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F. Cannata, R. Del Fabbro and O. Signore: GENERAL SURVEY OF DISCRETE SYMMETRY VIOLATIONS. -

> Reviewing what we have learned of the symmetry exhibited by elementary particles in their strong interactions and the asymmetry in their weak interactions, one is tempted to ask whether an integrated pattern is in sight. Judging from the beautiful logical perfection and the profound experimental consequences of the successes of symmetry considerations in physics, one is entitled to believe that such a pattern, when it emerges, would transmute the whole enterprise. If no one has yet conceived of such a pattern, it is not because physicists have not tried, but because nature has yet not revealed enough of herself.
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I. - INTRODUCTION. -

The aim of the present paper is to investigate critically the present experimental possibilities of testing the validity of C, T and CP symmetries.

It is well known that the discovery of CP non conserving effects in the K^0 mesons physics(1) has put in question the very existence of all discrete symmetries.

The operations of charge conjugation C, space reflection P and time reversal T have been theoretically criticized; the problem is fundamental, since, for instance, CTP invariance, which is connected with the basic concepts of modern physics, might have to be rejected.

As a matter of fact the experimental situation, with exclusion of well established CP noninvariant effects in the K^0 mesons physics, is in general still open.

Many experiments performed to detect the breakdown of C, CP and T symmetry show either conflicting results or inconclusive data. They frequently reach a good degree of accuracy, but the results obtained are inconclusive because the theoretical models often cannot be strictly verified in so far as they do not give sufficiently precise predictions.

"The "amount" of violation in the basic interaction cannot be related to the observed "amount" of violation without a detailed model and a fairly reliable method of calculation, both of which are lacking.

A relatively large "amount" of violation in the basic interaction produces small "amount" of violation in the observables because of selection rules, low energy limits, summing over final states, vanishing of lowest order contributions etc."(2).

At present time the question as to the strength of the CP violating interaction has no answer.

Indeed the possible value of coupling constant range from 10^{-2} to 10^{-15} ($\hbar=c=m=1$, where m is the pion mass).

Among current theoretical hypotheses, there are the electromagnetic, the milliweak and superweak model of CP violation. There is also a theoretical suggestion, which tries to explain the CP puzzle through a breakdown of the superposition principle.

In the following sections the predictions given by various models are compared with recent experimental data and the possibilities of future experiments are critically analyzed.

In general we remark that, as we said before, the problem is far from solved(x).

"All the theoretical predictions considered here, which started elaborate experiments, are rather soft in nature and such that the absence of effect is not necessarily significant, while its presence is highly significant. It is difficult to give to the experimentalist the quantitative limit beyond which the verification becomes really useful. Moreover, these limits easily change with time from one theoretical estimate to another, while the inertia of a big experiment, once it is started, is much bigger"(3).

II. - K^o MESONS. -

II.1. - Long and short lived kaons.-

K^o and $\bar{K}^o$ have definite hypercharge (± 1): this is the only quantum number which distinguishes them. Weak interactions do not conserve hypercharge: therefore, there can be transitions between K^o and $\bar{K}^o$, for instance through virtual processes of the type $K^o \rightleftarrows 2\pi \rightleftarrows \bar{K}^o$. So, an ini-

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(x) - Indeed it has been shown(116) that no unambiguously interpretable experimental evidence is now available for the time reversal invariance of the semileptonic weak Hamiltonian.

tially pure K^o or $\bar{K}^o$ state becomes a K^o - $\bar{K}^o$ superposition in its life time.

This situation is unique. It can never occur for charged kaons, because of charge conservation, nor can it occur for neutral baryons or leptons, because of the conservation of barionic or leptonic numbers.

Usually two different quantum states are given: the so called long and short lived kaons, which are expressed by the general relations$^{(4)}$:

$$\begin{pmatrix} |S\rangle \\ |L\rangle \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} 1+\varepsilon_+ & 1-\varepsilon_+ \\ 1+\varepsilon_- & -(1-\varepsilon_-) \end{pmatrix} \begin{pmatrix} |K^o\rangle \\ |\bar{K}^o\rangle \end{pmatrix}$$

(for purposes of simplification here and in future expressions, $|\varepsilon_{\pm}|^2$ has been neglected in comparison with unity).

The CTP invariance requires $\varepsilon_+ = \varepsilon_-$, while T invariance $\varepsilon_+ = -\varepsilon_-$. Therefore if CTP and CP or T invariance holds, $\varepsilon_+ = \varepsilon_- = 0$.

The time evolution of short and long lived kaons in their proper time are:

$$|S\rangle \rightarrow e^{-iM_s t}|S\rangle \qquad\qquad |L\rangle \rightarrow e^{-iM_L t}|L\rangle$$

where $M_S = m_S - i/2\ \Gamma_S$ and $M_L = m_L = m_L - i/2\ \Gamma_L$, being m_S and m_L the masses and Γ_S and Γ_L the widths of these states.

Experimentally:

$$m_S \simeq m_L = (497.75 \pm 0.18)\ \text{MeV} \qquad\qquad \frac{m_L - m_S}{S} = (0.46 \pm 0.02)\ \text{MeV sec.}$$

$$\Gamma_S = (1.17 \pm 0.01)\,10^{10}\ \text{sec}^{-1} \qquad\qquad \Gamma_L = (1.89 \pm 0.05)\,10^{7}\ \text{sec}^{-1}$$

If we represent with $\psi(t)$ ($\bar{\psi}(t)$) the wave function of pure K^o ($\bar{K}^o$) state, we can get the following differential equations$^{(4)}$:

$$i\frac{d}{dt}\begin{pmatrix} \psi \\ \bar{\psi} \end{pmatrix} = \begin{pmatrix} \frac{\Delta_+}{2} + \frac{\Delta_-}{2}(\varepsilon_+ - \varepsilon_-) & \frac{\Delta_-}{2} + \frac{\Delta_+}{2}(\varepsilon_+ + \varepsilon_-) \\ \frac{\Delta_-}{2} - \frac{\Delta_-}{2}(\varepsilon_+ + \varepsilon_-) & \frac{\Delta_+}{2} - \frac{\Delta_-}{2}(\varepsilon_+ - \varepsilon_-) \end{pmatrix} \begin{pmatrix} \psi \\ \bar{\psi} \end{pmatrix}$$

where $\Delta_+ = M_S + M_L$ and $\Delta_- = M_S - M_L$.

If CTP invariance holds, the matrix in the above formula has equal diagonal elements, while holding T invariance the off diagonal elements are equals.

It is well known that "detection of T noninvariant effects would not of course prove CTP invariance; nevertheless, CTP invariance requires the existence of T noninvariance to the same extent as CP noninvariance"(52).

It is reasonable to require indipendent tests for the two important symmetries: CTP and T. Indeed, time reversal symmetry and its breaking are of sufficient intrinsic interest that it seems worth analyzing the data on K^o decay to test the two pion mode for T nonconservation directly, rather than inferentially via CTP and CP.

For these kind of analysis we remand to Ref. (4, 6, 31, 87). An explicit violation of T and consistency with CTP conservation has been found till now.

In particular, in Casella (I)(6) T invariance is assumed at the outset, and T nonconservation is established by contradiction of a fairly wide range of values for experimental parameters within the present experimental data.

In Casella (II)(6) a more extended analysis allows to establish that T is not conserved in $K^o \rightarrow 2\pi$ decay, irrespective of CPT symmetry.

