SU (5) predictions regarding parity-violating effects in atomic physics

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The experimental phenomenology of parity-violating effects in atomic physics is presently consistent with the predictions of the *SU* (5) asymptotic-freedom model, although there may be important differences from predictions of the Weinberg–Salam model.

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The successful development of the grand unified theory has attracted interest to the experimental detection of parity-violating effects in atomic physics. Such effects were first predicted by Zel'dovich[1] in 1959 and have been discussed since then by several other authors.[2] In particular, the Weinberg–Salam model of a unified interaction, which has been supported by many experimental facts, also predicts a nonzero parity-violating effect in atomic physics, and an experimental test of such predictions has now become a problem of the utmost importance.

The experimental results which have been obtained, however, have contradictory implications, and the situation remains unclear, both experimentally and theoretically. Particularly inconsistent are the experimentally based predictions of the magnitude of the parity-violating effect in heavy atoms. The results of some experiments[3] on this question agree well with the predictions of the Weinberg–Salam model, while the results of other experiments[4] imply that the observed effect should be much smaller. Experiments have also been carried out on *ed* scattering of polarized electrons,[5] and in this case the effect agrees completely with the Weinberg–Salam predictions.

The theory for the parity-violating effects is based on an effective quark–lepton Lagrangian, which is conveniently parametrized as follows, after Ref. 6:

$$\mathcal{L}_{eq} = -\frac{G}{\sqrt{2}}\left\{(\bar{e}\gamma_\mu\gamma_5 e)\left[\frac{\tilde{\gamma}+\tilde{\alpha}}{2}\,\bar{u}\gamma_\mu u + \frac{\tilde{\gamma}-\tilde{\alpha}}{2}\,\bar{d}\gamma_\mu d\right] + (\bar{e}\gamma_\mu e)\left[\frac{\tilde{\delta}+\tilde{\beta}}{2}\,\bar{u}\gamma_\mu\gamma_5 u + \frac{\tilde{\delta}-\tilde{\beta}}{2}\,\bar{d}\gamma_\mu\gamma_5 d\right]\right\} \quad (1)$$

The experimental data are analyzed in terms of the four parameters of Lagrangian (1), which are functions of the Weinberg angle. The effect of the parity-violating interactions, which leads to an optical rotation of the polarization plane, is proportional to the "weak charge"

$$Q_W = (A - 2Z)\tilde{\alpha} - 3A\tilde{\gamma}, \tag{2}$$

which is determined, according to (1), by only the parameters $\tilde{\alpha}$ and $\tilde{\gamma}$. In Eq. (2), A and Z are the atomic weight and the atomic number, respectively. The asymmetry of deep-inelastic *ed* scattering,

$$A(y)/q^2 = a_1 + a_2 \{[1-(1-y)^2]/[1+(1-y)^2]\}, \tag{3}$$

is determined by all the coefficients in (1) and may be parametrized by the following two quantities, as in (3):

$$\tilde{a}_1 = a_1/k = \tilde{\alpha} + \frac{1}{3}\tilde{\gamma}, \quad \tilde{a}_2 = a_2/k = \tilde{\beta} + \frac{1}{3}\tilde{\delta}, \tag{4}$$

where $k = 9\,G_F/5\sqrt{2}\,e^2$. For the Weinberg–Salam model these coefficients are given by

$$\begin{aligned} \tilde{\alpha} &= -(1 - 2\sin^2\theta_W), & \tilde{\alpha} + \frac{1}{3}\tilde{\gamma} &= -\left(1 - \frac{20}{9}\sin^2\theta_W\right), \\ \tilde{\gamma} &= (2/3)\sin^2\theta_W, & \tilde{\beta} + \frac{1}{3}\tilde{\delta} &= -\left(1 - 4\sin^2\theta_W\right), \end{aligned} \tag{5}$$

and the effects are extremely sensitive to the choice of $\sin^2\theta_W$. The SU(2) model predicts $\sin^2\theta_W = 0.23$.

