I. 4. The Isospin-forbidden $\beta^+$-Decay of $^{64}$Ga

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Isospin-forbidden $\beta$-transition between states of the same spin but different isospin have been studied. Figure 1 shows the isospin impurities and effective Coulomb matrix element deduced from $\beta$-decay experiments summarized by Raman et al.\textsuperscript{1)} The observation of a non-zero Fermi matrix element in isospin-forbidden $\beta$-transitions can provides useful information on the isospin impurity of the nuclear states. This admixture is caused by Coulomb interaction and the charge-dependent (non-Coulomb) nucleon-nucleon interaction. As we can see in figure 1, the isospin impurities are extremely small, so the measurements are very difficult. Especially, since there are few odd-odd nuclei whose spin is $0^+$, only a few pure Fermi transitions ($0^+ \rightarrow 0^+$) data exist. But a $0^+ \rightarrow 0^+$ $\beta$-transition involves only the Fermi matrix element $M_F$, because the Gamow-Teller matrix element $M_{GT}$ is zero. So from the experimental value of $M_F$ of such a transition we can easily deduce the effective Coulomb matrix element.

The $f_I$ value for a $0^+ \rightarrow 0^+$ ($\Delta T \neq 0$) transition can be used to deduce $M_F$, which leads to $\alpha$, the amplitude with which the analogue state is admixed into either the initial ($\beta^+$-decay) or the final ($\beta^-$-decay) states. The states no longer have pure isospin as the result of charge-dependent effects. More detailed discussion has been provided by Blin-Stoyle\textsuperscript{2)} who has derived the following expressions.

\[
|M_F| = \frac{\sqrt{2(J_{\text{super allowed}})}}{f_I}\exp, \quad \alpha = \frac{|M_F|}{\sqrt{2T}},
\]

\[
|<V_{CD}>| = \alpha \times \Delta E,
\]

\[
\Delta E = \Delta E_{CD} + T_{\beta^+}^{\text{max}} - 782 \text{ keV} \quad \text{for } \beta^-\text{-decay},
\]

\[
\Delta E = \Delta E_{CD} - (T_{\beta^+}^{\text{max}} + 1022) - 782 \text{ keV} \quad \text{for } \beta^+\text{-decay},
\]

where $\Delta E$ and $T_{\beta^+}$ denote the Coulomb displacement energy and the end-point energy of the $\beta$-transition, respectively.
We were interested in the data of $^{64}$Ga in figure 1 because of its large isospin impurity in comparison with other nuclei. The ground state of $^{64}$Ga has $J^\pi = 0^+$, $T = 1$ and decays into $^{64}$Zn by $\beta^+$ transition with a 2.6 min. half-life. The ground state of $^{64}$Zn has $J^\pi = 0^+$, $T = 2$ and the $^{64}$Ga(g.s.) $\rightarrow ^{64}$Zn(g.s.) transition is an isospin-forbidden ($\Delta T = 1$) transition. So if we can get the branching ratio of this transition experimentally, we can deduce the isospin impurity in the ground state of $^{64}$Ga.

There are some experimental results of isospin-forbidden transition measurements of $^{64}$Ga, but they are not consistent with each other. For determination of the branching ratio we usually measure the beta rays on the basis of the 511 keV annihilation gamma rays in the case of $\beta^+$ decay to know the number of decays. But if mass-separated beam is not used, a large background of 511 keV gamma rays arising from other positron emitters exist. A significant portion arises from 3.37 h $^{61}$Cu produced by the (p,$\alpha$) reaction on $^{64}$Zn. Even if the decay curve for the 511 keV gamma ray peak was decomposed into two components — a 2.6 min. component due to $^{64}$Ga and a 3.3 h component due to $^{61}$Cu —, a large uncertainty remains. So far there are no data which used mass-separated $^{64}$Ga beams. Therefore the purpose of the present study is to measure precisely the $\beta^+$ decay branching ratio of $^{64}$Ga which is mass-separated in an IGISOL and deduce more reliable data of isospin impurity and Coulomb matrix element of the $^{64}$Ga ground state.