We remark that a recent experiment(14) confirm that CP violation is predominantly due to a CTP-conserving amplitude, and that T invariance is violated. The contribution of the T-conserving, CTP violating amplitude is zero with an upper limit of about one-third of the CP-violating amplitude.

II.2.- Experimental results.-

a) $K^o_L \rightarrow 2\pi$

In 1964 the $K^o_L \rightarrow \pi^+\pi^-$ decay was observed. In the subsequent years, experimentalists tried to determine with accuracy the relevant parameters, which appear in the phenomenological analysis, in particular the $|\eta_{+-}|$, φ_{+-}, $|\eta_{oo}|$ and φ_{oo} quantities, where

$$\eta_{+-} = \frac{\langle \pi^+\pi^- | T | L \rangle}{\langle \pi^+\pi^- | T | S \rangle} = |\eta_{+-}|\, e^{i\varphi_{+-}} ; \quad \eta_{oo} = \frac{\langle 2\pi^o | T | L \rangle}{\langle 2\pi^o | T | S \rangle} = |\eta_{oo}|\, e^{i\varphi_{oo}}$$

Clearly the neutral decay experiments are more difficult, so the corresponding measured quantities have large errors.

In particular the phase φ_{oo} is badly known; experiments are in progress in order to improve the present experimental data(88): These are shown in Table I.

TABLE I

parameter	value	reference
$\lvert\eta_{+-}\rvert$	$(1.92 \pm 0.05)\,10^{-3}$	(8)
φ_{+-}	$(44^o \pm 5^o)$	(8)
φ_{+-}	$(41^o \pm 15^o)$	(9)
φ_{+-}	$(40^o \pm 12.5)$	(10)
$\lvert\eta_{oo}\rvert^2$	$(-2 \pm 7)\,10^{-6}$	(7)
$\lvert\eta_{oo}\rvert^2$	$(3.5 \pm 1.7)\,10^{-6}$	(11)
$\lvert\eta_{oo}\rvert^2$	$(4.9 \pm 1.3)\,10^{-6}$	(12)
$\lvert\eta_{oo}\rvert^2$	$(9.9 \pm 3.4)\,10^{-6}$	(13)
$\lvert\eta_{oo}\rvert^2$	$(11.03 \pm 4.3)\,10^{-6}$	(14)
$\lvert\eta_{oo}\rvert^2$	$(14.1 \pm 3.4)\,10^{-6}$	(15)
φ_{oo}	$(17^o \pm 31^o)$	(16)
φ_{oo}	$(51^o \pm 30^o)$	(14)

The $\lvert\eta_{oo}\rvert$ data do not agree, nevertheless a $\lvert\eta_{oo}\rvert$ averaged value may be given(8):

$$\lvert\eta_{oo}\rvert = (2.5 \pm 0.8)\,10^{-3}$$

b) $K_S^o \to 3\pi$.

Being K_S^o a CP=+1 state, the CP conservation requires the $K_S^o \not\to 3\pi^o$ and $K_S^o \to \pi^+\pi^-\pi^o$ allowed in the I=0 or 2 3π states.

The I=2 state is the most probable between the CP conserving states, but the centrifugal barrier introduces a depressing factor $\sim (k_\pi R)^4$; where k_π is an averaged pion moment and R the interaction range. Taking $k_\pi \sim 100$ MeV/c and $R \sim (m_K)^{-1} \sim (500)^{-1}$ MeV^{-1}, this factor provides to be $(k_\pi R)^4 \sim 10^{-3}$. Hence it is reasonable to consider only the CP violating 3π states, which are related to the following parameters:

$$\eta_{+-o} = \frac{\langle \pi^+ \pi^- \pi^o | T | S \rangle}{\langle \pi^+ \pi^- \pi^o | T | L \rangle} \qquad \eta_{ooo} = \frac{\langle 3\pi^o | T | S \rangle}{\langle 3\pi^o | T | L \rangle}$$

If the η's are small, measuring these parameters is a serious experimental problem: the main reason of the difficulty lies in the fact that $\Gamma_S \sim \sim 10^3 \Gamma_L$.

In the Table II we show the following upper limits.

TABLE II

parameter	value	reference
$\lvert\eta_{+-o}\rvert$	1.5	(17)
$\lvert\eta_{+-o}\rvert$	0.7	(18)
$\lvert\eta_{+-o}\rvert$	3.0	(19)
$\lvert\eta_{ooo}\rvert$	1.5	(20)

c) K^o_L leptonic decay..

The leptonic decay of the long lived kaon exhibit: CP violating effects when the $\pi^+ e^- \nu$ is not so probable as $\pi^- e^+ \nu$ decay.

The asymmetry parameter is

$$\delta = \frac{N^+ - N^-}{N^+ + N^-}$$

where $N^+ (N^-)$ is the rate of positive (negative) leptons.

The experimental results of Table III show a clear CP violating effect.

Assuming the CTP validity, the leptonic K^o_L decay data can be related to Re(ε) i.e. to $\langle K^o_L | K^o_S \rangle$.

Let us consider the four amplitudes

$$f = \langle e^{+} \pi^{-} \nu | T | K^{o} \rangle \qquad g = \langle e^{+} \pi^{-} \nu | T | \bar{K}^{o} \rangle$$

$$f' = \langle e^{-} \pi^{+} \nu | T | \bar{K}^{o} \rangle \qquad g' = \langle e^{-} \pi^{+} \nu | T | K^{o} \rangle$$

where f and f' are $\Delta S = \Delta Q$ and g and g' the $\Delta S = - \Delta Q$ amplitudes. The following relations hold:

$$f^{x} = f' \qquad g^{x} = g'$$

The $\Delta S = - \Delta Q$ amplitudes are smaller than $\Delta S = \Delta Q$ ones, indeed we have $|x| < 0.2$, where $x = g/f$.

TABLE III

parameter	value	reference
$\delta_{L,e}$	$(2.24 \pm 0.36) 10^{-3}$	(21)
$\delta_{L,e}$	$(3.15 \pm 0.3\ ) 10^{-3}$	(22)
$\delta_{L,e}$	$(3.41 \pm 0.37) 10^{-3}$	(23)
$\delta_{L,\mu}$	$(4.05 \pm 1.35) 10^{-3}$	(24)
$\delta_{L,\mu}$	$(4.9\ \pm 1.65) 10^{-3}$	(25)

The following expression

$$\delta_L = \frac{1 - |x|^2}{|1 - x|^2} \, 2 \, \mathrm{Re}(\varepsilon) \approx \frac{1 - |x|^2}{|1 - x|^2} \langle K_L^o | K_S^o \rangle$$

shows that δ_L can be expressed in term of $\mathrm{Re}(\varepsilon)$ and $\langle K_L^o | K_S^o \rangle$; so using the results of Bennett et al.(26):

$$\frac{1 - |x|^2}{|1 - x|^2} = .96 \pm .05$$

and assuming the value of $\delta_{L,e} = (2.85 \pm 0.28) 10^{-3}$, we obtain

$$\mathrm{Re}(\varepsilon) = \frac{1}{2} \langle K_L^o | K_S^o \rangle = (1.49 \pm 0.14) 10^{-3}$$

d) muon transverse polarization. -

An effect of T violation can be sought in the K decays:

$$K^o_L \rightarrow \pi^- \mu^+ \nu \qquad K^+ \rightarrow \pi^{\acute{o}} \mu^+ \nu$$

The matrix elements of these decays can be expressed as the sum of two terms f_+ and f_-, proportional to $p_K + p_\pi$ and $p_K - p_\pi$ respectively.

