PARITY NONCONSERVATION EFFECTS INDUCED BY WEAK INTERACTIONS IN NUCLEAR AND ELECTROMAGNETIC FORCES

E. M. Lipmanov
Volgograd Pedagogical Institute
Submitted 24 June 1965

The current-current form of universal weak interactions [1] predicts parity nonconservation effects in nuclear forces, proportional to the first power of the Fermi constant C [1,2]. Such effects were apparently observed experimentally recently at the Institute of Theoretical and Experimental Physics of the USSR Academy of Sciences [3] and at the California Institute of Technology [4]. What will the isotopic properties of parity-nonconserving nuclear interactions turn out to be? The character of the theoretical answer to this question depends essentially on the choice of the concrete model which must supplement the current-current form of the weak interaction to satisfy the known empirical rules $|\Delta\vec{T}| \equiv 1/2$, $|\Delta S| < 2$, and $\Delta S = +\Delta Q$, and the fact that lepton decays of strange particles are suppressed (see [5-8]).

In the model with minimum violation of isotopic symmetry of hadron weak interactions [8], the parity nonconserving nuclear interactions have exact isotopic invariance and in this respect do not differ from ordinary forces.

In this letter we call attention to several characteristic predictions with respect to parity nonconservation effects in nuclear and electromagnetic forces which appear when the model of reference [8] is generalized, and which it would be desirable to verify experimentally.

Let us write down the "preliminary" isotopical- and CP-invariant Lagrangian of semi-weak interactions in the form

$$L_X = g[\vec{j}^V\vec{X}^V + j^s X^s + j^{\gamma(0)} X^{\gamma(0)} + f j^{u(0)} X^{u(0)}] \tag{1}$$

where j^V, j^s, and $j^{\gamma(0)}$ are the isovector, isospinor, and isoscalar hadron currents, respectively. We assume that these currents constitute a complete set of components of a unitary octet 1). The isoscalar current $j^{u(0)}$ will be regarded as a unitary singlet. The intermediate vector X-bosons also form a unitary octet and singlet. The masses of all the X-bosons will at first be assumed equal to M. By violating the universality of the coupling constant for the singlet current $j^{u(0)}$ in (1), choosing $f \cong 2 \times 10^{-3}$, we can take into account the observed small violation of CP-invariance (see the discussion in [9]). We consider below the consequences resulting from inclusion of the eighth component of the current octet $j^{\gamma(0)}$ in (1). This inclusion is attractive from the point of view of formulating an analogy with electrodynamics [10].

The mixing of the bosons $X^{v(0)}$ and $X^{\gamma(0)}$ leads to the following transformation for part of the Lagrangian (1)

$$j^{v(0)}X^{v(0)} + j^{\gamma(0)}X^{\gamma(0)} \rightarrow [(2)^{-1/2}(j^{v(0)} + j^{\gamma(0)})X_1^{(0)}] + [(2)^{-1/2}(j^{v(0)} - j^{\gamma(0)})X_2^{(0)}] \tag{2}$$

The masses of the $X_{1,2}^{(0)}$-bosons are $M_{1,2}^2 = M^2 \mp \kappa^2$, where κ is the off-diagonal matrix element causing the particle mixing. The vector part of the current $(j^{v(0)} + j^{\gamma(0)})$ is identical in its isostructure to the electric current, while the current $(j^{v(0)} - j^{\gamma(0)})$ has an additional isostructure. The entire subsequent formulation of the model corresponds to [8], provided we make in the corresponding formulas of that paper the substitutions

$$j^{v(0)} \rightarrow [(2)^{-1/2}(j^{v(0)} - j^{\gamma(0)})], \qquad X^{v(0)} \rightarrow X_2^{(0)} \tag{3}$$

The isotopic structure of weak strangeness-conserving non-lepton interaction now depends essentially on two circumstances - on the value of κ and on the physical meaning possessed by the "isolated" weak interaction appearing in the theory

$$\Delta L = g/\sqrt{2}(j^{v(0)} + j^{\gamma(0)})X_1^{(0)} \tag{4}$$

We note that, according to [10], the lepton terms can be absent from the neutral current $(j^{v(0)} - j^{\gamma(0)})$, but must enter in the current $(j^{v(0)} + j^{\gamma(0)})$, as well as in the electric current.

