *does* involve some model-dependent assumptions.

As in Ref. 1, we will be concerned with μ meson decay and with ordinary $(\Delta S=\Delta C=0)$ charged-current semileptonic interactions. Let $v_\mu=\sum_{l=e,\mu}\bar{l}\gamma_\mu\nu_l$ and $a_\mu=\sum_{l=e,\mu}\bar{l}\gamma_\mu\gamma_5\nu_l$ be the vector and axial-vector lepton currents; let V_μ and A_μ be the corresponding hadronic currents [we accept the conserved-vector-current (CVC) hypothesis and normalize V_μ so that its matrix element for neutron β decay, g_V, is unity].

The effective Lagrangians $L_{\rm lept}$ and $L_{\rm semilept}$ for low-energy leptonic and semileptonic processes have been written out in Ref. 1. They are parametrized there in terms of two quantities, η_{AA} and η_{AV}, which can be related to the parameters m_2/m_1 and $\tan\zeta$ of the $U(1)\times SU(2)_L\times SU(2)_R$ model but which can be adopted in their own right, without reference to that model. We shall find it convenient here to employ a different choice of parameters, x and y, related to η_{AA} and η_{AV} of Ref. 1 by

$$x=\frac{1+\eta_{VA}}{1-\eta_{VA}}\ ,\quad y=\frac{\eta_{AA}+\eta_{VA}}{\eta_{AA}-\eta_{VA}}\ . \tag{1}$$

We also introduce the dependent quantity

$$\rho=\frac{1-x}{1-y}\ . \tag{2}$$

Then

$$L_{\rm lept}=\frac{G_l}{\sqrt{2}}[(v_\mu^+-\rho a_\mu^+)(v_\mu-a_\mu)+(xv_\mu^++y\rho a_\mu^+)(v_\mu+a_\mu)], \tag{3}$$

$$L_{\rm semilept}=\frac{G_{sl}}{\sqrt{2}}[V_\mu^+-\rho A_\mu^+)(v_\mu-a_\mu)+(xV_\mu^++y\rho A_\mu^+)(v_\mu+a_\mu)+\text{H.c.}]\,. \tag{4}$$

Notice that the usual exclusively left-handed structures arise for the limit $x\to 0$, $y\to 0$ (hence $\rho\to 1$). In the standard four-quark and four-lepton picture the hadronic currents are formed bilinearly out of the u quark and a Cabibbo mixture of the d and s quarks. In this case

$$G_{sl}=G_l\cos\theta_C\,, \tag{5}$$

where θ_C is the Cabibbo angle. We shall return to this relation later on, but for the moment we do not exploit it.

Bég *et al.*[1] have focused on two sets of precision data to bound their weak-interaction parameters η_{AA}, η_{AV}: the longitudinal polarization P_L of electrons produced in Gamow-Teller β decay and the Michel ρ parameter that enters into the spectrum of μ-meson decay. In our notation these quantities are given by

$$P_L=\frac{v}{c}\left(\frac{1-y^2}{1+y^2}\right)\underset{y\ll 1}{\approx}\frac{v}{c}(1-2y^2)\,, \tag{6}$$

and

$$\rho=\tfrac{3}{4}\{1-\tfrac{1}{2}(x-y)^2[(1+y^2)(1+x^2)-(x+y)(1+xy)]^{-1}\}$$
$$\underset{x,y\ll 1}{\approx}\tfrac{3}{4}[1-\tfrac{1}{2}(x-y)^2]\,. \tag{7}$$

The experimental results for P_L (Ref.2) and ρ (Ref. 3) are

$$P_L=\frac{v}{c}(1.001\pm 0.008)\,,$$
$$\rho=0.752\pm 0.003\,. \tag{8}$$

We now turn to an additional experimental input, namely the asymmetry parameter for β decay of a polarized parent nucleus. In particular, we consider the case of $^{19}N_e$ decay[4]—where this parameter is small, owing to an accidental cancellation, and therefore sensitive to right-handed current contributions. For a parent of polarization P the spectrum in positron momentum p and angle θ relative to the polarization vector is given by $f(p)[1+PA(p)\cos\theta]dp\,d\cos\theta$. We are concerned with the zero-momentum limit $A(0)$. It is given by