An interference of these terms could produce a muon transverse polarization

$$P_\perp = (\overline{P}_\pi \times \overline{P}_\mu) \cdot \overline{\sigma}_\mu$$

In the $K^o_L \rightarrow \pi^- \mu^+ \nu$ decay there is a small polarization effect, which is originated by electromagnetic final state interaction. The effect, proportional to α, gives a fictitious transverse polarization of the order 1%(27). The experimental results relative to $K^o_L \rightarrow \pi^- \mu^+ \nu$ decay are shown in Table IV.

TABLE IV

parameter	value	reference
$P_\perp$	$(0.25 \pm 1.25)\,10^{-2}$	(28)
$P_\perp$	$(2. \pm 7.)\,10^{-2}$	(29)
$Im(\xi)$	$(-1.4 \pm 6.6)\,10^{-2}$	(28)
$Im(\xi)$	$(11. \pm 35.)\,10^{-2}$	(29)

We have indicated with ξ the ratio f_-/f_+.

The experimental results agree with $Im(\xi) = 0$. The present known value of $Re(\xi)$ is $-.59 \pm 0.1$(30).

II. 3. - Theoretical models. -

In recent years many theoretical models have been proposed, but up to now none is satisfactorily consistent with all measured K^o parameters.

These theoretical approaches may be divided into three classes of models, according to the supposed origin of CP violation.

1) - CP is really conserved and the observed effects are due to:

a) the existence of a third neutral kaon(32, 33, 34), which does not interact strongly, but is mixed with K^o and $\bar{K}^o$ in weak processes.
b) the breakdown of the quantum mechanics, namely the validity limits of the superposition principle(35).
c) effects which have a cosmological origin(36).
d) the presence of unknown decays(37).
e) parastatistics.

2) - CP is violated in K^o decay (millistrong, electromagnetic(81) and milliweak models).

3) - The CP violation has its origin in the stationary states (superweak or Wolfenstein model)(5).

The hypothesis 1 does not have been supported by experimental evidence till now. Among others, we remember here a recent results of C.D. Buchananet al.(114) which is evidence against the hypothesis of a third neutral kaon.

In point 2 the violation may occur through a $\Delta S = \pm 1$ CP non-conserving part of weak interaction. Of course the CP non-conserving part is 10^{-3} times the CP conserving.

At present the experimental facts outside of K^o physics are neither capable of proof nor a disproof of validity of these models.

In the milliweak model the $\Delta I = 3/2$ amplitude in the K^o decays is expected to be about 10^{-2} times smaller than $\Delta I = 1/2$ amplitude, hence $\varepsilon'/\varepsilon \approx 10^{-2}$(89).

The CP violation may occur through interference with the $\Delta S = 0$ strong or electromagnetic C violating interaction.

At present there does not yet exist a 10^{-3} experimental sensitivity in strong processes in order to check the millistrong model.

The model indicated under 3) is more verifiable than other models, indeed it has the merit of giving well defined previsions on the basis of one parameter.

The superweak model postulates a CP violating and CTP conserving very weak interaction (the coupling constant is $\sim 10^{-13}$), which has off diagonal matrix elements with $\Delta S = 2$ in the mass matrix:

$$\langle K^o | H_{SW} | \bar{K}^o \rangle \neq 0$$

A remarkable implication, which is not disproved at present, of this model is that CP violating effects are present only in K^o decays.

The previsions of superweak model are:

$$\eta_{+-} = \eta_{oo} = \mathcal{E}$$

hence

$$|\eta_{oo}| = |\eta_{+-}| = |\mathcal{E}| \qquad \varphi_{+-} = \varphi_{oo} = \arg \mathcal{E} \simeq \mathrm{arctg} \frac{m_L - m_S}{\sqrt{S}/2} \simeq 43^o$$

The comparison of these previsions with the experimental results is shown in Table V.

TABLE V

parameter	experimental	superweak
$\lvert\eta_{+-}\rvert / \lvert\eta_{oo}\rvert$	$.768 \pm .246$	1.
φ_{+-}	$44^o \pm 5^o$	$43^o \pm 1^o$
φ_{oo}	$(17^o + 31^o)$ and $(51^o + 30^o)$	$43^o \pm 1^o$
$\mathrm{Re}\,\mathcal{E}$	$(1.49 \pm .14) 10^{-3}$	$(1.39 \pm .05) 10^{-3}$

III. - INVARIANCE UNDER CHARGE CONJUGATION. -

III.1. - Hadronic systems. -

Since the discovery of parity violation$^{(38)}$, charge conjugation was believed to be conserved in electromagnetic and strong interactions and maximally violated in weak interactions.

In 1964 a Princeton group detected the CP violating process $K_L^o \rightarrow 2\pi$ $^{(1)}$. Subsequently many different explanations were proposed.

Owing to lack of accurate experimental tests on charge conjugation conservation in electromagnetic interactions of hadrons, it was possible to think that a C violating second order electromagnetic effect be responsable$^{(39)}$ for the CP violation in $K_L^o \rightarrow 2\pi$ decay. If this hypothesis is true, one may find other C violating effects in electromagnetic processes of hadrons.

Let us discuss the following processes:

$$\pi^o \rightarrow 3\gamma$$
$$\eta^o \rightarrow \pi^o e^+ e^-$$
$$\eta^o \rightarrow \pi^+ \pi^- \pi^o$$
$$\eta^o \rightarrow \pi^+ \pi^- \gamma$$

$$\phi \rightarrow \omega\gamma$$
$$\phi \rightarrow \rho\gamma$$
$$\omega \rightarrow \rho\gamma$$

$$\phi \rightarrow \pi^+ \pi^- \gamma$$
$$\omega \rightarrow \pi^+ \pi^- \gamma$$
$$\rho \rightarrow \pi^+ \pi^- \gamma$$
$$e^+ e^- \rightarrow \pi^+ \pi^- \pi^o$$

a) $\pi^o \rightarrow 3\gamma$.-

The existence of $\pi^o \rightarrow 3\gamma$ decay would be a proof of C violation. The present experimental limit is(40)

$$\left|\frac{\text{Rate}(\pi^o \rightarrow 3\gamma)}{\text{Rate}(\pi^o \rightarrow 2\gamma)}\right|_{\text{exp}} \leq 5 \times 10^{-6}$$

and a rough theoretical estimation gives(41):

$$\left(\frac{\text{Rate}(\pi^o \rightarrow 3\gamma)}{\text{Rate}(\pi^o \rightarrow 2\gamma)}\right)_{\text{th}} \sim \alpha (k_\gamma R)^8 \, \frac{(\text{phase space}) 3\gamma}{(\text{phase space}) 2\gamma} \leq 10^{-8}$$

therefore the experimental limit is not satisfactory. More accurate previsions are model dependent (see, for instance, the effective lagrangian proposed by Berends(42)).

An experiment is in progress(43), but, if the result will consist only in lowering the upper limit, the lack of an accurate prevision will probably not make it possible to give a definitive answer to the question of C invariance in electromagnetic interactions.

b) $\eta^o \rightarrow \pi^o e^+ e^-$.-

If C is violated in electromagnetic interactions, this decay is of α^2 order, which is the same order as the dominant η^o decay mode. If C is conserved the decay must be of α^4 order, i.e. 10^4 times smaller.

