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Possible Electric Dipole Moment of Nucleons*

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It is noted that the existence of a four-nucleon weak interaction which violates T invariance and P invariance would lead to a nucleon electric dipole moment which is of first order in the Fermi coupling constant. The observation of such a moment is therefore not necessarily evidence for intermediate bosons.

THE possibility that elementary particles possess electric dipole moments (EDM) has been considered on several occasions,[1] in particular after the discovery of parity nonconservation in weak interactions. However, this possibility was not taken very seriously because of the assumed invariance of all interactions under time reversal and the demonstration that time-reversal invariance implied[2] the vanishing of EDM for nondegenerate systems.

Recently there has appeared evidence for a violation of CP invariance[3] in $\Delta S=1$ interactions. If one accepts the TCP theorem, it follows that in such interactions T is also violated. In view of this possibility and of some suggestions[4] for detecting a much smaller EDM than has higherto been possible, it is of some interest to reexamine the question of possible origins and magnitudes of EDM.

In this note we point out that there are at least two mechanisms by which the weak interactions could generate a weak EDM for the nucleon, if they violate time reversal. By weak, we mean that the EDM measured in nuclear magnetons would be of the order $G_F m_N^2 \approx 10^{-5}$ where G_F is the Fermi coupling constant. A "doubly weak" EDM, of order $G_F^2 m_N^4 \approx 10^{-10}$ is presumably too small to measure.

One mechanism for producing an EDM occurs if weak interactions are mediated by an intermediate vector boson (W meson). This has recently been considered by Meister and Radha.[5]

We do not wish to comment in detail on their calculation, but only to note that even if T violation is restricted to the $\Delta S=1$ interactions of the W meson, this will still generate a weak EDM for the nucleons. To see this for example in the case of the proton, it is only necessary to consider an intermediate state with a Λ^0 and W meson, rather than the state of neutron and W meson considered by Meister and Radha. The EDM obtained this way will be comparable to that given in Ref. 5, perhaps multiplied by the squared ratio of the $\Delta S=1$ and $\Delta S=0$ coupling constants.

It is also possible, under plausible assumptions, to obtain weak EDM even in the absence of the W meson. In particular, it is only necessary to assume that there exist four-baryon weak interactions which conserve strangeness, and these violate parity and time reversal invariance also.

The existence of a weak-nucleon-nucleon scattering interaction is required by the usual current×current model of weak interactions.[6] If any of the weak currents do not have a definite transformation property under T, we expect that the $\Delta S=0$ four-fermion interaction generated by the products of these currents will have a part which violates T invariance. Some evidence has recently been reported for the existence of a parity-violating nucleon-nucleon interaction.[7] However there is no indication of a violation of T invariance. Let us therefore examine the consequences of assuming such an interaction, which we symbolize by $\bar{n}p\bar{p}n$, exists with a strength comparable to G_F, and has a nonnegligible part that violates time reversal. It is then easy to see that this interaction, in combination with the strong and electromagnetic interactions of the nucleons. will generate an EDM for the nucleons which is linear in G_F. In order to demonstrate this, one graph is worth several paragraphs, and in Figs. 1 and 2 we give two examples of graphs which generate EDM of this type. Both of these graphs give EDM whose strength in nuclear magnetons is of the order $10^{-7}\sin\theta$ where $\sin\theta$ is the ratio of the T-violating to T-invariant part of the $\bar{n}p\bar{p}n$ interaction.

While it is possible to compute these and other graphs

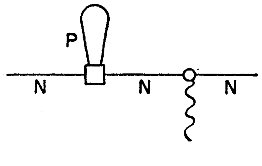

FIG. 1. A graph contributing to the nucleon EDM. The square vertex represents the T and P invariance violating weak interaction $\bar{n}p\bar{p}\gamma_5 n$ and the circular vertex comes from the electromagnetic interaction of the photon with the anomalous magnetic moment of the nucleon.

