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[2]We let k_j ($k_{j'}$) be the initial (final) momentum of particle j. We work in the c.m. frame with the z axis chosen along the direction of average space momentum of particle 1. The principal vectors are $k_{a1}=\frac{1}{2}(k_1+k_{2'})=(E_1,\vec{0},k_a)$, $k_{a2}=\frac{1}{2}(k_2+k_{2'})=(E_2,\vec{0},-k_a)$, and $q=k_1-k_1'=(0,\vec{q},0)$. Throughout this Letter we use the conventions of Bjorken and Drell, *Relativistic Quantum Fields* (McGraw-Hill, New York, 1965).

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Gauge Models and Neutral-Current Interactions

Nilendra G. Deshpande and David Iskandar
Institute of Theoretical Science, University of Oregon, Eugene, Oregon 97403
(Received 3 November 1978)

A general analysis of the gauge group SU(2) ⊗ U(1) ⊗ U′(1) is carried out and models are constructed that admit positive result for parity nonconservation in electron-deuteron scattering while giving small parity nonconservation in bismuth.

In view of the recent confirmation of parity nonconservation in electron-deuteron scattering at Stanford Linear Accelerator Center,[1] and the completion of the detailed program[2] to determine the neutrino-hadron coupling as reported by Abbott and Barnett[3] and by Sidhu and Langacker,[4] the case for the Weinberg-Salam (W-S) model[5] is greatly strengthened. However, the lack of evidence for parity nonconservation in the atomic physics experiment[6] on bismuth by Lewis *et al.*, and only a third of the expected value as found by Baird *et al.*, is a matter of grave concern. It may well be that there are both experimental[7] and theoretical problems in relating theory to experiment. On the other hand, because the atomic physics experiments measure a linear combination of coupling constants that is almost orthogonal to the one measured in electron-deuteron scattering, as emphasized by Bjorken,[8] this could herald a significant departure from the W-S model.

Present data on ν-hadron scattering and e-deuteron asymmetry already rule out any multiplet assignment other than the standard one of left-handed doublets and right-handed singlets if one restricts oneself to the group SU(2) ⊗ U(1). We therefore examine the question, what models based on larger groups are still allowed, if any? Since ν-hadron data are in excellent agreement with W-S model, we can restrict ourselves[9] to the groups SU(2) ⊗ U(1) ⊗ G. Since charged-current results, too, are in excellent agreement with W-S, only neutral currents in G are relevant. We study the simplest such group: SU(2) ⊗ U(1) ⊗ U′(1).[10] We emphasize that the reason for a general analysis of this type is to see what future experiments will serve to rule out such models. As we shall see, the present data already impose stringent restrictions on such models.

We first review electron-neutrino and electron-hadron data. If the effective interactions are written as[11]

$$-\sqrt{2}\,G_F^{-1}\mathcal{L}_{e\text{-}\nu}=[\bar{\nu}\gamma^\mu(1+\gamma_5)\nu][\bar{e}\gamma_\mu(g_V+g_A\gamma_5)e], \tag{1}$$

$$\sqrt{2}\,G_F^{-1}\mathcal{L}_{e\text{-}q}(\text{odd parity})=\bar{e}\gamma_\mu e[\epsilon_{VA}(e,u)\bar{u}\gamma_\mu\gamma_5 u+\epsilon_{VA}(e,d)\bar{d}\gamma_\mu\gamma_5 d] + \bar{e}\gamma^\mu\gamma_5 e[\epsilon_{AV}(e,u)\bar{u}\gamma_\mu u+\epsilon_{AV}(e,d)\bar{d}\gamma_\mu d], \tag{2}$$

the electron-neutrino data admit of two alternative[12] solutions: (a) *axial dominant solution*, $g_A=-0.52\pm0.15$, $g_V=-0.03\pm0.12$; and (b) *vector dominant solution*, $g_V=-0.52\pm0.15$, $g_A=-0.03\pm0.12$. The asymmetry, A, in electron-deuteron scattering is given by[13]

$$A/Q^2=-3G_F(10\sqrt{2}\,\pi\alpha)^{-1}\{[2\epsilon_{AV}(e,u)-\epsilon_{AV}(e,d)]+f(y)[2\epsilon_{VA}(e,u)-\epsilon_{VA}(e,d)]\}, \tag{3}$$

where $f(y)=[1-(1-y)^2]/[1+(1-y)^2]$. The measurement $A/Q^2=-(9.5\pm1.6)\times10^{-5}$ $(\mathrm{GeV}/c)^{-2}$ at $y=0.21$ then yields

$$[2\epsilon_{AV}(e,u)-\epsilon_{AV}(e,d)]+(0.23)[2\epsilon_{VA}(e,u)-\epsilon_{VA}(e,d)]\approx0.89\pm0.15. \tag{4}$$