The decay has not been observed and the present upper limit is(8)

$$\frac{\text{Rate}(\eta^o \rightarrow \pi^o e^+ e^-)}{\text{Rate}(\eta^o \rightarrow \text{all})} \lesssim 10^{-4}$$

It is however not clear to what extent this limits a possible T violation, since the decay is inhibited by angular momenta barriers and possibly also by SU_3 symmetry.

This possibility has been stressed by Cabibbo$^{(44)}$.

To give some theoretical previsions let us introduce the useful parameter

$$R = \frac{\text{Rate}(\eta^o \rightarrow \pi^o e^+ e^-)}{\text{Rate}(\eta^o \rightarrow \pi^o \gamma\gamma)}$$

The present experimental value is still uncertain. However it is likely that $R \lesssim 3 \times 10^{-2}$ (45).

1) - If all CP violation occurs through a P and S conserving semi strong interaction, the coupling constant g being given by

$$g^2/4\pi \lesssim 4 \times 10^{-2}$$

R must be 10^{-2}.

2)- If the violation has an electromagnetic origin, the prevision is

$$R \sim 2$$

but this model is capable of explaining a much lower value.

3) - If the milliweak hypothesis holds ($\Delta S \lesssim 2$) then

$$R < 10^{-11}$$

4) - Finally the superweak model gives $R \leq 10^{-25}$.

The present value for R cannot be used for the test of 3) and 4) hypotheses, and up to now the experimental value is not resolutive for the 1) and 2) points.

c) $\eta^o \rightarrow \pi^+ \pi^- \pi^o$.-

The $\eta^o \rightarrow \pi^+ \pi^- \pi^o$ decay is allowed by C, but could contain a C violating contribution. The experimental effect of the presence of a C violating amplitude in these channels would come from an interference between states of different C and angular momentum of the $\pi^+ \pi^-$ system. Indeed for a $\pi^+ \pi^-$ system $C(\pi^+ \pi^-) = P(\pi^+ \pi^-) = (-1)^L$.

The interference between the $C = \pm 1$ amplitudes may yield an asymmetry in the energy distribution of π^+ and π^-. The asymmetry parameter is defined as

$$A = \frac{N_+ - N_-}{N_+ + N_-}$$

where N_+ (N_-) is the number of π^+ (π^-) characterized by the following condition

$$E_{\pi^+} > E_{\pi^-} \qquad\qquad (E_{\pi^-} > E_{\pi^+})$$

The experimental results are shown in Table VI.

TABLE VI

events number	A	reference
1300	5.8 ± 3.4 %	(90)
562	4.1 ± 4.1 %	(91)
1351	7.2 ± 2.8 %	(92)
10665	$0.3 \pm 1.$ %	(93)
765	-6.1 ± 4.0 %	(94)
36800	1.5 ± 0.5 %	(95)

These asymmetry data have a poor conclusive value, with exclusion of last Columbia experiment, which has recently yielded the new value $A = (1.66 \pm .63)$ % with more severe geometrical cuts$^{(117)}$. Furthermore, the asymmetry, if it exists, has a very small value, due to centrifugal barriers and to the fact that due to CTP invariance the effect is proportional to $\sin\delta$, being δ the relative $\pi\pi$ scattering phase shift of the interfering final states. So it is difficult to obtain a relevant effect indipendently of the C violating interaction strenght.

For example, an estimate of the order of magnitude, indicates that the model of Frenkel et al.$^{(46)}$, which gives the experimental results on the charge asymmetry in η^o decay within one standard deviation, is not in contradition with the experimental results of the K^o_L decay.

Furthermore it has been suggested that the presence of a small asymmetry is not necessarily an evidence of C violation$^{(47)}$.

Indeed an asymmetry effect can be generated by an interference between resonant and nonresonant $\pi^+\pi^-\pi^o$ production in the reactions:

$$\pi^- p \rightarrow n\,\eta^o \qquad\qquad \pi^- p \rightarrow n\,\pi^+\pi^-\pi^o$$
$$\hookrightarrow \pi^+\pi^-\pi^o$$

Let us consider the total matrix element M:

$$M = \frac{M_\eta\, M_D}{S-(m_\eta - i/2\ \Gamma_\eta\ )} + \frac{M_B}{m_\pi^2}$$

where M_η, M_D and M_B are the matrix elements of η^o production, η^o decay and the background production respectively, and S is the squared invariant 3π mass.

The observable charge asymmetry A is given by

$$A = \left(\frac{2\pi\sqrt{\eta}}{\Delta m}\ \frac{\sigma_B}{\sigma_\eta}\right)^{1/2} \sin\delta$$

where Δm is the range of 3π invariant mass and δ the phase between $(M_\eta\ M_D)$ and M_B.

The maximum value of A is found with a total asymmetric background and $\sin\delta = 1$:

$$A_{max} \simeq 1.6\ 10^{-2}$$

using the typical values :

$$m \approx 10\ \text{MeV} \qquad \text{and} \qquad \sigma_B/\sigma_\eta \approx 10^{-1}$$

However Gormley et al.(119) argue that an upper limit of 0.23% for this effect can be given in their sample of data.

For instance in the reaction $K^- p \longrightarrow \Lambda^o\pi^+\pi^-\pi^o$ the allowed isospin 3π states are I = 0, 1.

I = 1 state is predominant, because I = 0 is strongly depressed due to centrifugal barriers. An η^o sample obtained in this way can show "simple" interference asymmetry only through I = 2 amplitudes contributed by isospin-non-conserving interaction in the production reaction which are depressed(82).

The $\eta^0 \to \gamma \pi^+ \pi^-$ decay yields another possibility of studing the charge asymmetry of the π^+ and π^- energy spectrum. The 2π system can be either in an I = 1 P state, produced by J^V_μ (C-odd) current, or in an I = 0 D state produced by K^S_μ (C-even) current.

The presence of an asymmetry in this decay gives informations on the isoscalar part of C-even electromagnetic hadronic current. We report in Table VII the experimental results of $\eta^0 \to \gamma \pi^+ \pi^-$ decay.

TABLE VII

events number	A	reference
1620	1.5 ± 2.5 %	(96)
6710	2.4 ± 1.4 %	(97)
33	$-2.0 \pm 7.$ %	(98)
160	$-4.0 \pm -8.$ %	(99)
	1.2 ± 1.6 %	(100)

The experimental limit in the decay $\eta^0 \to \pi^0 e^+ e^-$ gives a more stringent limit on K^V_μ than the experimental asymmetry limit in $\eta^0 \to \to \pi^+ \pi^- \pi^0$. Indeed, using the equation relating A^2 and the rate ($\eta^0 \to \to \pi^0 e^+ e^-$) given in the analysis of Barret et al.(49), one sees that the present experimental limit rate ($\eta^0 \to \pi^0 e^+ e^-$) < 0.63 eV is equivalent to $A < 0.17\%$ and so five times more stringent than the present value of A_{exp}.