Experiments were performed at CYRIC. The $^{64}$Ga nuclei were produced by the $^{64}$Zn(p,n) reaction with 16 MeV proton beams and mass-separated by the IGISOL (Ion-Quide Isotope Separator On-Line). $^{64}$Ga sources implanted into tape were transport to the detector station and gamma-rays spectroscopy were employed there using a large HP-Ge detector. Figure 2 shows our tape-transport system connected to the IGISOL in CYRIC. Details of the IGISOL and tape-transport system are described in references (3) and (4).

Figure 3 shows the decay scheme of $^{64}$Ga, branching ratios and log $ft$ values from our experiments. In our analysis, to determine the energy dependence of detection efficiency of the HP-Ge detector, we used a $^{56}$Co($T_{1/2} = 77$ d) source for high-energy region up to 3.5 MeV in addition to a $^{152}$Eu source. The $^{56}$Co source was produced by the $^{56}$Fe(p,n) reaction and was separated chemically at CYRIC.

In table 1, we compared our result with that of Raman et al. The value of the ground state $\beta^+ + e$ branching ratio was found to be (24.7±1.0)%. Our result is significantly different from the value of (33.8±1.1)% deduced by Raman et al. From the above branching ratio we deduced log $ft$ value, Fermi matrix element and Coulomb matrix element. One reason of this difference is the intensity of the 511 keV annihilation gamma rays. In our experiment we used mass-separated $^{64}$Ga beams, so there is no 511 keV gamma rays except for those of $^{64}$Ga. Furthermore we made some corrections for positron annihilation in flight, and in calculation the attenuation suffered by the gamma radiation.
arising from different locations in the absorber material was taken into account. Consequently our experimental result, the branching ratio of (24.7±1.0)%., seems to be the most reliable data.

In figure 4 we summarized the effective Coulomb matrix element deduced from the present pure-Fermi-transition measurements. Even if the present value is somewhat small compared with the value of Raman et al., it is still quite bigger than the values of other nuclei. We conclude that the isospin mixing into the ground state of $^{64}$Ga is very large. We plotted the theoretical Coulomb matrix element of $^{64}$Ga. This value has been calculated by Yap and Tee$^6$ on the basis of Coulomb-interaction and Nilsson wave functions. Yap and Tee obtain $<V_{CD}> = 72$ keV to be compared with our experimental value of 35.4±0.8 keV. One of the main difficulties in obtaining a reliable calculated value of $V_{CD}$ is that it sensitively depends on the nuclear wave functions.

References


Table 1. Comparison of the present data with those of Raman et al. for isospin-forbidden $\beta^+$ transition of $^{64}$Ga.

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<thead>
<tr>
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<th>Present data</th>
<th>Raman et al.</th>
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<tr>
<td>branch</td>
<td>(24.7±1.0)%</td>
<td>(33.8±1.1)%</td>
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<tr>
<td>T$_{1/2}$</td>
<td>157.6±0.7 sec</td>
<td>157.8±1.2 sec</td>
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<tr>
<td>Q$_{EC}$</td>
<td>7.165±0.004 MeV</td>
<td>7.176±0.009 MeV</td>
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<tr>
<td>E$_{CD}$</td>
<td>9.879±0.006 MeV</td>
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<tr>
<td>log ft</td>
<td>6.66±0.02</td>
<td>6.516±0.020</td>
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<tr>
<td>lM$_{fl}$</td>
<td>(36.7±0.8) × 10$^{-3}$</td>
<td>(43.4±1.1) × 10$^{-3}$</td>
</tr>
<tr>
<td>lα</td>
<td>(18.3±0.4) × 10$^{-3}$</td>
<td>(21.7±0.6) × 10$^{-3}$</td>
</tr>
<tr>
<td>l$&lt;V_{CD}&gt;$l</td>
<td>35.4±0.8 keV</td>
<td>41.7±1.1 keV</td>
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Fig. 1. Isospin impurity and effective Coulomb matrix element deduced from $\beta$-decay experiments in Ref. 1.
Fig. 2. Collector station and detector station in the tape-transport system.
Fig. 3. Decay scheme of $^{64}$Ga. Level energies and transition energies are given in keV. The number next to the γ-ray energies refer to transition intensity per 100 decays of the parent.
Fig. 4. Coulomb matrix element deduced from pure-Fermi-transition measurements.