Atomic physics experiments measure optical rotation ρ, which is related to Q_W, defined as

$$Q_W=2[(2Z+N)\epsilon_{AV}(e,u)+(Z+ZN)\epsilon_{AV}(e,d)]. \tag{5}$$

For bismuth, $Z=83$, $N=126$, and $Q_W=584[\epsilon_{AV}(e,u)+1.15\epsilon_{AV}(e,d)]$. Data indicate[6,7]

$$|Q_W|<20 \text{ (Lewis } et\ al.\text{)},$$
$$Q_W=-34\pm7 \text{ (Baird } et\ al.\text{)},$$
$$Q_W=-120\pm40 \text{ (Barkov)}. \tag{6}$$

We now examine the group $\mathrm{SU}(2)\otimes\mathrm{U}(1)\otimes\mathrm{U}'(1)$ and seek models that allow smaller values of Q_W. The generators of this group are taken as $\vec{T}$, Y, and Y', and the gauge coupling as g, g', and g'', respectively. We can always choose U(1) such that charge $Q=T_3+Y$. We restrict the Higgs structure to arbitrary number of doublets Φ_i and singlets ψ_i, so that the strength of the ν-hadron couplings agree with experiment. The most general neutral-current effective interaction is given by[14]

$$-\sqrt{2}(8G_F)^{-1}\mathcal{L}=J_\mu{}^ZJ^{\mu Z}+\alpha^2(J_\mu{}^Z+J_\mu{}^{Y''})(J^{\mu Z}+J^{\mu Y''}). \tag{7}$$

Here $J_\mu{}^Z=J_\mu{}^3-xJ_\mu{}^{em}$ is the neutral current in the W-S model, with $x=\sin^2\theta_W=g'/(g^2+g'^2)^{1/2}$; $J_\mu{}^{Y''}=-[g''/(g^2+g'^2)^{1/2}](M_Z{}^2/M_{CZ}{}^2)J_\mu{}^{Y'}$ and $\alpha^2=M_{CZ}{}^4/(M_C{}^2M_Z{}^2-M_{CZ}{}^4)$. The 2×2 mass matrix of the gauge bosons Z_1 and Z_2 is given in terms of vacuum expectation values λ_i of the Higgs bosons by

$$M_Z{}^2=(g^2+g'^2)\textstyle\sum_i(T_{3i}{}^2)\lambda_i{}^2,\quad M_{ZC}{}^2=g''(g^2+g'^2)^{1/2}\sum_i(T_{3i}Y_i')\lambda_i{}^2,\quad M_C{}^2=g''^2\sum_i(Y_i')^2\lambda_i{}^2. \tag{8}$$

We define a quantum number $Y''=\int J_0{}^{Y''}d^3x$. The necessary and sufficient condition that ν-hadron scattering be the same as in the W-S model is that $Y''(\nu_L)=-\frac{1}{2}$. From Eq. (8) and the definition of Y'' it is easy to verify that this condition is satisfied *naturally*, i.e., for arbitrary values of λ_i, only if each Higgs doublet satisfies the condition $Y'(\Phi_i)=-Y'(\nu_L)$ resulting in

$$Y''(\Phi_i)=\tfrac{1}{2}. \tag{9}$$

We at first restrict ourselves to only natural models. Assuming μ-e universality, the most general Y'' assignment of various particles relevant to experiment are

$$Y''(e_L)=-\tfrac{1}{2},\quad Y''(e_R)=\gamma,\quad Y''(u_L,d_L)=\beta,\quad Y''(u_R)=\beta+\tfrac{1}{2},\quad Y''(d_R)=\beta-\tfrac{1}{2}. \tag{10}$$

If e_R is a singlet under SU(2), $\gamma=-1$; if a doublet, γ can be arbitrary. The effective coupling constants are then

$$g_V=-\frac{1+D}{2}+Zx,\quad g_A=\frac{D-1}{2},\quad \epsilon_{VA}(e,u)=-\epsilon_{VA}(e,d)=\left[\frac{1+D-4x}{2}\right],$$
$$\epsilon_{AV}(e,u)=\frac{1-D}{2}\left[1-\frac{8x}{3}\right]+4\alpha^2D(\gamma+\tfrac{1}{2})\left(\beta+\frac{1}{2}-\frac{2x}{3}\right), \tag{11}$$
$$\epsilon_{AV}(e,d)=-\frac{1-D}{2}\left[1-\frac{4x}{3}\right]+4\alpha^2D(\gamma+\tfrac{1}{2})\left(\beta-\frac{1}{2}+\frac{x}{3}\right),$$

where $D=0$ for e_R singlet and $D=1$ for e_R in a doublet.