In conclusion: improvement by one order of magnitude of experimental accuracy would be useful in $\eta^0 \to \pi^+ \pi^- \gamma$ for putting a limit on K^S_μ ; also such an improvement in $\eta^0 \to \pi^0 e^+ e^-$ would be significant for K^V_μ (50).

d) Vector mesons radiative decays. -

Some authors (39) have suggested to look for

$$\phi^0 \to \omega^0 \gamma \qquad \phi^0 \to \rho^0 \gamma \qquad \omega^0 \to \rho^0 \gamma$$

decays, which are all C violating, but at present there is no experimental proof of their existence.

These reactions would be interesting, because the first can occur only through the isoscalar and the other two only through the isovectorial part of the C-even electromagnetic current.

Theoretical branching ratio of $\sim 2\%$ have been computed by Bernstein et al.(39) for

$$\phi^o \rightarrow \omega^o \gamma \qquad \phi^o \rightarrow \rho^o \gamma$$

in the hypothesis of strong C violation in the electromagnetic interactions. $\omega^o \rightarrow \rho^o \gamma$ should be much less.

Probably as the storage rings luminosities improve, it will be easier to study these reactions, using the storage rings facility of producing only the wanted vector meson.

A future storage rings possibility is also to look for the charge asymmetry of the processes $e^+ e^- \rightarrow \pi^+ \pi^- \pi^o$ (as well as $p\bar{p} \rightarrow p\bar{p}\, \pi^+ \pi^- \pi^o$). Indeed, the spurious asymmetry disappears when the η^o is produced by particle antiparticle annihilation.

The experimental situation is rather uncertain and the existence of a crucial test to look for C nonconserving effects of electromagnetic or millistrong model seems rather doubtful. (For detailed discussions about storage rings possibilities see(51) Pais and Treiman, B. Stella and also Tetsuro Sakuma).

Nevertheless we quote here a recent result of N. Cabibbo et al.(115) which, starting with a "parton" model predict the absence of a final state $\pi^+ \pi^- \pi^o$ in the annihilation e^+e^-. Thus the study of $e^+e^- \rightarrow \pi^+ \pi^- \pi^o$ would be a critical test, because a suppression of three particle final states would not be expected if other mechanism, such as resonant production, are operative.

III.2.- Leptonic systems.-

Some authors(52) observed that up to now the symmetry violating facts exist solely in the neutral K physics. Why does it happen? A possible answer to this question may lie in the fact that the K^o-$\bar{K}^o$ is a very peculiar system.

Indeed, the K^o_L and K^o_S particles have the values of their masses extremely near to each other; furthermore their mass difference is roughly equal to the half width of K^o_S:

$$\frac{m_L - m_S}{m_{K^o}} \approx 10^{-14} \qquad\qquad m_L - m_S \approx \Gamma_S/2$$

This peculiarity is unique in the elementary particles family, so an eventual breakdown of quantum mechanics basic concepts may take place(52).

In this line it has recently been suggested to look for the positronium in analogy to K^o system(53).

The electron-positron bound state in S wave can exist either in singlet (parapositronium) or in triplet (orthopositronium) state. The difference of mass values results to be:

$$\frac{m_{ortho} - m_{para}}{m_{positr.}} \approx 10^{-9}$$

Furthermore the ortho and para states are a quantum superposition analogous perfectly to the K_1^o and K_2^o states:

$$|ORTHO\rangle = 2^{-1/2}(\,|\varphi\rangle + |\bar{\varphi}\rangle\,) \qquad |K_1^o\rangle = 2^{-1/2}(|K^o\rangle + |\bar{K}^o\rangle\,)$$

$$|PARA\rangle = 2^{-1/2}(\,|\varphi\rangle - |\bar{\varphi}\rangle\,) \qquad |K_2^o\rangle = 2^{-1/2}(|K^o\rangle - |\bar{K}^o\rangle\,)$$

where $\varphi = f_e(\uparrow)\,f_{\bar{e}}(\downarrow)$ and $\bar{\varphi} = f_e(\downarrow)\,f_{\bar{e}}(\uparrow)$, with obvious meaning of symbols.

So being the 3γ (2π) system a $C_-(CP_+)$ state, the C (CP) invariance leads to the selections rules:

$$^1S \not\rightarrow 3\gamma \qquad \left(\begin{array}{l} |K_2^o\rangle \not\rightarrow 2\pi \\ |K_1^o\rangle \rightarrow 2\pi \end{array}\right)$$
$$^3S \rightarrow 3\gamma$$

Mills and Berko(54) have searched for the $^1S \rightarrow 3\gamma$ decay, putting for the branching ratio

$$\frac{\text{Rate}\,(^1S \rightarrow 3\gamma)}{\text{Rate}\,(^1S \rightarrow 2\gamma)}$$

the upper limit of $2.8\ 10^{-6}$ with 68% confidence level.

This experiment has met with some difficulties in distinguishing the $^1S \rightarrow 3\gamma$ from the allowed $^3S \rightarrow 3\gamma$ decay.

Del Fabbro et al.(53) have observed that in a microwave magnetic field it is possible to obtain a quantum superposition of para and or thopositronium with $S_z=0$. So the amplitude of the allowed decay $^3S \rightarrow 3\gamma$ and that of the C violating decay $^1S \rightarrow 3\gamma$ are coherent, and interference effects can be observed.

This method should be capable of lowering the present experimental limit$^{(54)}$ of a factor by at least 10^4.

All existing models we have spoken about, with exclusion of those related to quantum mechanical arguments, give a zero result for $^1S \rightarrow 3\gamma$ decay investigation.

The good agreement between lepton electrodynamics and experimental data (anomalous magnetic moment, Lamb shift etc.) is an indirect proof of C conservation in these tests. However, we note that importance of a direct test is not diminished, because one can reach a much higher sensitivity level.

IV. - TIME REVERSAL INVARIANCE. -

IV.1. - General discussion.-

Time reversal invariance requires:

$$|M_{i \rightarrow f}|^2 = |M_{Tf \rightarrow Ti}|^2$$

where $M_{i \rightarrow f}$ $(M_{Tf \rightarrow Ti})$ is the amplitude for the processes $i \rightarrow f$ $(Tf \rightarrow Ti)$ where Tf and Ti are the final and initial states with the momenta and spin reversed.

The comparison of the matrix elements $|M_{i \rightarrow f}|^2$ and $|M_{Tf \rightarrow Ti}|^2$ is often very difficult. We give here the main reason following the line developed by Karpman, Leonardi and Strocchi.

a) - Phase space.
b) - The difficulty of reversing the decay processes.
c) - Some interactions are present only in the incoming or outgoing channel. (For instance in electromagnetic process $\gamma N \rightarrow \pi N$ there is a final state strong interaction).

In order to avoid these trouble, one generally looks at indirect time reversal implications$^{(55)}$.

If we limit to the weak and electromagnetic interactions, we have

$$M_{i \rightarrow f} = \langle f|T|i\rangle \simeq \langle f|H|i\rangle$$

and

$$|M_{i \to f}|^2 \simeq \langle f|H|i\rangle \langle i|H|f\rangle \simeq |M_{f \to i}|^2$$

so

$$|M_{i \to f}|^2 = |M_{Tf \to Ti}|^2 \simeq |M_{Ti \to Tf}|^2$$

then we obtain

$$|M_{i \to f}|^2 \simeq |M_{Ti \to Tf}|^2$$

this important relation shows that one may look for odd correlations instead of comparing reversed processes, when it is possible to describe the process to the first order approximation.