$$A(0)=2\frac{g_A(g_A+g_R)-yg_A(yg_A+xg_V)+T_1}{g_V{}^2+3g_A{}^2+(x^2g_V{}^2+3y^2g_A{}^2)+T_2}\,, \tag{9}$$

where the T_i are tiny corrections arising from recoil effects, weak magnetism, and induced tensor form factors.[5] They are taken into account in the numerical analysis but we do not display here the lengthy expressions for the T_i. In Eq. (9) g_V and g_A are related to the Fermi and Gamov-Teller coupling constants. From the CVC hypothesis we adopt $g_V=1$.[6] The coupling constant g_A is not similarly known in advance, but we can get another relation among g_A, x, y by comparing the ft value for ^{19}Ne decay[7] with the ft value for $0^+\to 0^+$ analog β transitions.[8] Thus

$$\frac{(ft)^{0^+\to 0^+}}{(ft)^{19_{\rm Ne}}}=\frac{g_V{}^2+3g_A{}^2+(x^2g_V{}^2+3y^2g_A{}^2)+T_3}{2(1+x^2)g_V{}^2}\,. \tag{10}$$

The experimental values are

$$A(0)=-0.0391\pm 0.014\,,$$
$$(ft)^{0^+\to 0^+}=3085.4\pm 1.3\text{ sec}\,, \tag{11}$$
$$(ft)^{19_{\rm Ne}}=1716.8\pm 2.0\text{ sec}\,.$$

It is now a straightforward matter, using these inputs, to eliminate g_A between Eqs. (9) and (10) and solve for x and y—or rather, allowing for experimental uncertainties, to set limits on x and y.

Throughout, following Ref. 1, we allow two standard deviations for the limits on all input data. The boundary region in the x-y plane is shown in Fig. 1; the allowed values of x and y are constrained to lie inside the curve formed by solid

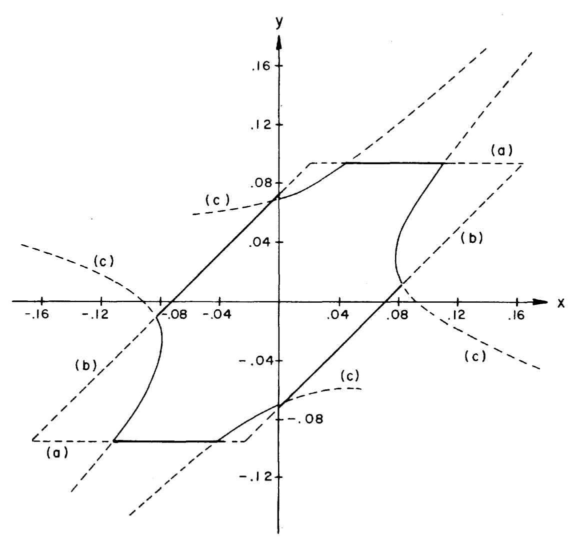

FIG. 1. Allowed region (solid curve) for parameters x and y, as set by data on longitudinal polarization (a), Michel ρ parameter (b), and Ne^{19} β decay asymmetry parameter (c).

lines. The horizontal lines (a) correspond to the limits on y set by the longitudinal polarization data [Eqs. (6) and (8)]. The slanted straight lines (b) come from the b parameter data [Eqs. (7) and (8)]. The curved lines (c) arise from the asymmetry parameter data [Eqs. (9), (10), and (11)]. The dotted extensions of each edge are shown in order to indicate the limits that are separately set by each of the inputs. It is evident that the asymmetry parameter input serves to noticeably narrow the allowed region for x and y.

Finally, let us consider what we can learn from a comparison of the ft values for μ-meson decay and $0^+ \to 0^+$ analog transitions. If we knew the values of x and y, and if we could ignore electromagnetic corrections, we could deduce the coupling constant G_l of Eq. (3) from data on the μ-meson lifetime. Let us denote by G_l^{eff} the value that we would infer supposing that $x=y=0$ and supposing that electromagnetic corrections can be ignored. Similarly, let G_{sl}^{eff} be the value of the coupling constant G_{sl} of Eq. (4) that we would infer from the ft values for $0^+ \to 0^+$ transitions, again supposing that $x=y=0$ and that electromagnetic corrections can be ignored. Then, if we accept the Cabibbo relation of Eq. (5), we have

$$\cos^2\theta_C\left(\frac{G_l^{\text{eff}}}{G_{sl}^{\text{eff}}}\right)^2(1+\Delta)=\frac{(1+x^2)(1+y^2)-(x+y)(1+xy)}{(1+x^2)(1-y)^2} \underset{x,\,y\ll 1}{\approx} 1+y-x\,. \tag{12}$$

