The Mass-8 Experiment - Measuring the β - α angular correlations

J.F. Amsbaugh, M. Beck, L. De Braekeleer*, D.W. Storm, E. Swanson,
K.B. Swartz[§], J.P.S. van Schagen, D.C. Wright, Z. Zhao⁺

Physics Department, University of Washington, Seattle, WA 98195

* Present address Physics Department, Duke University, Durham, NC 27706

[§] Present address Physics Department, Yale University, New Haven, CT 06520

⁺ Present address McKinsey Co., Atlanta, GA 30303

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Abstract: The objective of the Mass-8 experiment is to perform a precision test of the conservation of the vector current hypothesis and a search for second class currents. We present preliminary data on the correlation coefficients of the β - α angular correlations of the β -delayed α -decays of ^8Li and ^8B .

Introduction

The standard model of electroweak interaction is being tested extensively by many experiments. The two questions investigated by the present experiment are the validity of the Conservation of the Vector Current hypothesis (CVC)¹ and the possible existence of Second Class Currents (SCC)². CVC equates the vector part of the weak interaction with the vector part of the electromagnetic interaction. It is a fundamental property of the standard model. Present limits on the validity of CVC are at the level of 6 %³. SCC are defined by their transformation properties under G-parity; they only appear in the standard model at the level of isospin breaking:

First class currents:

$$GV_\mu G^{-1} = V_\mu$$

$$GA_\mu G^{-1} = -A_\mu$$

Second class currents:

$$GV_\mu G^{-1} = -V_\mu$$

$$GA_\mu G^{-1} = A_\mu$$

The investigation of CVC and SCC usually involves the comparison of the weak magnetism form factor from weak decays with the magnetic form factor from electromagnetic decays. The former can be obtained from e.g. precision measurements of β -spectral shapes, μ -capture, β - α and β - γ angular correlations. The latter can be retrieved from e.g. the isobaric analogue γ -transitions. Another process used for a test of CVC that does not involve nuclear physics is π/μ -decay (see ref. ³ for a summary). The experiment discussed here measures the $\beta^\pm$ - α angular correlations in the $A=8$ system (Fig. 1):

FIGURE 1. Decay scheme in $A=8$

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$$\omega^{\pm}(E_{\beta}, \vartheta_{\beta\alpha}) = a_0 \cdot (1 + a_1 \cdot \cos \vartheta_{\beta\alpha} + a_2^{\pm} \cdot \cos^2 \vartheta_{\beta\alpha}) \quad (1)$$

which together with the width of the isovector M1 γ -decay of the isobaric analogue state⁴ in $^8\text{Be}^*$, $\Gamma_{M1}^{T=1}$, makes the CVC and SCC tests possible. In a simplified picture the a -coefficients can be written, with $M_n \cdot A$ the mass of ^8Be and v_{α} a mean α -velocity, as

$$a_1(E_{\beta}) = -\frac{2 \cdot p_{\beta}}{M_n \cdot A \cdot v_{\alpha}} \quad (\text{kinematical term}) \quad (2)$$

$$a_2^{\pm}(E_{\beta}) \approx \frac{p_{\beta}}{2 \cdot M_n \cdot A \cdot c} \cdot (\mp b + d_i \mp d_{II}) \quad (3)$$

and

$$b = M_n \cdot A \cdot \sqrt{\frac{6 \cdot \Gamma_{M1}^{T=1}}{\alpha \cdot E_{\gamma}^3}} \quad (4)$$

where b , d_I and d_{II} are induced nuclear matrix elements (table 1). Here d has been expanded into a first class and a second class part. The derivation of these coefficients can be found in ref. ⁵.

TABLE 1. Explanation of matrix elements.

b	weak magnetism (first forbidden vector)
c	allowed Gamov-Teller
d	induced Tensor

When deducing (3) for the $A=8$ system only the c , b and d matrix elements yield a significant contribution⁴. One tests CVC and SCC by comparing b extracted from (3) with b extracted from (4). The CVC and SCC tests are not independent: Only when assuming that there are no

SCC can one test CVC and vice versa. The quantity extracted from the experimental data is

$$\delta^- = a_2^- - a_2^+ = \frac{E_{\beta}}{M_n \cdot A} \cdot \left(\frac{b}{c} + \frac{d_{II}}{c} \right)$$

The Experiment

The experimental setup to measure the β - α angular correlations is shown in fig. 2. The activity is produced in the target area and transported by a rotating arm into the counting area. This is in the center of two perpendicular planes of seven β -counters and four α -counters. The β -counters are scintillation counters consisting of the main β -energy counter with a veto counter around it and a ΔE -counter in front of it. The α -detectors are three multiwire gas-counters and one Silicon detector. In order to remove any β -efficiency dependence the angular correlation is extracted as

$$\omega(E_{\beta}, \vartheta_{ij}) = \frac{N_{ij}(E_{\beta})}{N_{i3}(E_{\beta})}$$

where $i=\{1, \dots, 7\}$ is the index of for the β -counters, $j=\{1, 2\}$ are the two gas-counters at $\vartheta_{\beta\alpha}=0^\circ$

and 180° and α_3 is the gas-counter at 90° .

Preliminary Results

This is an ongoing experiment. The preliminary angular correlation coefficients are shown in fig. 3. The a_1 -coefficients for ^8B deviate slightly more from the theoretical prediction than the ones for ^8Li , which follow the theory in most of the energy range. The deviations at the smallest and highest energies are most likely due to the response function of the β -detectors. The a_2 -coefficients for ^8B as well as ^8Li are described by a straight line

$$a_2 = m \cdot (E_{\beta\text{tot}} - 0.511\text{keV})$$

except at the lowest and highest energies. The average slopes m of a_2 are

$$\begin{aligned} ^8\text{B} \quad m^+ &= -4.02 \pm 0.17 \text{GeV}^{-1} \\ ^8\text{Li} \quad m^- &= +3.37 \pm 0.09 \text{GeV}^{-1} \end{aligned}$$

which leads with $\delta^- = a_2^- - a_2^+$ to

$$\delta^- \cdot \frac{M_n}{E_\beta} = 6.9 \pm 0.2 \text{GeV}^{-1}$$

Estimates of the systematic uncertainties of a_2 are 3%, mostly due to the uncertainty of the response function. Table 2 shows the comparison of the δ^- of this experiment with results of previous measurements in the $A=8$ system.

FIGURE 3. Angular correlation coefficients

TABLE 2. Comparison of experiments

$\delta^- \cdot \frac{M_n}{E_\beta} [1/\text{GeV}]$	Reference
$6.9 \pm 0.2_{\text{stat}} \pm 0.2_{\text{sys}}$	This work
6.5 ± 0.2	6
7.0 ± 0.5	7

We expect to improve the statistical uncertainties further by taking more ^8B data. We are presently studying the systematic uncertainties, especially the effect of the response function on the angular correlation coefficients, and expect to improve the systematic uncertainties considerably.

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