IV.2.- Final state interaction.-

Tests involving T-odd correlation are frequently complicated by final states interactions. For instance, we may observe a non negligible final state effect in the reaction

$$\nu\ (\bar{\nu}) + \text{nucleus} \to \mu^{+}\ (\mu^{-}) + \text{everything}$$

where a μ transverse polarization is an evidence for T violation. An estimation(56) for final state interactions corrections to the differential cross section, in the kinematic region where the nucleus contribute incoherently, gives effects of the order of 5% for heavy nuclei (e.g. uranium). There are some cases where the effects are not appreciable, e.g. in the hyperon β-decay it has been found that generally the contribution to an eventual T-odd correlation dirived by the final state interactions is 2.10^{-4}, which is small compared with the T-odd effect(57).

Cannata Leonardi and Strocchi(58) give some general advice in order to overcome these difficulties; in particular they have considered the behaviour of a T-odd correlation (as $S_N(P_N \times k)$) in photo-electro- and neutrino-production of pion.

Two different kinematic possibilities are investigated.

a) - Pion production at N_{33} resonance energy.
b) - Pion production at threshold.

Other intermediate kinematical configurations are shown to give nothing new. In the b) case effects of the final state interactions become small in comparison with eventual maximal T violating effects (indeed the ratio of the two effects behaves like tg δ, where δ is the relative π N phase shift) and at threshold all phase shifts are very small.

At threshold it is interesting to note that this test is more sensible than reciprocity, which gives no effect.

Among the various T violation test in weak interactions (for instance the β-decay), the neutrino-production of pion is particularly advantageous in the future, a large kinematical region being available for testing; furthermore, parity violation allows us to consider odd correlations under T with three momenta, so that no measure of polarization is required.

Perhaps the proposed method of eliminating the final state interactions effects may be useful in order to distinguish the interferences of opposite parity in the barionic excitation spectrum.

Substantially the method consists in adding (subtracting) $d\sigma/d\theta\,(\theta = \bar{\theta})$ to $d\sigma/d\theta\,(\theta = \pi - \bar{\theta})$, so that the odd (even) parity interfences are eliminated(59).

IV.3.- Elastic lepton scattering.-

It is well known that T violating form factors do not appear in the matrix elements of the electromagnetic current between states of spin 1/2 on the mass shell. Hence any effect of T violation in nuclear physics must be due to nuclear binding, and in consequence must roughly be of the order of 10^{-2}.

For a detailed analysis of nucleon-nucleon T violating force from electromagnetic interactions see ref. (50).

For the same reasons electron nucleon elastic scattering cannot be used as a test of time reversal invariance. Therefore one has to analyse inelastic electron nucleon scattering, or decays like $\Sigma^0 \rightarrow \Lambda^0 e^+ e^-$, which involves the matrix elements(61):

$$\langle \Sigma^0 | J_\mu | \Lambda^0 \rangle$$

Otherwise there is the chance of observing a T violating correlation in electron-deuteron elastic scattering which has been dealt in many papers(62, 83).

In elastic electromagnetic scattering of a spin 1 particle, the photon-particle vertex may be described by P and T conserving form factor, corresponding to charge and to electric quadrupole and magnetic dipole moments. Now, if we do not impose T invariance, the vertex is described by the three previous form factor plus a T violating additional term(84).

In this description the cross section for e-D elastic scattering may be written in Born approximation as:

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Ruth} \left[A(q^2) + B(q^2)\,tg^2\,\theta/2\right]$$

where

$$A(q^2) = F_c^2 - 8/9\,\eta^2 F_q^2 + \frac{B(q^2)}{8(1-\eta)}$$

and

$$B(q^2) = 4/3\,\eta\,(1+\eta)\left[F_M^2 + 4\,\eta^2 G^2\right]$$

The form factor have the following non-relativistic limits:

$$F_c(0) \to 1 \qquad F_q(0) \to M_D^2 Q_D \qquad F_M(0) \to \mu_D \frac{M_D}{M}$$

being:

Q_D = static quadrupole electric moment of deuton
M_D = deuton magnetic moment
$M(M_D)$ = nucleon (deuton) mass
E = incoming electron energy in laboratory system
θ = electron scattering angle in laboratory system

also

$$\eta = q^2/4M^2 \qquad \mathcal{E} = E/M_D$$

The additional form factor G is a T noninvariant term. The polarization vector at first order is given by:

$$P = \frac{8/3\;G\;F_q\;\eta^2(\eta - \mathcal{E})\,tg\theta/2}{A + B\,tg^2\,\theta/2}$$

An experimental test of T invariance has been performed at high momentum transfer, the recoil deuterons polarization is measured in the process e+D -> e+D. The deuteron target was no polarized, the incident electron energy was 1 GeV and the recoil deuteron momentum 721 MeV/c. The measured polarization has resulted:

$$P = (7.5 \pm 8.8)\ \%^{(85)}$$

The spurious contribution to the polarization due to the two photons exchange is considered small. Such a hypothesis is supported bu polarization results of electron-proton elastic scattering$^{(63)}$.

IV.4.- Inelastic lepton scattering.-

It was suggested by Christ and Lee$^{(64)}$ that a T violating term of the kind

$$(\underline{p} \times \underline{p}') \cdot \underline{S}_p$$

might be detectable by inelastic scattering of electrons of initial momentum $\underline{p}$, final momentum $\underline{p}'$, scattering on protons of polarization $\underline{S}_p$.

We have shown that such a term cannot be present in elastic scattering. However, it can be shown that should the data exhibit the asymmetry, this can be taken as a proof of violation of T invariance only if the process can be described by one photon exchange.

Therefore, if an asymmetry is found, the result has as a rule to be checked with inelastic positron scattering. In fact the T-odd correlation can also be generated by the interference term between the single photon exchange processe and two photons exchange process, without violating T invariance.

The amount of such T invariant correlation, is small, since it contains an additional power of the fine structure constant α ; furthermore, it is proportional to the sign of the charge of the lepton, whereas the T noninvariant term is not.

A theoretical calculation of this spurious correlation has been done by Cahn and S. Tsai$^{(101)}$ assuming that the final state is an $N^{x}(1238)$ and the intermediate state is a proton; for these particular final and intermediate states the contribution to the up down asymmetry is found to be roughly 10^{-1} of the maximum observed asymmetry in the experimental results of Berkeley SLAC collaboration$^{(65)}$.

The choice of the specific excited state offers an additional complication; the most important state available by inelastic electron scattering is the $N^{x}(1238)$. However, since the isotopic spin of $N^{x}(1238)$ is 3/2, no asymmetry would be expected in inelastic scattering if the T violating interaction is an isotopic scalar, which may instead contribute to e-D elastic scattering (par. IV.3).

Therefore the most conclusive test on this question would be a study of the asymmetry of inelastic scattering from $N^{x}(1512)$, which has isotopic spin 1/2.

Experimental results have been reported by Chen et al.(66) and Rock et al.(65). A very high background is a serious difficulty presented by these experiments (usually the target is a mixture of water and hydrocarbons).

Consequently, experimental sensitivity is poor, substantially not greater than 1%. Another difficulty arise when the incoming electron beam damages the target polarization per local heating in a unknown manner. Therefore, as a rule, either the target is periodically substituted (Chen) or a "sweeping" electron beam on the target is used (Rock).