The SU(5) unified-interaction model[7,8] combines quantum chromodynamics and the Weinberg–Salam SU(2) × U(1) model in a common gauge group. All the predictions of this model are retained for the usual generalizations of the Weinberg–Salam model, although a different value of $\sin^2\theta_W$ should be used in analyzing the experimental data. Specifically, the value $\sin^2\theta_W = 0.21$ should be used. This is not, however, a qualitative change. If the experiments of Ref. 3 prove incorrect, then it will be extremely difficult to reconcile the experimental result of Ref. 4 with the SLAC data on inelastic *ed* scattering in the framework of the standard SU(5) model. This situation has forced several authors[9] to reject the SU(5) grand-unification scheme and to seek a resolution of the difficulty in more complicated models.

In this letter we will show that such drastic conclusions about the SU(5) theory are premature. In particular, all the difficulties which have arisen to date can be easily resolved for the SU(5) grand-unification model proposed in Ref. 8. Some straightforward changes in the multiplet composition within the framework of the SU(5) model are sufficient to reconcile the experimental results of Ref. 4 with the SLAC data[5] in a quite natural way. Clarification of the experimental situation for the SU(5) model would require the determination of a completely definite multiplet composition for this model.

The SU(5) model, as set forth in Ref. 8, agrees with only the experimental data of Refs. 3 and 5. In the present study we have not found it possible to change the predictions of this model without changing its multiplet composition, although there are some realistic possibilities for doing so. For this SU(5) composition of spinor multiplets, the weak charge is determined by not only $\sin^2\theta_W$ (as it is in the Weinberg–Salam model) but also two additional parameters:

$$Q_W = \left[(A - 2Z)\left(-\frac{1 + c_L^2}{2} + 2\sin^2\theta_W \right) - 3A\left(-\frac{1 - c_L^2}{2} + \frac{2}{3}\sin^2\theta_W \right) \right](1 - s_R^2) \tag{6}$$

In principle, these new parameters could substantially change the situation: Since $c_L^2 = \cos^2(d_L \hat{,} b_L)$ and $c_R^2 = \cos^2(e_R \hat{,} \tau_R)$, which are parameters that determine the mixing angles of the corresponding particle, are somewhat arbitrary, the predictions of the model could be easily reconciled with the experimental data of Ref. 4 by choosing this mixing to be sufficiently pronounced. The experiments of Ref. 5 on *ed* scattering, whose parametrization also changes,

$$\tilde{a}_1 = -\left[\left(1 - \frac{1}{3} s_L^2\right) - \frac{20}{9}\sin^2\theta_W \right](1 - s_R^2)$$
$$\tilde{a}_2 = -[(1 + s_R^2) - 4\sin^2\theta_W], \tag{7}$$

do not contradict this possibility, because of the large uncertainty in the experimental value of the parameter $\tilde{a}_2$. In this SU(5) model, however, the two angles turn out to be rigidly coupled,

$$\tan(e_R \hat{,} \tau_R) = \left(\frac{q_1 \rho}{\sqrt{2}}\right)\frac{1}{m_\tau}\ ;\ \tan(d_L, b_L) = \left(\frac{q_1 \rho}{\sqrt{2}}\right)\frac{1}{m_b}, \tag{8}$$

and, furthermore, the parameter c_R^2 cannot be changed, since it determines the "exotic" decays of the τ lepton. These decays have not yet been found experimentally, and the upper limit on the parameter s_R^2 is

$$s_R^2 \lesssim 10^{-4}, \tag{9}$$

so that we cannot extract from this SU(5) model any predictions regarding parity-violating effects which are different from those of the model of Ref. 7.

However, we can immediately see a way out of this situation: We must change the multiplet composition of the spinor fields in such a manner that the parameters c_L^2 and c_R^2 become independent. It turns out that a redefinition of the $\psi_{L,R}$ multiplets makes it a simple matter to replace the $(u, d)_L$ quarks by $(c, s)_L$:

$$\psi_R = \begin{pmatrix} & (c_R)_3^c & -(c_R)_2^c & u_L^1 & d_L^1 \\ u_R^3 & & (c_R)_3^c & u_L^2 & d_L^2 \\ u_R^2 & u_R^1 & & u_L^3 & d_L^3 \\ (c_L)_1^c & (c_L)_2^c & (c_L)_3^c & & \mu_L^+ \\ (s_L)_1^c & (s_L)_2^c & (s_L)_3^c & e_R^- & \end{pmatrix} = \psi_L \quad \begin{pmatrix} d_R^1 \\ d_R^2 \\ d_R^3 \\ \mu_R^+ \\ \nu_R \end{pmatrix} = \theta_R$$
$$\theta_L = \left((s_R)_1^c \quad (s_R)_2^c \quad (s_R)_3^c \quad e_L^- \quad \nu_L \right) \tag{10}$$