A very attractive assumption is that $\kappa = M$ and that $X_1^{(0)}$ is none other than the photon, while the interaction (4) is simply the electromagnetic interaction, so that the model describes in fact a united electromagnetically-weak interaction. [2)] However, such an assumption is a new hypothesis, since the interaction (4) does not conserve parity and the question of how the parity conservation is restored (the actual current vanishes) when the mass of the vector boson tends to zero remains open [3)].

If the electromagnetic interaction has "split off" from the weak interaction in the sense indicated above, i.e., if it is simply a modification of interaction (4), then transitions with $|\Delta\vec{T}| = 0$, 1, or 2 should be of comparable magnitude in nuclear parity-nonconservation effects, and the analogous electromagnetic effect should be much larger in magnitude than αC [4)]. On the other hand, if interaction (4) is a "weak double" of the electromagnetic interaction, then we can expect the appearance of electromagnetic parity nonconservation effects up to a value $\sim\alpha C$ [13], or even more, in spite of the fact that the reaction $\nu_\mu + p \rightarrow \nu_\mu + p$ has not been experimentally observed [14]. Effects with magnitude of the order of αC are obtained in the simplest variant of the unified model with $\kappa = 0$. It can be shown that in this case the approximate selection rule $\Delta T = 0$ will hold in nuclear parity-nonconservation effects (the $|\Delta\vec{T}| = 1$ admixture is less than 1/30th in amplitude). When

$\kappa \neq 0$, however, and when the X-boson masses are not equal, the parity nonconservation effects in electromagnetism can have different magnitudes, smaller or larger than αC, and transitions with $|\Delta\vec{T}| = 0$, 1, and 2 can then make comparable contributions to parity nonconserving nuclear forces 5).

In sum, the unified model of broken isotopic symmetry of weak interactions predicts definite correlations of the parity nonconservation effects in nuclear and electromagnetic interactions.

In particular, if the magnitude of the electromagnetic parity nonconservation effects differs appreciably from the estimate αC, then transitions with $|\Delta\vec{T}| = 0$ and 1, and possibly also $|\Delta\vec{T}| = 2$, should be comparable in parity nonconserving nuclear forces, and the absence in the latter of transitions with $|\Delta\vec{T}| = 1$ and 2 calls for the presence of parity nonconserving electromagnetic effects of the order of αC.

Typical experiments for the observation of parity nonconservation effects in electromagnetic phenomena, such as ep scattering, mixing of levels of different parity in the hydrogen atom, etc., were discussed earlier by Zel'dovich et al. [13] The considerations presented above show the desirability of such research, in spite of the lack of interactions between neutrino pairs and nucleons [14]. Particularly promising are investigations at large momentum transfers, since the relative magnitude of these effects increases like q^2.

[1] R. P. Feinman and M. Gell-Mann, Phys. Rev. 109, 193 (1958).

[2] R. Blin-Stoyle, Phys. Rev. 118, 1605 (1960); 120, 181 (1961).

[3] Abov, Krupchitskii, and Oratovskii, Phys. Lett. 12, 25 (1964); YaF 1, 479 (1965), Soviet JNP 1, 341 (1965).

[4] F. Boehm and E. Kankeleit, Phys. Rev. Lett. 14, 312 (1965).

[5] N. Cabibbo, Phys. Rev. Lett 10, 531 (1963); 12, 62 (1964).

[6] Dashen, Frautschi, Gell-Mann, and Hara, Proceedings of the Dubna Conference 1964; I. S. Shapiro, paper at Conference on Particle Symmetries, Moscow, February 1965.

[7] B. D. Espagnat and Y. Villachon, Nuovo Cimento 33, 948 (1964).

