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REMARK ON THE STATUS OF NON-CONSERVATION OF PARITY IN NUCLEAR BETA-DECAY

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Equality of β-decay coupling constants $C'_A/C_A = C'_V/C_V = 1$, implying V − A interaction, is less verified than commonly assumed. Deducing limits $0.52 < C'_V/C_V < 1.93$ and $0.82 < C'_A/C_A < 1.22$ we discuss a possible V + A admixture with a mass ratio $m(W^{V-A})/m(W^{V+A}) < 0.56$ for intermediate bosons $W^{V\pm A}$.

Unification of weak and electromagnetic interaction draws the attention of many investigators both in theoretical and in experimental physics. One of the profound differences between these two types of interaction is the fact that parity violation is manifest with overwhelming evidence in, e.g., nuclear β-decay, but not in electromagnetic transitions. As brought forward by Beg et al. [1], and several years ago in a somewhat different context by Lipmanov [2], it is relevant to investigate to which extent the experiments indicate a *maximum* non-conservation of parity in β-decay with pure V − A currents or, in other words, to which extent a V + A admixture can be present.

The experimental results so far obtained are consistent with an exclusive V − A interaction and a hamiltonian with equal-coupling constants for the parity conserving and the parity violating part of the interaction: $C_i = C'_i$ with i = V (vector) or A (axial-vector). Unfortunately, the ratio C'_i/C_i is observed in parity experiments via a form $x_i = 2C'_iC_i/(C'^2_i + C^2_i)$ which is insensitive to small deviations of C'_i/C_i from unity. The determination of C'_A/C_A is largely confined to work in the years immediately after the discovery of parity violation in weak interactions, possibly because a realization of drastic improvements seemed to be difficult.

In a survey of 1965 Steffen and Frauenfelder [3] proposed

$$0.4 < C'_V/C_V < 2.5, \quad 0.85 < C'_A/C_A < 1.15. \quad (1)$$

In 1970 Paul [4] deduced from a least-squares adjustment to data from the literature $0.69 < C'_V/C_V < 1.22$ and $1.04 < C'_A/C_A < 1.16$, using the smallest of external and internal error margins. Later Kropf and Paul [5] felt it safer (as we do) to use the larger of the two error assignments. Enlarging the margins by a factor $1/0.41$ from ref. [4] the ranges become

$$0.50 < C'_V/C_V < 1.80, \quad 0.95 < C'_A/C_A < 1.25. \quad (2)$$

The limits (1) and (2) have not been derived in such a way that quantitative confidence levels could be specified. In the following a confidence level is obtained by taking into account the a priori knowledge $|x_i| \leqslant 1$.

This letter is restricted to processes giving straightforward and unambiguous information. No observables are used which depend on $C'_V C_A + C_V C'_A$ as the β-symmetry with oriented neutrons. We consider only allowed transitions (unlike in ref. [1]) and we assume CP conservation and absence of scalar and tensor interactions [4].

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Table 1
Average β-polarization and $\beta\gamma$ circular polarization correlation
results. Systematic errors were added quadratically when orig-
inal papers give only statistical errors. Older data are in refs.
[4,6].

Vector interaction via P_β:

	source	x_V
Hopkins et al. [8]	^{14}O	0.97 ± 0.19
Koks and van Klinken [6]	^{3}H	1.03 ± 0.14
	adopt:	1.01 ± 0.11

Axial-vector interaction

	source	x_A
via P_β [6, 11]:		
Lazarus and Greenberg	^{60}Co	1.02 ± 0.03
van Klinken	^{60}Co	1.002 ± 0.016
Brosi et al.	^{32}P	0.99 ± 0.02
van Klinken	^{32}P	0.98 ± 0.02
Wenninger et al.	^{32}P	1.01 ± 0.03
Koks and van Klinken	^{3}H	1.01 ± 0.03
via $A_{\beta\gamma}$ [12]:		
Appel	^{60}Co	1.01 ± 0.08
Steffen	^{60}Co	1.03 ± 0.08
Schopper et al.	^{60}Co	0.97 ± 0.04
Schopper et al.	^{22}Na	1.00 ± 0.05
	adopt:	1.001 ± 0.012

Both for pure Fermi and for pure Gamow–Teller de-
cays x_i can be measured via the longitudinal polariza-
tion of β rays: $P_\beta/(v/c) = \pm x_i$; + for β^+ and − for β^-
decays. Further information is obtained from the
mixed decay of tritium [6] for which

$$-P_\beta/(v/c) = x_m = \rho x_V + (1-\rho)x_A, \qquad (3)$$

with a mixing parameter $\rho = 0.187$. For Gamow–Teller
decays x_A can also be measured via the $\beta\gamma$ circular po-
larization correlation ($A_{\beta\gamma} = \pm\frac{1}{3} x_A \cdot v/c$, higher-order
terms can be neglected [7]) or via the β-asymmetry of
oriented nuclei. The latter way has, to our knowledge,
not yet been used for *absolute* measurements of sig-
nificant accuracy, but may offer good future possibili-
ties.