The u_R and c_R quarks do not necessarily have to be redefined, since, to a large extent, this question affects only the phenomenology of the proton decay and should be discussed separately. The parameters c_L^2 and c_R^2 are now fixed by different parameters of the SU(5) theory,

$$\tan(e_R \hat{,} \tau_R) = \left(\frac{q_1 \rho}{\sqrt{2}}\right)\frac{1}{m_\tau}, \quad \tan(d_L \hat{,} t_L) \approx \left(\frac{q_2 \sigma}{\sqrt{2}}\right)\frac{1}{m_t}, \tag{11}$$

and by choosing them independently it is a simple matter to reconcile the predictions of this version of the SU(5) theory with the experimental data of Refs. 4 and 5. The parameter c_L^2 is an adjustable parameter in the SU(5) theory; in particular, the results of Refs. 4 and 5 are consistent if

$$s_L^2 \approx 0.1. \tag{12}$$

Thus we see that there is no problem in explaining the parity-violating effects in atoms for the SU(5) model of Ref. 8, and a clarification of the experimental situation will make it possible to eliminate some of the arbitrariness of the model regarding its multiplet composition.

It is also interesting to note certain features of the SU(5) model with the multiplet composition in (9), expecially the possibility of (b, s) mixing. This possibility may prove extremely important for interpreting νN experiments, where the existence of a $(\bar{b}\gamma_\mu c)$ current is currently considered a leading possibility. Furthermore, in this SU(5) theory we can expect changes in the fundamental decay modes of the proton, since the "partner" of the d quark is now a muon instead of an electron. The (e, τ) phenomenology is naturally left unchanged, and the same can be said of all the low-energy physics of the weak and electromagnetic interactions.

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1. Ya. B. Zel'dovich, Zh. Eksp. Teor. Fiz. **36**, 964 (1959) [Sov. Phys.–JETP **9**, 682 (1959)].
2. M. A. Bouchiat and C. C. Bouchiat, Phys. Lett. **48B**, 111 (1974); A. N. Moskalev, R. M. Ryndin, and I. B. Khriplovich, Usp. Fiz. Nauk **118**, 409 (1976) [Sov. Phys. Usp **19**, 220 (1976)].
3. L. N. Barkov and M. S. Zolotarev, Pis'ma Zh. Eksp. Teor. Fiz. **27**, 379 (1978) [JETP Lett. **27**, 357 (1978)]; L. M. Barkov and M. S. Zolotorev, Phys. Lett. **85B**, 308 (1979).
4. Yu. V. Bogdanov, I. I. Sobel'man, V. N. Sorokin, and I. I. Struk, Pis'ma Zh. Eksp. Teor. Fiz. **31**, 234 (1980) [JETP Lett. **31**, 214 (1980)].
5. C. Y. Prescott *et al.*, Phys. Lett. **77B**, 347 (1978); **84B**, 524 (1979).
6. P. Q. Hung and J. J. Sakurai, Phys. Lett. **88B**, 91 (1979); I. Liede and M. Roos, Nucl. Phys. **167B**, 397 (1980).
7. H. Georgi and S. L. Glashow, Phys. Rev. Lett. **32**, 438 (1974); A. J. Buras, J. Ellis, M. K. Gaillard, and D. V. Nanopoulos, Nucl. Phys. **135**, 66 (1978).
8. E. S. Fradkin and O. K. Kalashnikov, Phys. Lett. **64B**, 177 (1976); O. K. Kalashnikov, Preprint N166, Lebedev Phys. Int., 1980.
9. H. Georgi and S. Weinberg, Phys. Rev. D **17**, 275 (1978); P. Fayet, CERN Preprint TH.2907, 1980.

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