The small correction factor Δ is introduced to represent electromagnetic correction effects.[9] The experimental values for the effective coupling constant are[10]

$$\begin{aligned} G_l^{\text{eff}} &= (1.41220 \pm 0.00043)\times 10^{-49}\ \text{erg cm}^3\,,\\ G_{sl}^{\text{eff}} &= (1.4358 \pm 0.0001)\times 10^{-49}\ \text{erg cm}^3\,. \end{aligned} \tag{13}$$

What is significant here is that the right-hand side of Eq. (12) contains terms *linear* in x and y; in contrast, for the other phenomena we have been discussing these small parameters appear only in quadratic combinations (x^2, y^2, xy). Thus the comparison embodied in Eq. (12) could obviously serve to considerably restrict the allowed region in the x, y plane. However, this equation is useless unless we can acquire independent information on the parameter $\cos\theta_C$. In the general case, for models with many quarks and leptons and with general mixings, $|\cos\theta_C|$ could even be larger than unity; and in any case we could not determine its value from other sources without specifying the details of the underlying model. In the Cabibbo picture, however, the angle θ_C can be independently determined, by comparison of $\Delta S=0$ and $\Delta S=\pm 1$ semileptonic decay reactions—provided that one invokes strong SU(3) symmetry [strictly speaking, the unknown parameters x and y enter the analysis, but they can be ignored on the scale of SU(3) and electromagnetic correction uncertainties].

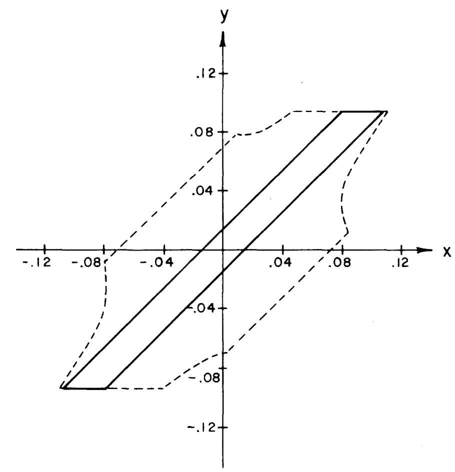

FIG. 2. Allowed region (solid curve) for parameters x and y, with additional input of Cabibbo hypothesis. The dotted curve here is a reproduction of the solid curve of Fig. 1.

On the assumption of strong-interaction SU(3) symmetry, one finds from hyperon β decay data[11]

$$\sin\theta_C = 0.232 \pm 0.003 \text{ or } \cos\theta_C = 0.973 \pm 0.001 \tag{14a}$$

and from K_{e3} decay data[11]

$$\sin\theta_C = 0.220 \pm 0.002 \text{ or } \cos\theta_C = 0.976 \pm 0.001\,. \tag{14b}$$

Rounding up the uncertainties we shall take

$$\cos^2\theta_C = 0.950 \pm 0.010\,. \tag{14c}$$

Using a theoretical estimate of the electromagnetic correction factor Δ we find[12]

$$2.00\times 10^{-2} < \Delta < 2.14 \times 10^{-2}\,. \tag{15}$$

Given the theoretical uncertainties we shall be more generous in the assignment of errors, taking $\Delta = (2 \pm 1)\times 10^{-2}$. From Eq. (12) we then have

$$\begin{aligned} 1+y-x &= 1.002 \pm 0.014\\ &\approx 1 \pm 0.014. \end{aligned} \tag{16}$$

Because of our generosity in assigning uncertainties, we shall suppose that strong SU(3) breaking has been adequately allowed for in (16) and we take the limits to be given by one "standard deviation." The allowed region set by Eq. (16), taken together with the solid curve of Fig. 1, is shown as the solid curve of Fig. 2. We emphasize again that Eq. (16) rests on the Cabibbo hypothesis—the hypothesis that the square of the effective leptonic coupling constant is equal to the sum of squares of the coupling constants for $\Delta S=0$ and $\Delta S=\pm 1$ semileptonic transitions.

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