Most parity experiments gave no *absolute* results in
the strict sense that uncertainties in instrumental asym-
metries and in sensitivity of utilized polarimeters have

been taken into account fully. For instance P_β can be
measured with a Mott polarimeter by observing $\delta - \delta^0$
$= P_\beta S$. Here δ is the observed asymmetry from which a
possible instrumental asymmetry δ^0 must be subtracted
in order to obtain the true polarization asymmetry; δ^0
must be small with respect to δ. In Groningen the po-
larization sensitivity S has been measured via double
scattering of unpolarized electrons [6]. Other investiga-
tors used calculated S-values with an estimated compu-
tational accuracy of 1.0 to 1.5% for infinitely thin scat-
terers. Adaptation of theoretical S-values for realistic
scatterers and solid angles leads, however, in our ex-
perience to at least 2% uncertainty in P_β measurements.
We judge that the analysing efficiency can be uncertain
to 3% or more for $A_{\beta\gamma}$ measurements.

In table 1, a compilation of average P_β and $A_{\beta\gamma}$ re-
sults, the only pure Fermi decay concerns the P_{β^+}
measurement by Hopkins et al. with ^{14}O. Unfortunately,
the conditions imposed by this isotope caused relatively
large uncertainties. In order to obtain narrower con-
straints on C_V'/C_V we reanalysed the beta-polarization
for the mixed decay of tritium with respect to its sep-
arate Fermi and Gamow–Teller parts. Fig. 1 shows iso-
polarization contours according to eq. (3) and an area
for $0.960 < x_m \leqslant 1$, the range to which x_m is confined
with 90% confidence by the measured [6] value x_m
$= 1.005 \pm 0.026$. The outer tritium contour gives

$$0.48 < C_V'/C_V < 2.06, \qquad 0.73 < C_A'/C_A < 1.38. \qquad (4)$$

The separate x_V and x_A values for ^{3}H in table 1 cor-
respond to these ranges.

The uncertainties assigned to the finally adopted
values for x_V and x_A are intended to be standard de-
viations. The error in x_V stems from the combined
statistical evidence for ^{14}O and ^{3}H data, the error in
x_A from combining the accuracies of uncorrelated ab-
solute measurements. We searched a posteriori for
values x_i' such that we are willing to accept with 90%
confidence that the true but unknown value of x_i is
within the interval $x_i' < x_i \leqslant 1$. With an objectivistic
treatment [9] and with a subjectivistic bayesian[+1] ap-
proach [10] we obtained essentially the same limits:

[+1] Using the Bayes rule, we assumed that within the confine-
ment $|x_i| \leqslant 1$ each value of x_i is equally probable. Assuming
equal probability for the corresponding C_i'/C_i values would
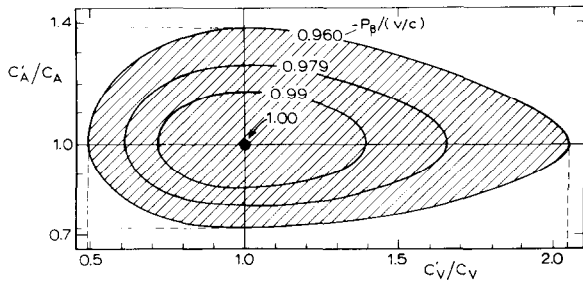slightly narrow the ranges (5): e.g. $0.57 < C_V'/C_V < 1.91$.

Fig. 1. Iso-polarization contours for various $P_\beta(^3\mathrm{H})$ values. The outer contour corresponds to the result of ref. [6] with a 90% confidence level, and confines C'_V/C_V and C'_A/C_A to the shaded area.

$$x'_V = 0.817, x'_A = 0.98, \text{ giving}$$

$$0.52 < C'_V/C_V < 1.93, \quad 0.82 < C'_A/C_A < 1.22. \quad (5)$$

These limits do not impeach a pure V − A interaction with $C'_i = C_i$, but they offer a surprising leeway for alternative possibilities; e.g. admixtures of a V + A interaction mediated by a W^{V+A} boson. Lipmanov [2] gave the relation

$$-P_\beta/(v/c) = 1 - 2G_+^2/(G_-^2 + G_+^2), \quad (6)$$

where $G_\pm$ are coupling constants related to V ± A interactions: $G_+/G_- = (C_i - C')/(C_i + C'_i)$ with $i = $ V or A. For instance, if a V + A admixture would proceed with $C'_V \neq C_V$ and with $x_V > 0.817$ (the 90% confidence limit), we find $m(\mathrm{W}^{V-A})/m(\mathrm{W}^{V+A}) = (G_+/G_-)^{1/2}$ < 0.56 for the ratio of corresponding boson masses.

The limits (5) are based on allowed nuclear β-decay. The bounds can be narrowed, though not rigorously, by using a broader range of input data from less straightforward processes. Recently, we learned that this complementary approach has been made by Holstein and Treiman [13], taking results from first-forbidden β-decay, muon decay and decay of polarized $^{19}\mathrm{Ne}$ with 2σ deviations without truncations. They did not take into account the P_β data for V-interaction via decay of $^{14}\mathrm{O}$ and $^3\mathrm{H}$, but their constraint on C'_A/C_A (via their parameter y) is somewhat narrower than (5) due to additional input of data from first-forbidden β-decay.

Considering future experiments, it is evident that improved β-polarization measurements are desirable, especially measurements on Fermi transitions. With proper investment of time and facilities it must be possible to improve polarimeters based on Mott scattering, on Bhabha scattering or on polarization effects of bremsstrahlung and annihilation radiation. For absolute $A_{\beta\gamma}$ measurements essential improvements seem not to be achievable for the moment. The reason is that the analysing efficiency for the γ-ray circular polarization can not be measured with an accuracy of a few percent.

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