We reach the following conclusions:

(a) If e_R *is singlet:* All couplings are identical to W-S model. The only difference is that the mass of one of the $Z_{1,2}$ bosons could be much lighter than the W-S value of 86 GeV.

(b) If e_R *is in doublet:* (i) The vector-dominant solution is preferred over the W-S axial-dominant solution in ν-e scattering; (ii) In electron-deuteron experiment, y dependence of the asymmetry is predicted uniquely, and is more rapid than W-S model. We find for asymmetry

$$A/Q^2=-1.066\times10^{-14}[\lambda(\beta+\tfrac{3}{2}-\tfrac{5}{3}x)+f(y)(3-6x)], \tag{12}$$

where $\lambda = 4\alpha^2(\gamma + \frac{1}{2})$. We have plotted these curves in Fig. 1 for $x = 0.25$. (iii) The value of Q_W comes out to be

$$Q_W = 584\lambda[2.15\beta - 0.075 - 0.28x]. \tag{13}$$

We prefer the choice $\beta = 0$ which corresponds to $Y'(u_L) = 0$. This choice predicts remarkably $Q_W = -43 \pm 11.83$ for $x = 0.25$ in excellent agreement with data of Baird *et al.* We further find $\lambda = 0.503 \pm 0.139$. This implies that the Z boson would be lighter than in the W-S model, the exact value depending on the value of γ. For $\gamma = 0$, $M_{Z_1} < (0.9) \times (86\text{ GeV})$, where $x = 0.25$ is assumed.

We have also examined unnatural models[15] based on the group $SU(2) \otimes U(1) \otimes U'(1)$. If two Higgs doublets Φ_1 and Φ_2 with Y' quantum numbers ± 1 and the symmetry $\Phi_1 \leftrightarrow \Phi_2$ are chosen, then $\lambda_1 = \lambda_2$ at the tree level, and there is no Z-C mixing. We can then take the limit $M_{CZ} \to 0$ of Eq. (7). The Y' quantum number assignment is then restricted to

$$Y'(\nu_L, e_L) = 0, \quad Y'(e_R) = \gamma,$$
$$Y'(u_L, d_L) = \beta, \quad Y'(u_R) = \beta + \eta, \quad Y'(d_R) = \beta + \xi, \tag{14}$$

where $|\eta| = |\xi| = 1$. The coupling g_A and g_V are as before. The other couplings are

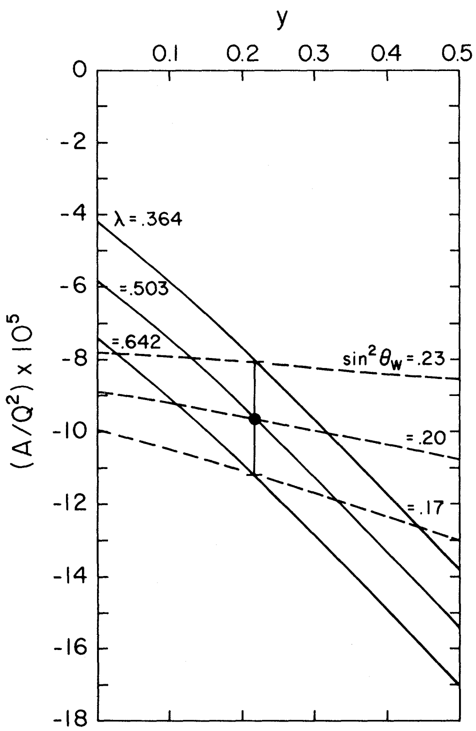

FIG. 1. The y dependence of the electron-deuteron asymmetry for the natural model considered in the text. The numbers on the solid lines refer to different values for λ when $\beta = 0$ and $x = 0.25$. The dashed curves are for the W-S model.

$$2\epsilon_{VA}(e,u) = (1 + D - 4x) + 4\alpha^2\gamma\eta, \quad 2\epsilon_{VA}(e,d) = -(1 + D - 4x) + 4\alpha^2\gamma\xi,$$
$$2\epsilon_{AV}(e,u) = (1 - D)\left(1 - \frac{8x}{3}\right) + 4\alpha^2\gamma(2\beta + \eta), \quad 2\epsilon_{AV}(e,d) = -(1 - D)\left(1 - \frac{4x}{3}\right) + 4\alpha^2\gamma(2\beta + \xi), \tag{15}$$

where α^2 now stands for $g''^2 M_Z^2/(g^2 + g'^2)M_C^2$.

