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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 \( m(WV-A)/m(WV+A) < 0.56 \) for intermediate bosons \( WV\pm A \).

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 \( x_i = 2C_i'C_i/(C_i'^2 + C_i^2) \) 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

\[
0.4 < C_V'/C_V < 2.5, \quad 0.85 < C_A'/C_A < 1.15. \tag{1}
\]

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

\[
0.50 < C_V'/C_V < 1.80, \quad 0.95 < C_A'/C_A < 1.25. \tag{2}
\]

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 \( |x_i| < 1 \).

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].
Table 1

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

<table>
<thead>
<tr>
<th>Source Description</th>
<th>$x_V$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hopkins et al. [8]</td>
<td>$^{14}\text{O}$ $0.97 \pm 0.19$</td>
</tr>
<tr>
<td>Koks and van Klinken [6]</td>
<td>$^3\text{H}$ $1.03 \pm 0.14$</td>
</tr>
<tr>
<td>adopt: $1.01 \pm 0.11$</td>
<td></td>
</tr>
</tbody>
</table>

Axial-vector interaction

<table>
<thead>
<tr>
<th>Source Description</th>
<th>$x_A$</th>
</tr>
</thead>
<tbody>
<tr>
<td>via $P_B$ [6, 11]:</td>
<td></td>
</tr>
<tr>
<td>Lazarus and Greenberg</td>
<td>$^{60}\text{Co}$ $1.02 \pm 0.03$</td>
</tr>
<tr>
<td>van Klinken</td>
<td>$^{60}\text{Co}$ $1.002 \pm 0.016$</td>
</tr>
<tr>
<td>Brosi et al.</td>
<td>$^{32}\text{P}$ $0.99 \pm 0.02$</td>
</tr>
<tr>
<td>van Klinken</td>
<td>$^{32}\text{P}$ $0.98 \pm 0.02$</td>
</tr>
<tr>
<td>Wenninger et al.</td>
<td>$^{32}\text{P}$ $1.01 \pm 0.03$</td>
</tr>
<tr>
<td>Koks and van Klinken</td>
<td>$^3\text{H}$ $1.01 \pm 0.03$</td>
</tr>
<tr>
<td>via $A_{\beta\gamma}$ [12]:</td>
<td></td>
</tr>
<tr>
<td>Appel</td>
<td>$^{60}\text{Co}$ $1.01 \pm 0.08$</td>
</tr>
<tr>
<td>Steffen</td>
<td>$^{60}\text{Co}$ $1.03 \pm 0.08$</td>
</tr>
<tr>
<td>Schopper et al.</td>
<td>$^{60}\text{Co}$ $0.97 \pm 0.04$</td>
</tr>
<tr>
<td>Schopper et al.</td>
<td>$^{22}\text{Na}$ $1.00 \pm 0.05$</td>
</tr>
<tr>
<td>adopt: $1.001 \pm 0.012$</td>
<td></td>
</tr>
</tbody>
</table>

Both for pure Fermi and for pure Gamow—Teller decays $x_i$ can be measured via the longitudinal polarization of $\beta$ rays: $P_B/(v/c) = \pm x_i + \rho x_V$ for $\beta^+$ and $-\rho x_V$ for $\beta^-$ decays. Further information is obtained from the mixed decay of tritium [6] for which

$$-P_B/(v/c) = x_m = \rho x_V + (1-\rho)x_A,$$

with a mixing parameter $\rho = 0.187$. For Gamow—Teller decays $x_A$ can also be measured via the $\beta\gamma$ circular polarization correlation ($A_{\beta\gamma} = \pm \frac{1}{2} x_A \cdot v/c$, higher-order terms can be neglected [7]) or via the $\beta$-asymmetry of oriented nuclei. The latter way has, to our knowledge, not yet been used for absolute measurements of significant accuracy, but may offer good future possibilities.

Most parity experiments gave no absolute results in the strict sense that uncertainties in instrumental asymmetries and in sensitivity of utilized polarimeters have been taken into account fully. For instance $P_B$ can be measured with a Mott polarimeter by observing $\delta = \delta^0 = P_B S$. Here $\delta$ is the observed asymmetry from which a possible instrumental asymmetry $\delta^0$ must be subtracted in order to obtain the true polarization asymmetry; $\delta^0$ must be small with respect to $\delta$. In Groningen the polarization sensitivity $S$ has been measured via double scattering of unpolarized electrons [6]. Other investigators used calculated $S$-values with an estimated computational accuracy of 1.0 to 1.5% for infinitely thin scatterers. Adaptation of theoretical $S$-values for realistic scatterers and solid angles leads, however, in our experience to at least 2% uncertainty in $P_B$ 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 $P_B$ and $A_{\beta\gamma}$ results, the only pure Fermi decay concerns the $P_B^+$ measurement by Hopkins et al. with $^{14}\text{O}$. Unfortunately, the conditions imposed by this isotope caused relatively large uncertainties. In order to obtain narrower constraints on $C_V/C_V$ we reanalysed the beta-polarization for the mixed decay of tritium with respect to its separate Fermi and Gamow—Teller parts. Fig. 1 shows isopolarization contours according to eq. (3) and an area for $0.960 < x_m < 1$, 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

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

The separate $x_V$ and $x_A$ values for $^3\text{H}$ in table 1 correspond to these ranges.

The uncertainties assigned to the finally adopted values for $x_V$ and $x_A$ are intended to be standard deviations. The error in $x_V$ stems from the combined statistical evidence for $^{14}\text{O}$ and $^3\text{H}$ data, the error in $x_A$ from combining the accuracies of uncorrelated absolute 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 $x_i - x_i \leq 1$. With an objectivistic treatment [9] and with a subjectivistic bayesian* approach [10] we obtained essentially the same limits:

* Using the Bayes rule, we assumed that within the confinement $|x_i| \leq 1$ each value of $x_i$ is equally probable. Assuming equal probability for the corresponding $C_V/C_V$ values would slightly narrow the ranges (5): e.g. $0.57 < C_V'/C_V < 1.91$.  

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$J(u/c) = 1 - 2G_+/G_-$, \hspace{1cm} (6)

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

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

$$-P_\beta/(u/c) = 1 - 2G_+^2/(G_-^2 + G_+^2),$$ \hspace{1cm} (6)

where $G_\pm$ are coupling constants related to V ± A interactions: $G_+/G_- = (C_i - C'_i)/(C_i + C'_i)$ 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 $m(W^V-A)/m(W^V+A) = (G_+/G_-)^{1/2} < 0.56$ for the ratio of corresponding boson masses.

The limits (5) are based on allowed nuclear $\beta$-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 $\beta$-decay, muon decay and decay of polarized $^{19}$Ne with 2o deviations without truncations. They did not take into account the $P_\beta$ data for V-interaction via decay of $^{14}$O and $^3$H, but their constraint on $C'_V/C_V$ (via their parameter $y$) is somewhat narrower than (5) due to additional input of data from first-forbidden $\beta$-decay.

Considering future experiments, it is evident that improved $\beta$-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 $A_\alpha$ measurements essential improvements seem not to be achievable for the moment. The reason is that the analysing efficiency for the $\gamma$-ray circular polarization can not be measured with an accuracy of a few percent.

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References