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Archives.

CONSEQUENCES OF AN APPROXIMATE C_γ INVARIANCE OF THEPHYSICAL HADRONSL. Horwitz^{*)}Institut de Physique Théorique
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A B S T R A C T

An approximate C_γ invariance in the presence of strong interactions, applicable to physical hadrons, is shown to imply a doubling of the hadron spectrum in which the new states could be heavier.

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This note is motivated by the recent reporting ¹⁾ of an asymmetry in the energy distribution of $\eta \rightarrow 3\pi$. We follow the suggestion ²⁾ that both this and the $K_2^0 \rightarrow 2\pi$ effect ³⁾ are due to C violating electromagnetic transitions of the hadrons. It has been conjectured ²⁾ that particle-antiparticle conjugation C_{st} is indeed a symmetry only of the strong interactions ; it has further been suggested ⁴⁾ that the electromagnetic interactions, though violating C_{st} , may still be invariant under a different operation C_γ representing actual charge-inversion,

$$C_\gamma^{-1} j^\mu C_\gamma = -j^\mu \quad (1)$$

where j^μ is the total hadron current density.

In this suggestion, j^μ was considered to be the "bare" current, expressed in terms of "bare" field operators. The physical conclusions that can be drawn from such a symmetry are extremely limited for the hadrons ; the action of C_γ upon the known physical hadrons is difficult to gauge. As far as the bare hadrons go, it could be identical ⁵⁾ with the action of C_{st} ; in this case, for example, in the absence of strong interactions, the $\eta \rightarrow 3\pi$ anomalous mode would be replaced by a decay into anomalous particles ^{*}) (provided we conserve energy and momentum through the interaction with a spectator particle) which would conserve C_γ but violate C_{st} .

^{*}) It is conceivable that some electromagnetic interactions at long range may conserve C_γ for physical existing hadrons. The Coulomb interaction between existing and anomalous hadrons would conserve C_γ and violate C_{st} . The authors are indebted to Professor T.D. Lee for this clarification.

However, the successful description of hadron matter in terms of an algebraic structure is based upon the interpretation of the system of hadron currents in a fully renormalized sense. Such a result ⁶⁾ as the $\mu_p/\mu_n = -\frac{3}{2}$ prediction cannot be interpreted in a theory of bare fields. We are thus led to explore the possibility of defining a C_γ operation applicable to physical hadrons. Aside from the advantage of observing further invariance properties, one could then connect this discrete operation with the algebra of the currents and interpret Eq. (1) in that sense.

For C_γ to be observed as a strict invariance property of the hadrons, we would have to suppose that

$$[H_{st}, C_\gamma] = 0. \quad (2)$$

We shall show that this would lead to difficulties with the definition of C_{st} and would not allow for the observed violation. However, we find that one may construct a theory with an approximate C_γ invariance ; this would be an observable invariance effect of the same type as the approximate universality of both vector and axial vector weak currents.

In the following we shall present a model of such an approximate C_γ invariance. We find it implies a doubling of the hadron spectrum in which the new states could be heavier than the existing ones (see the figure). This seems essential to the existence of an observable hadron C_γ ; if such states are not found, we would infer that C_γ cannot be defined meaningfully on physical hadrons.

The proton system under an approximate C_γ invariance P_c is the counter-particle of the proton, $\bar{P}$ its anti-particle.

C_{st} non-invariance has been assumed to arise through the existence of a part of j^μ which is invariant under it. Thus,

$$j^\mu = J^\mu + K^\mu \quad (3)$$

$$C_{st} J^\mu C_{st}^{-1} = -J^\mu \quad (4)$$

$$C_{st} K^\mu C_{st}^{-1} = K^\mu \quad (5)$$

The electromagnetic current is a component of the $U(3)$ algebra. The total charges have to satisfy ^{*)}

$$[Q_J^a + Q_K^a, Q_J^b + Q_K^b] = i f^{abc} (Q_J^c + Q_K^c). \quad (6)$$

The known hadron states contribute only to Q_J ; we thus have

$$[Q_J^a, Q_J^b] = i f^{abc} Q_J^c. \quad (7)$$

^{*)} We do not consider here the case ⁷⁾ of $Q_K = 0$ when $K^\mu \neq 0$.

There are two simple solutions to these commutators. We may have *)

$$[Q_J^a, Q_K^b] = i f^{abc} Q_K^c \quad (8)$$

$$[Q_K^a, Q_K^b] = i f^{abc} Q_J^c \quad (9)$$

with proper normalization of the f^{abc} , or alternatively

$$[Q_K^a, Q_K^b] = i f^{abc} Q_K^c \quad (10)$$

$$[Q_J^a, Q_K^b] = 0 \quad (11)$$

with the original normalization for f^{abc} . The latter picture corresponds to a complete separation of the two spaces.