Asymmetry in inelastic scattering is caused by interference between scattering of longitudinal and transversal virtual photons. The ratio between the effective longitudinal and transversal photon content involved in scattering process is given by the well-known polarization factor:

$$\varepsilon = 1/\left\{1+2\left[1+(E-E')^2/q^2\right] \mathrm{tg}^2\, \theta/2\right\}$$

here E and E' are the primary and secondary electron energies respectively; and $q^2 = 4\,EE' \sin^2 \theta/2$ is the square of the four-momentum transfer.

In general, the differential cross section for inelastic scattering can be written as:

$$\frac{d^2\sigma}{d\Omega\, dE'} = \Gamma_t \left\{ \sigma_T + \varepsilon\, \sigma_S + \left[2\varepsilon\,(1+\varepsilon)\right]^{1/2} \frac{\bar{\sigma}_p\,(\bar{p} \times \bar{p}')}{|\,\bar{p} \times \bar{p}'\,|}\, \sigma_{TS} \right\}$$

where $\Gamma_t(q^2, E-E')$ is a purely kinematic factor given by

$$\frac{\alpha}{2\pi}\;\frac{E'}{E}\;\frac{K}{q^2}\;\frac{1}{1-\varepsilon}$$

with

$$K = E - E' - q^2/2M = (M^{x2} - M^2)/2\,M$$

Here K is the energy of the photon giving the same exitation N^x to the nucleon system as inelastic scattering of electron. The quantities σ_T and σ_S are the cross section for equivalent transverse and longitudinal photon respectively. The quantity σ_{TS} is the effective cross section due to interference between transverse and longitudinal photon amplitudes.

The degree of T violation can be measured by a phase difference δ

between these two amplitudes. The asymmetry can then be shown to be

$$a = A\sin\delta = \frac{[2\varepsilon(1+\varepsilon)]^{1/2}}{\sigma_T + \varepsilon\sigma_S}\,\sigma_{TS}\sin\delta$$

The relation of σ_{TS} to σ_S and σ_T depends on the multipolarity of transition which is well established for the 1238 and 1512 MeV resonances.

Table VIII shows the experimental results available up to now.

A similar experiment at higher sensitivity, where a new experimental set up avoides the troubles with target, has been proposed(67).

TABLE VIII

reference and incoming lepton	energy of incoming lepton (GeV)	Asymmetry value, A (%)		
		$N^*(1238)$	$N^*(1512)$	$N^*(1688)$
(65) e^-	18.0	2.8±1.4	-1.3±1.7	0.8±2.1
(65) e^+	12.0	-3.0±1.8	---	---
(65) e^-	15.0	2.3±2.9	3.1±2.2	2.0±3.1
(65) e^-	18.0	-2.8±3.3	-4.8±3.6	-8.2±4.7
(66) e^-	3.98	3.8±4.3	---	---
(66) e^-	5.97	---	3.6±4.7	-0.5±4.4
(66) e^-	5.98	---	-2.6±8.2	3.6±7.3

IV.5.- Detailed balance.-

It is known that the "detailed balance" principle is a consequence of the time reversal invariance.

Hence in the process like $A + a \rightleftarrows B + b$, the T invariance requires:

$$\frac{\left[\frac{d\sigma}{d\Omega}(E,\theta)\right]_{f\to i}}{\left[\frac{d\sigma}{d\Omega}(E,\theta)\right]_{i\to f}} = \frac{(2S_A+1)(2S_a+1)}{(2S_B+1)(2S_b+1)}\left(\frac{P_a}{P_b}\right)^2$$

where the $d\sigma/d\Omega$ are considered at same energy and angle, the P_i and s_i are the momenta and spins in the center of mass system.

The above relation establishes a correlation between the spin averaged squared matrix elements and has therefore some limitations.

Moreover, there are cases which satisfy the above relation, but are not a T invariance proof ; for instance, when the process may be descibed at the first order of Born approximation.

A further limitation of the detailed balance arises through the unitarity of the S matrix. If only two state are relevant, or if the reaction proceeds through an isolated resonance, then measurements of the cross section backward and forward do not test T invariance. The reason is that the most general 2 x 2 unitary S matrix can be written as

$$S = \begin{pmatrix} \cos\theta\, e^{i\alpha} & i \sin\theta\, e^{i\varphi} \\ i \sin\theta\, e^{i\varphi} & \cos\theta\, e^{-i\alpha} \end{pmatrix}$$

The diagonal matrix elements represent elastic scattering in initial and final states, and the off-diagonal matrix elements are proportional to the reaction amplitudes. Since the phases are not measured, no test of T occurs.

The theorem can be extended(68) and applies, for instance, whenever other elements of S matrix are nonvanishing, but do not interfere with those of the preceding equation.

We shall not discuss these restrictions further, because for most hadronic reactions there are many open channels, which make the S matrix a much larger matrix than 2 x 2 (exception may arises close to threshold), and unitarity is not a severe restriction.

An experimental test of T violation can be the deuteron photodisintegration and the inverse reaction: $\gamma + D \rightleftarrows n + p$ in the energy region, where the intermedie state $NN^{x}(1238)$ is available. However, the asymmetry can be well evaluated only if we have a good theory of deuteron disintegration.

At present the following models are available, amongst other:

- D. Schiff et al. (102)
- J.P. Leroy et al. (103)
- Barshay(104).

An experimental test has been carried out by D. Cheng et al. (69) and D.F. Bartlett(118). These experimentalists have studied the reaction using neutron in a (300 ÷ 700 MeV) energy range.

The data are compared with the results of the inverse reaction. In general the agreement is almost satisfactory; only at about 500 MeV energy there is a disagreement of about 3 standard deviation in the parameter A_2/A_o, being:

$$\frac{d\sigma}{d\Omega} \simeq A_o + A_2 P_2(\cos\theta)$$

The theoretical and experimental uncertainties make rather doubtful the existence of a T violation.

We remark that the theoretical models give an effect of about a 30% for a "maximal violation".

We have shown further experimental results in Table IX. Here we have indicated the forward and backward processes studied, and the ratio A of noninvariant amplitude under T.

TABLE IX

reaction	A	reference
$^{24}Mg + D \rightleftarrows {}^{25}Mg + p$	$\lesssim 3\ 10^{-3}$	(105)
$^{24}Mg + \alpha \rightleftarrows {}^{27}Al + p$	$\lesssim 3\ 10^{-3}$	(106)
$^{16}O + D \rightleftarrows {}^{14}N + \alpha$	$\lesssim 3\ 10^{-3}$	(107)

For a detailed discussion of test of T in nuclear physics see the excellent review by Henley(113).

IV.6.- Tests of T in weak decays.-

A possible T invariance test is available with weak decays (for instance β-decays).

Indeed in the weak interactions theory it is well known that there are two coupling constant: the vector g_V and the axial g_A constant.

If the T invariance holds, these coupling constant must be relatively real, namely:

$$g_A/g_V = |g_A/g_V|\ e^{i\varphi} \qquad \varphi = 0^o,\ 180^o$$

We remark that, if $\Delta S = 0$ part of weak hamiltonian satisfies the charge symmetry, then the $\varphi = 0^o, 180^o$ condition is verified indipendently by T invariance.

A method for testing the phase differences between the "vector" and "axial" part of weak interactions is to set up an angular correlation neutrino-electron, successively to the β-decay of the polarized nucleus, namely a correlation of the kind:

$$\vec{\sigma}(N) \cdot (\vec{p}(e) \times \vec{q}(\nu))$$

The present results of the β-decays:

$$n \rightarrow p + e^- + \bar{\nu} \qquad {}^{19}N_e \longrightarrow {}^{19}F_e + e^+ + \nu$$

are reported in Table X, from which one can see that T violation is smaller than about 1%.

