ゲージの半減期測定：$^{7/2}$シールドのミラー核を用いたIGISOL

著者

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I. 9 Precision Half-Life Measurements of the Mirror Nuclei in the 
$f_{7/2}^{-}$-Shell Using an IGISOL

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The $T_{2} = -1/2$ nucleus decaying to its mirror nucleus by the superallowed 
$\beta$-transition is playing an important role to study the quenching problem of 
Gamow-Teller strength. The systematic behavior of the quenching of GT matrix 
element, defined as the ratio of an experimental GT matrix element to a 
thoretical one calculated with the shell model, has been studied in the 
region of lighter nuclei, i.e., p-shell and sd-shell nuclei. Wildenthal 
derived\(^1\) a mass-number independent quenching factor of $\rho = 0.76 \pm 0.03$ for the 
sd-shell nuclei on the basis of a full sd-space shell model calculation. 
Recently, for the nuclei of the $f_{7/2}^{-}$-shell region a similar comparison has 
been made\(^2\) on the basis of a shell model calculation considering up to two- 
particle jump from the $f_{7/2}^{-}$-shell, giving a similar value of $\rho = 0.75 \pm 0.03$. 
The present work reports on the results of accurate measurements of the half- 
lives of six mirror nuclei in the $f_{7/2}^{-}$-shell region, i.e., $^{45}$V, $^{47}$Cr, $^{49}$Mn, 
$^{51}$Fe, $^{53}$Co and $^{55}$Ni, using a new technique of on-line isotope separation, 
IGISOL (Ion-Guide Isotope Separation On-Line), in which we focus our attention 
to the quenching problem of the GT-matrix elements, especially of the mirror 
transitions in the $f_{7/2}^{-}$-shell.

The ion-guide method was firstly developed at University of Jyväskylä of 
Finland.\(^3\) The details of our IGISOL system has been described.\(^4\) The 
experimental conditions of producing the six mirror nuclei and the yields at 
the detector position are shown in Table 1.

The positrons from the decay of mirror nuclei except for $^{53}$Co were 
detected by the counter telescope of a $\Delta E$ (2mm thick) and $E$ (2"$\phi \times 2"$) plastic 
scintillators. The detector region is shown in Fig. 1. For the measurement 
of half-life the cyclotron beam was chopped using a pulse-type beam chopper in 
order to suppress the background during irradiations and the counts were 
accumulated in a two-dimensional list mode with energy and detection time 
after irradiation. The simultaneously produced $^{53m}$Co is a positron emitter 
having a similar half-life and end-point energy as those of $^{53g}$Co. Therefore, 
the only way to determine the half-life of $^{53g}$Co is to detect the $\gamma$-ray from 
the 1329 keV first excited state of $^{53}$Fe populated from $^{53g}$Co. Although the
γ-ray comes also from the decay of $^{53m}$Fe populated from $^{53m}$Co, the half-life of this isomeric state is so long (2.5 m) that its decay does not interfere with the decay of $^{53g}$Co.

In order to check the time axis of the measurement, we measured the time spectra of positrons from the decay of $^{46}$V and $^{54}$Co having well established half-lives. They were produced with the $^{46}$Ti(p,n) and the $^{54}$Fe(p,n) reactions, respectively, and similarly mass-separated. The obtained half-lives, 421.3±2.2 ms and 193.4±0.6 ms for $^{46}$V and $^{54}$Co respectively, are in good agreement with the reported values. For the details of measurement and analysis see Ref. 9. Furthermore, we carefully checked the degree of mass identification of our IGISOL by measuring the mass spectra of β-emitters produced with different reactions; in the case of $^{47}$Cr, the possibility of contamination from $^{46}$V simultaneously produced by the $^{46}$Ti($^3$He,pn) reaction was excluded on the basis of a mass spectrum taken using the $^{46}$Ti(p,n)$^{46}$V reaction which should not produce $^{47}$Cr. Although the obtained average resolving power of $M/ΔM = 150$ FWHM was considerably lower than for a conventional mass separator, disturbances from the neighboring mass were negligible.

In Table 2, the present half-life values of six mirror nuclei are shown together with the other two mirror nuclei, $^{41}$Sc and $^{43}$Ti. Due to sufficient statistics because of the stable operation of our IGISOL, all the experimental errors are smaller than 2% except that of $^{53}$Co.

The nucleus $^{45}$V was firstly mass-separated in the present experiment, and the result is in good agreement with that of Hornshøj. For the half-life of $^{47}$Cr, there was a considerable discrepancy among several reports as described by Burrows. The present result obtained with mass-separated $^{47}$Cr, however, is apparently different from that of Burrows, 508(10) ms. This discrepancy seems to be an open problem at present. In the case of $^{53}$Co, the error of our result is as large as 40% but the merit of our measurement is that $^{53g}$Co was definitely identified by mass separation and γ-ray detection. The previous half-life of $^{53g}$Co is from Kochan and Eskola; the former was obtained by a β-ray measurement possibly including the positrons from $^{53m}$Co and the latter by a β-γ coincidence measurement with a poor statistics similar to ours. The mirror nucleus $^{49}$Mn was mass-separated by Hardy and $^{51}$Fe and $^{55}$Ni by Äystö. The present results for those nuclei are in good agreement with their data.