We now study the action of C_Y upon the actual hadron states. The two above solutions correspond respectively to the following two possibilities of reproducing Eq. (1), either

$$C_Y^{-1} J_\mu C_Y = -J_\mu \quad (12)$$

$$C_Y^{-1} K_\mu C_Y = -K_\mu \quad (13)$$

or alternatively,

$$C_Y^{-1} J_\mu C_Y = -K_\mu \quad (14)$$

$$C_Y^{-1} K_\mu C_Y = -J_\mu \quad (15)$$

*) The $\eta \rightarrow 3\pi$ experiment seems to imply ¹⁾ that $\Delta I = 2$, and hence that K_μ is not a singlet current.

Solutions (12)-(13) allow the K_μ current to have a different structure than J_μ ; it may in this case consist of very few new fields or particles. Solutions (14)-(15) impose a one-to-one symmetry between the known charged hadrons (and their current J_μ) and a set of new charged anomalous hadrons contributing to K_μ .

Our requirement that C_γ be defined over the physical hadrons is inconsistent with solution (12) ; any transitions between normal hadrons violating C_{st} would violate automatically C_γ too. We are therefore left with solutions (14)-(15) and the commutators (10) and (11).

The charged particles and currents J_μ are described by $U(3)$; a set of triplet fields (quarks) provides a complete representation. To represent the K_μ contributing hadrons we have to adjoin an additional triplet q^c such that

$$\begin{aligned} C_\gamma |q\rangle &= \eta_\gamma |\bar{q}^c\rangle, & C_\gamma |\bar{q}\rangle &= \eta_\gamma^* |q^c\rangle \\ C_{st} |q\rangle &= \eta_s |\bar{q}\rangle, & C_\gamma C_{st}^{-1} C_\gamma^{-1} |q^c\rangle &= \eta_s^* |\bar{q}^c\rangle \end{aligned} \quad (16)$$

and

$$\begin{aligned} C_{st} |q^c\rangle &= |q^c\rangle \\ C_{st} |\bar{q}^c\rangle &= |\bar{q}^c\rangle \end{aligned}$$

Thus for every normal hadron we have a counter-particle. C_γ connects a particle to the anti-counter-particle which is thus analogous to an antiparticle, just as the counter particle resembles the particle in its $U(3)$ properties (see the figure).

Exact C_γ invariance would only be possible if Eq. (2) were satisfied. This would imply that particles and counter-particles have essentially equal masses. Using the operator corresponding to particle-antiparticle conjugation among the anomalous hadrons,

6.

$$C_{st,c} = C_\gamma C_{st}^{-1} C_\gamma^{-1}, \quad (17)$$

we note that

$$C_{st,c} K^\mu C_{st,c}^{-1} = -K^\mu \quad (18)$$

$$C_{st,c} J^\mu C_{st,c}^{-1} = J^\mu. \quad (19)$$

There exists, therefore, an operator

$$C'_\gamma = C_{st} C_{st,c} \quad (20)$$

for which [with (2)]

$$[C'_\gamma, H_{st}] = 0 \quad (21)$$

and

$$C'_\gamma^{-1} j^\mu C'_\gamma = -j^\mu. \quad (22)$$

Since the counter-particles would be indistinguishable from ordinary particles, they should be present in all our experiments. In this case C'_γ is the conventional C , we would get no violation and what we have called C_{st} would be undefined. This precludes exact C_γ invariance.

However, it is possible that

$$[H_{st}, C_\gamma] \sim 0 \quad (23)$$

in the sense of a broken symmetry. This is analogous to the situation which preserves an approximate universality even in the case of the axial vector weak current. The corresponding generators do not commute with H_{st} ; in fact the chiral symmetry is violated at least by the baryon mass term, i.e., $\Delta M \sim 1 \text{ GeV}$. It is thus conceivable that C_Y could represent a rough invariance property of hadron electrodynamics. Equation (23) implies of course that particles and counter-particles have different masses. On the basis of the situation in weak interactions, a mass difference of the same order could be expected.

On the other hand, Eq. (1) may not be valid for the hadrons, and our counter-spectrum would not exist. This raises questions in the interpretation of hadron electrodynamics.

A C_Y defined on bare fields only would be observed in long-range electrodynamics ; the C_Y we have described here would in addition be approximately effective in all other hadron electrodynamics. The main requirement it imposes is the existence of a complete counter spectrum.

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R E F E R E N C E S

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