TABLE X

decay		reference
$n \rightarrow p + e^- + \nu$	178.7 ± 1.3^o	(108)
${}^{19}Ne \longrightarrow {}^{19}Fe + e^+ + \nu$	180.2 ± 1.6^o	(109)
$K^o \longrightarrow \pi^- + \pi^+ + \nu$	180.5 ± 2.2^o	(110)

The β-decay tests at high energy are less accurate.

In the $K^o \rightarrow \pi \mu \nu$ decay one has measured the correlation $\vec{\sigma}(\mu)(\vec{p}(\pi) \times \vec{p}(\mu))$ with the obvious meaning of the symbols.

In the $\Lambda^o \rightarrow p + \pi^-$ decay a term of kind $\vec{\sigma}(p)(\vec{\sigma}(\Lambda) \times \vec{p}(p))$ is not expected unless there were present a phase difference between the S and P waves amplitudes.

In two experiments$^{(70,71)}$ the averaged data yield the value $\mathrm{arctg}\ \beta/\alpha = 9.3^o \pm 3.8^o$, where β and α are the decay parameters by Lee and Yang$^{(86)}$. But the final state interactions are important: indeed the phase shifts of π-N scattering with T conservation give $\mathrm{arctg}\ \beta/\alpha = 6.7^o \pm 1.7^o$.

We note that if the PC nonconservation occurs in the weak interactions, the expected degree of time reversal invariance in these experiments is model dependent. We remark that Glashow(72) model would here predict a 100% effect.

If the violation occurs in the $\Delta I \geq 3/2$ component as is suggested from the results of $K^0 \rightarrow 2\pi^0$ experiments, large violation would not be expected in this decay, since Λ^0 decay does not appear to violate $\Delta I = 1/2$ rule to any large degree.

If the CP nonconservation were due to the electromagnetic interaction, the effect here would presumably be less than 1% and would go undetected in this experiment.

IV. 7. - Neutron electric dipole moment.-

As has been pointed out by Landau(73) the static electric dipole moment of a non degenerate system vanishes identically unless both space parity and time reversal invariances are violated. .

The neutron is chosen for the following pratical reasons:

a) The neutron magnetic moment is about 10^{-3} times smaller than the atom moment, so the magnetic field uniformity is not critical.
b) The neutron has small induced polarization and consequently the squared electric effect are small, so that one may use very high fields.
c) A neutron beam can be totally reflected on a suitable mirror surface, so that a very good slow neutron beam with a particulary small energy spread is available.

As we have remarked, an eventual dipole moment effect can be investigated by putting the neutron into a sufficiently high electric field.

The choice of this field determines the following techniques: one method (Ramsey method) uses an external electric field observing the magnetic resonance shift; in the other (Bragg method) the electric field is a nuclear field, which determines an additional term in the scattering amplitude.

The method developed by Ramsey seems to be already so refined that no further progress can be regarded as likely; the actual limit is(74): $|\mu e/e| < 5 \times 10^{-23}$ cm.

On the other hand, it seems that the Bragg method may be further improved, so as to reach a much lower level of e. d. m.; the limit is(75): $|\mu e/e| = (2.4 \pm 3.4)\,10^{-22}$ cm.

Perhaps a suitable compound is barium tithanate, but more precise calculations have to be done(111).

We list here some predictions on the electric dipole magnitude provided by the up to date theoretical models.

1) Holding the C violation in electromagnetic and the space parity in weak interactions, the electric dipole moment should be $\mu e/e \sim$ $\sim G m_p \simeq 10^{-19}$, but also 10^{-22} cm is acceptable.

In particular, there exist models in which the zero momentum electromagnetic interaction involved in the static moment introduces no CP violation so that the moment becomes proportional to e^3 instead of e (T. D. Lee, private communication to L. Wolfenstein, Erice).

For example an electromagnetic CP violation model due to Filippov et al. (76) explains the CP violation source in terms of off mass shell virtual interactions of the particles assumed as components (quarks, barions) with a certain vertex. This point of view is equivalent to assuming that CP noninvariant terms appear only in the form factor of the neutron magnetic moment.

So the electric dipole vanishes at first order, but at third order it is predicted:

$$\mu e/e \approx 10^{-23} \text{ cm}$$

2) Some milliweak models and also combined effects of millistrong with weak interaction give (77):

$$\mu e/e \approx (2 \times 10^{-3}) \, G m_p \approx 2 \times 10^{-22} \text{ cm}$$

3) A pratical vanishing effect is predicted by the superweak model.

4) The Okubo model predicts no effect (78).

5) The model of T. Das (79) proposes a CP violation based on the current-current form of the weak interactions. The CP invariant (non leptonic) part obeis to $\Delta I = 1/2$ rule; but this rule is violated by the CP non conserving part. This model has no observable effects of T violation in the leptonic weak decays and on the neutron electric dipole moment.

6) In the Glashow model (72) the CP non conservation is due to phase angles between the normal octet of the vectorial and axial current. Relatively to this model Pati (80) predicts small effects; in particular, for the neutron electric dipole moment he gives the following value:

$$10^{-23} \text{ cm} \leq \mu e/e \leq 10^{-22} \text{ cm}$$

V. - CONCLUSIONS. -

It is a remarkable fact that CP violation, first found in the K^o-$\bar{K}^o$ system, remains up to now an effect related to K^o mesons physics.

An obvious advantage of K^o experimental research is that experiments can be well planned, because it is possible to know what degree of accuracy must be reached. Unfortunately outside K^o pnysics the present situation does not permit analogous experimental planning.

As far as the K^o-$\bar{K}^o$ system is concerned, it seems that CP violation may be limited to the mass operator.

However, a recent experimental result$^{(112)}$ gives:

$$R_L = 1.37 \pm .25\,(\text{stat.}) \pm .14\,(\text{syst.}) \neq R_S = 0.462 \pm .018$$

where

$$R_{L,S} = \text{Rate}\,(K_{L,S} \to 2\,\pi^o) \,/\, \text{Rate}\,(K_{L,S} \to \pi^+ \pi^-)$$

Apart from this, all other predictions of the so called superweak model have been verified with fairly good accuracy (cfr. the value of Re(ε) and the possible equality of η_{+-} and η_{oo}).

In the line of the quantum mechanical breaking interpretation of the CP violation, $e^+ e^-$ experiences are perhaps the most favourable.

As far as the Lee theory is concerned, the still nonvanishing asymmetry (yet obscure and perhaps spurious) suggest that electroproduction tests would be very useful. However, purely leptonic tests may depress the asymmetry, like the effects of the final state interactions, so it may be that more refined methods of eliminating these latter have to be used.

As a general conclusion it may be stated will be very interesting to study C or T violating effects by means of storage rings technique, when higher luminosities become available, such as vector mesons radiative decays, particle antiparticle asymmetry and electron or positron productions using polarized nucleon beams togheter with stored electron or positron beams.

Furthermore we note that, as we have pointed out above, the neutrino-production experiments seem "a priori" a very powerful tool for testing the T-invariance in the field of weak interactions. This kind of experiments, in fact, does not require polarization measurements. Nevertheless, a difficulty arises from the smallness of the cross sections for neutrino reactions.

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