A general analysis shows that following solutions exist. (a) If e_R *is a singlet:* (i) axial-dominant ϵ-ν scattering is as in the W-S model; (ii) e-d scattering can be chosen to correspond to the W-S model if $2\beta + 2\eta - \xi \approx 0$; and (iii) Q_W can be made arbitrarily small provided $\eta = -\xi$. (b) If e_R *is in doublet representation:* This yields solutions for small Q_W identical to Ma, Pramudita, and Tuan[15] who consider $\beta = 0$, $\eta = 1$, $\xi = -1$. This solution is quite similar to our natural model with e_R in doublet except that they obtain a more rapid y dependence in e-d scattering and the value of Q_W is -13.14 ± 3.5.

We have constructed different models that have the common feature of having a small value of Q_W for bismuth. The most attractive model is the natural model with $\beta = 0$. Determination of the y dependence of e-deuteron scattering is crucial to establish this model. Improvement on ν-electron data will also serve to check the doublet assignment of e_R. It is harder to test an unnatural model with e_R a singlet. Observation of parity nonconservation in other atoms, especially light atoms, can serve to distinguish this model from W-S theory.

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Yrast Isomers and Possible Oblate Shape in ^{152}Dy

J. C. Merdinger, F. A. Beck, T. Byrski, C. Gehringer, and J. P. Vivien
Centre de Recherches Nucléaires et Université Louis Pasteur, 67037 Strasbourg, France

and

E. Bozek and J. Styczen
Institute of Nuclear Physics, Cracow, Poland
(Received 28 September 1978)

Excitation energies, spins, and parities have been determined for ^{152}Dy in (HI, xn) reactions up to $I^\pi = 27^+$. Three isomers with $T_{1/2} = 49.5$ ns ($E_x = 5035$ keV, $I^\pi = 16^+$), 9.9 ns ($E_x = 6076$ keV, $I^\pi = 20^-$), and 1.6 ns ($E_x = 7828$ keV, $I^\pi = 26^-$) have been found. The g factor of the second isomeric state was measured to be $g = 0.55 \pm 0.06$. The present experimental data compares well with microscopic calculations which imply an oblate shape for ^{152}Dy at high angular momenta ($I^\pi \geq 16^+$).

Recently, a great deal of theoretical work has been devoted to the study of yrast traps occuring at high and very high spins. Systematic experimental search for delayed γ-ray cascades has shown the existence of high-spin isomers[1] belonging to nuclei situated around the neutron number $N = 82$. Theoretical calculations[2-4] have pointed to this region of isotopes as being especially favorable for the occurrence of yrast traps based on the oblate-coupling scheme. However, some isomers can be explained as shell-model isomeric states.[3-6] Detailed spectroscopic work on the high-spin isomers is therefore essential for a better comparison with the calculations. In this Letter we report on the existence of three high-spin isomeric states in ^{152}Dy. Their spins, parities, lifetimes, and decay properties have been established by γ-ray spectroscopic methods. The g factor of the second isomeric state ($E_x = 6076$ keV) has also been determined. The investigation of the nucleus $^{152}_{66}Dy_{86}$ by Jansen *et al.*[7] has already shown the existence of an isomer of $T_{1/2} \approx 60$ ns at $E_x \approx 5$ MeV with $15 \leq I \leq 18$. Theoretical calculations of Cerkaski *et al.*[3] predict at least three yrast traps in this nucleus.

The nuclide ^{152}Dy has been produced at high angular momenta by means of the heavy-ion reactions ^{140}Ce(^{16}O, $4n$)^{152}Dy ($E_{^{16}O} = 88$ MeV) and ^{141}Pr(^{15}N, $4n$)^{152}Dy ($E_{^{15}N} = 80$ MeV) at the Strasbourg MP accelerator. In-beam γ-spectroscopic experiments were performed using a variety of Ge(intrinsic), Ge(Li), and Si(Li) spectrometers,