From the present experimental results, we obtain the reduced Gamow-Teller matrix elements $^2$, $B(GT)^{1/2}$. The method of analysis is the same as in Ref. 9. For $|q_A/q_V|$ we adopted the recent value of 1.262(5). Table 2 shows the experimental GT matrix elements and the theoretical predictions from a shell-model calculation using the modified Ruo-Brown interaction and permitting up to two particle excitation from the $f_{7/2}$-shell to the upper $p_{3/2}$, $f_{5/2}$ and $p_{1/2}$-shells. Figure 2 shows the quenching factor for the eight mirror nuclei as well as the simple average (i.e., with equal weight) $\rho = 0.844±0.042$. It
is remarkable that in the middle of the $f_{7/2}$-shell the quenching factor is clearly larger than those at the beginning and end of the shell, and that the average value $\rho$ is larger than the quenching factor\footnote{of 0.76(3) derived for the sd-shell nuclei by Wildenthal and that of 0.75(3) derived for 25 GT transitions including the eight mirror ones by Miyatake.} derived for the present value of $\rho$ is larger than that derived for the $f_{7/2}$-shell\footnote{derived for the $f_{7/2}$-shell transitions, and 2) we used the present values of $T^{1/2}$ for $^{47}\text{Cr}$ the present value is considerably shorter than that of Burrows which was used in Ref. 2). It is therefore highly required to study further the mirror $\beta$-decays in the $f_{7/2}$-shell region, especially, around the middle of the shell, both experimentally and theoretically. We would like to thank Prof. K. Ogawa and Dr. H. Miyatake for their valuable discussions.}

References

Table 1. Experimental conditions.

<table>
<thead>
<tr>
<th>Parent Nucleus</th>
<th>Nuclear reaction</th>
<th>Projectile energy (MeV)</th>
<th>Yielda)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{45}$V</td>
<td>$^{46}$V (p, 2n)</td>
<td>30</td>
<td>55</td>
</tr>
<tr>
<td>$^{47}$Cr</td>
<td>$^{46}$V ($^3$He, 2n)</td>
<td>27</td>
<td>11</td>
</tr>
<tr>
<td>$^{49}$Mn</td>
<td>$^{50}$Cr(p, 2n)</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>$^{51}$Fe</td>
<td>$^{50}$Cr($^3$He, 2n)</td>
<td>27</td>
<td>18</td>
</tr>
<tr>
<td>$^{53}$Co</td>
<td>$^{54}$Fe(p, 2n)</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>$^{55}$Ni</td>
<td>$^{54}$Fe($^3$He, 2n)</td>
<td>27</td>
<td>20</td>
</tr>
</tbody>
</table>

a) At the tape in front of the detector.

Table 2. Properties of the $\beta$-decay of mirror nuclei and GT matrix elements in the $f_{7/2}$-shell.

<table>
<thead>
<tr>
<th>Parent Nucleus</th>
<th>Half-life (ms)</th>
<th>$Q_{EC}^{a)}$ (keV)</th>
<th>Branching Ratio (%)</th>
<th>B(GT)$^{1/2}$</th>
<th>Exp.</th>
<th>Theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{41}$Sc</td>
<td>596.3(17)$^{b)}$</td>
<td>6495(1)</td>
<td>99.963(13)</td>
<td>0.850(5)</td>
<td>1.134</td>
<td></td>
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<tr>
<td>$^{43}$Ti</td>
<td>513.0(80)$^{c)}$</td>
<td>6868(7)</td>
<td>100$^{d)}$</td>
<td>0.739(15)</td>
<td>0.947</td>
<td></td>
</tr>
<tr>
<td>$^{45}$V</td>
<td>547.2(53)</td>
<td>7132(17)</td>
<td>95.7(15)</td>
<td>0.494(23)</td>
<td>0.523</td>
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<tr>
<td>$^{47}$Cr</td>
<td>472.0(63)</td>
<td>7452(14)</td>
<td>96.3(12)</td>
<td>0.432(23)</td>
<td>0.409</td>
<td></td>
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<tr>
<td>$^{49}$Mn</td>
<td>381.7(74)</td>
<td>7718(24)</td>
<td>93.6(26)</td>
<td>0.441(39)</td>
<td>0.487</td>
<td></td>
</tr>
<tr>
<td>$^{51}$Fe</td>
<td>305.0(43)</td>
<td>8022(15)</td>
<td>95.0(13)</td>
<td>0.483(23)</td>
<td>0.589</td>
<td></td>
</tr>
<tr>
<td>$^{53}$Co</td>
<td>267 (109)</td>
<td>8304(18)</td>
<td>94.4(1.7)$^{e)}$</td>
<td>0.443(380)</td>
<td>0.614</td>
<td></td>
</tr>
<tr>
<td>$^{55}$Ni</td>
<td>212.1(38)</td>
<td>8696(11)</td>
<td>100$^{d)}$</td>
<td>0.493(20)</td>
<td>0.716</td>
<td></td>
</tr>
</tbody>
</table>

a) Ref. 15.
b,c) Refs. 16 and 17, respectively.
d) No branching to excited states is found.
e) Ref. 18.
Fig. 1. The region of the tape transport and the detectors.

Fig. 2. The quenching factors of the mirror nuclei in the $f_{7/2}$-shell.