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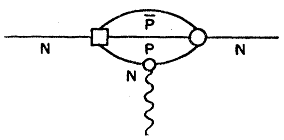

FIG. 2. Another diagram which can generate a nucleon EDM. Here the square vertex represents a T- and P-violating weak interaction, while the round vertex represents a strong nucleon-nucleon scattering interaction. The photon may be attached to any of the lines in the graph.

more accurately, we do not enter into this here, because there is no reason to believe that these are the dominant graphs in this model. We only wish to emphasize, in contradiction to Ref. 5, that the observation of a nucleon EDM of a strength 10^{-7} nuclear-magnetons can not be taken as an evidence for W mesons, but rather is likely to arise in any current × current theory of weak interactions in which T invariance is violated. It would nevertheless be of great interest to detect such an EDM.

In addition, it may be pointed out that the second mechanism discussed here will *not* lead to an EDM for the muon of order $G_F m^2$ magnetons, because of the absence of strong interactions of the muon. This is in contrast to the W-meson model.

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Spin Tests for the Ω^- Particle†

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Spin tests for Ω^- produced in the reaction $p+\bar{p}\rightarrow\Omega^-+\bar{\Omega}^+$ are proposed. The tests are in the form of a set of inequalities satisfied by the angular distributions of the decay products.

INTRODUCTION

ONE of the predictions of the octet model is that the Ω^- should be a spin $\frac{3}{2}$ state. The reported[1] Ω^- has been observed in the reaction

$$K^-+p\rightarrow K^++K^0+\Omega^-, \qquad (1)$$

and according to its mass can decay weakly through one of the following channels of nonleptonic decays:

$$\begin{aligned}&\Omega^-\rightarrow\Xi^0+\pi^-\\&\Omega^-\rightarrow\Xi^-+\pi^0\\&\Omega^-\rightarrow\Lambda^0+K^- \qquad (2)\\&(\Omega^-\rightarrow\Sigma^0+K^-\text{ probably}).\end{aligned}$$

This production-decay chain fulfills the conditions of Ademollo and Gatto.[2] Thus if enough Ω^-'s are produced in reaction (1), the spin of the Ω^- can be determined by the Ademollo-Gatto analysis.

Another reaction which may be used for Ω^- production is

$$p+\bar{p}\rightarrow\Omega^-+\bar{\Omega}^+. \qquad (3)$$

As reaction (3) proceeds via the strong interactions, the S matrix is invariant both under parity P and charge conjugation C. This fact correlates the orientations of the Ω^- and $\bar{\Omega}^+$. Another point to be noted is that even if only the analysis of Lee and Yang[3] is used, then decays of both Ω^- and $\bar{\Omega}^+$ can be analyzed, thus decreasing the statistical error. In the present work we deal with production-decay chains of the type (3)–(2) or more generally reactions like

$$a+\bar{a}\rightarrow b+\bar{b}, \qquad (4)$$

with subsequent two-body decays of b and $\bar{b}$.[4,5] Section I presents the decay amplitude in the helicity formalism. In Sec. II we use parity and charge-conjugation invariance to prove certain symmetry properties of the combined density matrix of Ω^- and $\bar{\Omega}^+$. Section III deals with the subsequent decays. In Sec. IV we discuss possible spin tests.

I. TWO-BODY DECAY AMPLITUDE

Particle b of spin s having four-momentum p and helicity λ decays into particles c and d of spins s_1, s_2, momenta p_1, p_2, and helicities λ_1, λ_2, respectively. The decay amplitude in the b rest frame is given by

$$\begin{aligned}\langle p_1\lambda_1,\,p_2\lambda_2|s|p\lambda\rangle=&(2\pi)^4\delta^{(4)}(p-p_1-p_2)(2s+1/4\pi)^{1/2}\\&\times(8M^2/\Delta)^{1/2}D_{\lambda_1-\lambda_2,\lambda}{}^{(s)}(\phi,-\theta,-\phi)S_{\lambda_1,\lambda_2}. \qquad (5)\end{aligned}$$

M is the mass of the decaying b particle. θ, ϕ are the polar angles of $\mathbf{p}_1$ $(=-\mathbf{p}_2)$ in the b rest frame.

$$\Delta=\{[M^2-(m_1-m_2)^2][M^2-(m_1+m_2)^2]\}^{1/2},$$

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