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The charge dependent nuclear interaction and Fermi matrix elements of $\beta$ decay

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If charge independence of nuclear forces were valid the Fermi matrix elements $M_F$ of $\Delta T = \pm 1$ $B$ transitions would vanish. Therefore deviations from charge independence can be found by determining $M_F$ from $3$-$\gamma$ circular polarization correlation or $3$ asymmetries from polarized nuclei.

Blin Stojle and Le Tourneux [1] have introduced the charge dependent nuclear potential

$$\mathcal{V}_n = \sum_{i,j=1}^{3} \left[ r(i) v_{ij} + s(i) v_{ij} \right] e^{-\beta r_{ij}^2}$$

Charge independence implies $r = q = r = s = 0$ and for charge symmetry $r = r = 0$. If the potential is spin independent one has $r = s = 0$.

With this potential Blin-Stojle and Novakovic [2], [3] derived the following expressions for Fermi matrix elements

$$\begin{align*}
\text{Na}^{24}: & \quad M_F = 0.012 - 1.57 p + 3.57 r \\
\text{Al}^{41}: & \quad M_F = 0.49 (p-q) + 0.93 (r-s) \\
\text{Sc}^{44}: & \quad M_F = 0.25 (p-q) - 0.40 (r-s) \\
\text{Mr}^{52}: & \quad M_F = 0.015 - 0.62 (p+q) + 1.17 (r+s)
\end{align*}$$

In addition Novakovic [3] has related $p$ and $r$ to the mass difference between $\text{Al}^{24}$ and $\text{Na}^{24}$ and obtains

$$- 222.4 p + 17.9 r = 1.370$$
New precise measurements of the B-γ circular polarization correlation of Na²⁴ and A⁴¹ by Behrens and Schopper [4] together with older data for Sc⁴⁴ and Mn⁶² (see the Table) make a determination of p, q, r and s possible. This can be achieved in the following way. Combining eq. (1) and (6) one obtains

\[
10^3 p = -6.7 \pm 0.02, \quad 10^3 r = \begin{cases} 5.9 \pm 0.3, & M_p(\text{Na}^{24}) > 0 \\ -6.7 \pm 0.3, & < 0 \end{cases}
\]

(7)

The ambiguity originates from the fact that experimentally only the sign of \(M_p/M_G\) can be determined. Since the sign of \(M_G\) is not known also the sign of \(M_p\) remains undetermined. Theoretical calculations [2] indicate that the signs of \(M_p\) for Sc⁴⁴ and Mn⁶² are both negative. This will be taken for granted for the subsequent analysis.

Adding and subtracting eq. (3) and (5) yields

\[
p - 19r = \begin{cases} 7 \pm 6 \times 10^{-3}, & M_p(\text{Na}^{24}) > 0 \\ 25 \pm 6 \times 10^{-3}, & < 0 \end{cases},
\]

(3)

\[
q - 19s = \begin{cases} 25 \pm 6 \times 10^{-3}, & M_p(\text{Na}^{24}) > 0 \\ 7 \pm 6 \times 10^{-3}, & < 0 \end{cases},
\]

(9)

If \(p = -6.7 \times 10^{-3}\) is inserted into the first relation one finds

\[
10^3 r = \begin{cases} -7 \pm 3, & M_p(\text{A}^{41}) > 0 \\ -17 \pm 3, & < 0 \end{cases}
\]

(10)

The value \(10^3 r \approx -7\) is in very good agreement with \(r\) as deduced from the Na²⁴ data whereas \(10^3 r = 17\) is too small. This implies that \(M_p(\text{A}^{41}) > 0\). It would be very interesting to explain this empirical result by nuclear model calculations.

In order to determine \(q\) and \(s\) separately the data for Sc⁴⁴ must be included. Combining eq. (4) and (5) gives

\[
q = 0.056 \pm 0.007
\]

\[
s = 0.015 \pm 0.004
\]
As a check the value of $s$ may be put into eq. (9) and one obtains

$$ q = \begin{cases} \gamma_{054} \pm 0.009 & M_P(A) > 0 \\ \gamma_{036} \pm 0.009 & < 0 \end{cases} $$

The upper value agrees with that deduced from $^{44}$Sc and corroborates that $M_P(A^{44})$ is positive.

Summarizing one can state that all data are consistent and a reasonable set of parameters would be

$$ 10^3 p = -6.7 \pm 0.22 \quad 10^3 r = 6.7 \pm 0.3 $$
$$ 10^3 q = 55 \pm 6 \quad 10^3 s = 15 \pm 4 $$

These numbers show that there is a definite deviation from charge independence. Also charge symmetry is violated although to a lesser degree (since $\gamma_{054} \neq \gamma_{036}$).

In addition an appreciable spin dependence is found, since $r$ and $s$ are of the same order of magnitude than $p$ and $q$.

Altman and MacDonald [6] have derived $p$, $r$, $q$, and $s$ from the energy level shifts and the fit values of the $^{14}A$, $^{14}N$, $^{14}C$ system. Data of the $p$-$p$ and $n$-$p$ scattering are also used. Our values of $p$ and $r$ agree nicely with their case II. These authors, however, find negative values for $q$ and $s$.

It is not quite clear if this discrepancy can be ascribed to a sign ambiguity.

Of course, the quantitative results for the parameters $p$, $q$, $r$ and $s$ should not be taken too seriously since eq. (2) to (6) have been derived on the basis of a particular nuclear model. However, it seems that the Fermi matrix elements cannot be explained entirely by ordinary Coulomb effects.
Table

Experimental data used in the analysis

<table>
<thead>
<tr>
<th>Nucleus</th>
<th>$\beta-\gamma$ circ. pol. asymmetry $A$</th>
<th>$M_\beta \times 10^3$</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na$^{24}$</td>
<td>$0.100 \pm 0.004$</td>
<td>$1.7 \pm 0.4$</td>
<td>Behrens and Schopper[4]</td>
</tr>
<tr>
<td>A$^{41}$</td>
<td>$0.063 \pm 0.02$</td>
<td>$9 \pm 6$</td>
<td>Behrens and Schopper[4]</td>
</tr>
<tr>
<td>Se$^{44}$</td>
<td>$-0.131 \pm 0.013$</td>
<td>$(-) \cdot 3$</td>
<td>Block et al. [7]</td>
</tr>
<tr>
<td>Xe$^{52}$</td>
<td>$-0.029 \pm 0.003$</td>
<td>$(-) \cdot 1 \pm 0.6$</td>
<td>Postrma et al. [9], Ambler et al [10], Daniel et al. [11], Mann et al. [12]</td>
</tr>
</tbody>
</table>

Literature

[4] H.Behrens, H.Schopper, to be published