[8] E. M. Lipmanov, JETP 47, 360 (1964), Soviet Phys. JETP 20, 239 (1965).

[9] E. M. Lipmanov, JETP 48, 750 (1965), Soviet Phys. JETP 21, 496 (1965).

[10] E. M. Lipmanov, JETP 43, 893 (1962), Soviet Phys. JETP 16, 634 (1963).

[11] J. Schwinger, Ann. of Phys. 2, 407 (1957).

[12] A. Salam and J. Ward, Nuovo Cimento 11, 568 (1959); Phys. Lett. 13, 168 (1965).

[13] Ya. B. Zel'dovich, JETP 36, 964 (1959), Soviet Phys. JETP 9, 681 (1959); Ya. B. Zel'dovich and A. M. Perelomov, JETP 39, 1115 (1960), Soviet Phys. JETP 12, 777 (1961); V. N. Baier and I. B. Khriplovich, JETP 39, 1374 (1960), Soviet Phys. JETP 12, 959 (1961).

[14] M. M. Block, H. Burmeister, et al., Phys. Lett. 12, 281 (1964).

1) We note that, unlike the Cabibbo model [5], there is no need in this case for assuming that the strangeness nonconserving hadron current is suppressed, and the equality of the values of "$\sin\theta$" is automatically obtained for the vector and axial current (see [8]).

2) The concept of a united electromagnetically-weak interaction was developed in the papers of Schwinger [11], Zel'dovich, and especially Salam and Ward[12]. This notion presupposes that g = e and that the intermediate boson has a large mass $M \approx 30\ m_p$. The concrete expression used here for the connection between the weak and the electromagnetic interactions corresponds to the author's paper [10].

3) The most direct, although presently very uneconomical, way of constructing a unified electromagnetic weak interaction with broken isotopic symmetry consists in increasing further the number of intermediate X-fields in (1) with additional currents of the (V + A) type and "neutrino-flip" transitions $(\nu_e\text{-}\mu^+)$ and $(\nu_\mu\text{-}e^+)$. Such a model can be reconciled with all the available data. An analysis of this interesting problem will be published elsewhere.

4) According to (1), a contribution to parity nonconservation effects in electromagnetic processes should be made by the self-action term of the singlet current $g^2f^2j^{u(0)}j^{u(0)}$. In addition, such effects, of course, appear in second order in C.

5) The requirement that the parity nonconservation in electromagnetic phenomena have a magnitude $\beta(\alpha C)$ can be satisfied, for example, by means of the following choice of constants:

$$M^2_{v(\pm)} = M^2_s = M^2, \quad M^2_{v(0)} = M^2_{\gamma(0)} = M^2/2(1/\beta + 1), \quad \kappa^2 = \pm M^2/2(1/\beta - 1)$$

where the plus sign is for $\beta < 1$ and the minus sign for $\beta > 1$.

VECTOR PAIRING IN SUPERCONDUCTORS OF SMALL DIMENSIONS

A. I. Larkin
Moscow Physico-technical Institute
Submitted 25 June 1965

It has been suggested in several papers [1,2] that electron pairing takes place in some superconductors in a state with unity orbital angular momentum, thus explaining the results of experiments on the Knight shift. However, the theoretical analysis of the vector pairing was made for infinite space, whereas the experiments were performed on samples with dimensions much smaller than the depth of penetration of the magnetic field.

It will be shown below that vector pairing vanishes when the pair dimensions are larger than the sample dimension or the electron mean free path. In ordinary scalar pairing the transition temperature is independent of both the sample dimensions and the impurity concentration. The reason for this difference is that in vector pairing the wave function F of the pair depends on the direction of the relative momentum of the electrons forming the pair, and vanishes when the momentum uncertainty becomes of the order of the pair dimensions.

Let us consider first the influence of impurities on vector pairing. We average the equations for the Green's functions in the same manner as in scalar pairing [4], obtaining the proper-energy parts $\overline{G}$ and $\overline{F}$