Determination Gamma Width and Transition Strength Of Gamma Rays from $^{48}$Ti(n$_{th}$, 2 gamma)$^{49}$Ti Reaction

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I. INTRODUCTION

The $^{49}$Ti nucleus, with two protons and one neutron hole outside the doubly magic $^{48}$Ca, constitutes a very good test for shell-model calculations. The studies of gamma decay of $^{49}$Ti have been previously published in many works based on two ways: on accelerator and on reactor. The results on $^{50}$V(t, $\alpha$)$^{49}$Ti, $^{49}$Ti(d, t)$^{49}$Ti, $^{48}$Ca($\alpha$, 3n)$^{49}$Ti$^{[6, 10]}$ showed spin and parity of $^{49}$Ti ground state was $7/2^-$ and compound state was $1/2^+$. Those results provided $0^\circ \sim 5$ MeV energy arrange. Activation of $^{48}$Ti by neutron was the method which was usually to do on the nuclear reactor. Those previous studies showed gamma rays, levels... more than research on accelerator$^{[4, 7, 8]}$. The same results in two ways of study were agreed with spin and parity of $^{49}$Ti at compound state and ground state. Almost previous works used a Multi Channel Analysis (MCA) system to got experimental data that could not determine gamma cascade energy, intensity of a pair of gamma cascades which were determined by Ritz algorithms. The lifetime of these levels: 1381 keV (<5ps), 1585 keV (<11ps) and 1762 keV (<14 ps) were determined$^{[2]}$, but high levels were incomplete. In this experiment, to get experimental data by gamma-gamma coincidence system which treats by SACP method therefore it reduced background effectively.

II. THEORY

The intensity of gamma cascade transfer was a function which depended on gamma width level:

$$I_{\gamma\gamma} = \sum \frac{\Gamma_{i\lambda} \times \Gamma_{if}}{\Gamma_i \times \Gamma_{f}}$$

(1)

where $\Gamma_{i\lambda}$ and $\Gamma_{if}$ were the partial widths of the transitions connecting the levels $\lambda \rightarrow \mathbf{i} \rightarrow f$; $\Gamma_i$ and $\Gamma_f$ were the total width levels of the decaying states $\lambda$ and $i$, respectively.

In this experiment, the relative intensity of gamma cascade transfer was calculated:

$$I_{i\lambda}^{\gamma\gamma} = \frac{S_{\gamma\gamma}^i}{\sum S_{\gamma\gamma}^i}$$

(2)

KEY WORDS: Gamma cascade; Gamma width; Transition strength; Lifetime; Level; Spin and parity
The total gamma width (Γ_γ) of an excited state of a certain mean lifetime (τ_m) was given by:

\[ \Gamma_\gamma = \frac{\hbar}{\tau_m} = \frac{\hbar \times \ln 2}{\tau_{1/2}} \]

where \( \hbar \) was the Dirac constant = 0.658212 × 10^{-34} eV·s and \( \tau_{1/2} \) was lifetime of level.

If two or more γ-rays de-excited from the same state, then the partial gamma width of \( i \)-th gamma transition (Γ_{γi}) was:

\[ \Gamma_{\gamma i} = B_{\gamma i} \times B_{\gamma i} \]

where \( B_{\gamma i} \) was the branching ratio of \( i \)-th gamma ray, and it was obtained from the following equation:

\[ B_{\gamma i} = \frac{I_{\gamma i}}{I_{\text{tot}}} \times 100\% \]

here, \( I_{\gamma i} \) was the intensity of \( i \)-th gamma transition and \( I_{\text{tot}} \) was the total intensity. From the total gamma width, we could calculate the transition strengths of \( E1, M1 \) and \( E2 \).

Components of the gamma rays were defined by the following [5]:

\[ |M(E, M(L))|^2 = \frac{\Gamma(E, M(L))}{\Gamma_{\gamma_{\text{iso}}}(E, M(L))} \]

where, \( \Gamma(E, M(L)) \) was the partial gamma width of electric transfer, magnetic transfer, \( L \) was multiple orders. In Weisskopf units could be obtained from the following relations in equations:

\[ \Gamma_{\gamma_{\text{iso}}}(E1) = 6.7492 \times 10^{-11} A^{2/3} E_\gamma^3 \]

\[ \Gamma_{\gamma_{\text{iso}}}(E2) = 4.7925 \times 10^{-23} A^{4/3} E_\gamma^5 \]

\[ \Gamma_{\gamma_{\text{iso}}}(M1) = 2.0734 \times 10^{-11} E_\gamma^2 \]

where, \( A \) represented the mass number of the nucleus and \( E_\gamma \) was the energy of the gamma transitions in keV units.

### III. EXPERIMENT AND METHOD

Experimental sample was natural titan. The isotope ratio of the titan samples and thermal neutron capture cross sections were: \(^{40}\text{Ti} (8.25\% ; 0.060 \text{ barn}), \(^{41}\text{Ti} (7.44\% ; 1.600 \text{ barn}), \(^{48}\text{Ti} (73.72\% ; 7.900 \text{ barn}), \(^{49}\text{Ti} (5.41\% ; 1.900 \text{ barn}) \) and \(^{50}\text{Ti} (5.18\% ; 0.179 \text{ barn}) \), respectively [1]. The neutron beam, sample and detector were set up for maximum efficiency of gamma detection. In this experiment the sample was set at 45° from neutron beam, two detectors were placed opposite (180°) with each other. The thermal neutron flux at sample position was about 10^8 n/cm²/s. Cadmium coefficient was 900 (1 mm in thickness).

The experimental system was a gamma – gamma coincidence spectrometer with the event-event counting method, as shown in Fig. 1. The operating principle was briefly described as follows: The signals from two detectors were amplified and shaped by the amplifiers (Amp. 7072A), that convert the output signals from the amplifiers to digital signals when the conditions of 7811R interfacing part were satisfied. Timing signals
from the two detectors were amplified and shaped by Timing Filter amplifiers (TFA 474). The output signals from TFA 474 went through the Constant Fraction Discriminators (CFD 584). There were two output signals from the CFDs, one was directly sent to Start input and the other was delayed before coming to Stop input of TAC 566. The linear output signal of TAC went to the input of ADC 8713, and the valid convert used for control of three coincidence gates of ADCs. ADC 8713 was used for the timing channel while two other ADCs 7072 were used for the energy channels.

![Diagram of the experimental system for gamma-gamma coincidence measurement](image)

Fig. 1. The experimental system for gamma-gamma coincidence measurement [9]

### IV. RESULTS AND DISCUSSION

Energy, relative intensity, spin, the intermediate level of two-step cascade transfer

The time for titan sample measurement was about 300 hours. The numbers of event – event coincidence were about $30 \times 10^6$ events, the statistic counts of sum peak at $B_n$ ($B_n$: neutron binding energy) were about 12000. Table 1 showed information of sum peaks, Fig. 2 was a part of sum spectrum of $^{49}$Ti.

#### Table 1. The information of sum peaks

<table>
<thead>
<tr>
<th>No</th>
<th>Sum peak energy (keV)</th>
<th>Final level (keV)</th>
<th>Spin and parity of final level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8142.50</td>
<td>0</td>
<td>7/2</td>
</tr>
<tr>
<td>2</td>
<td>6761.08</td>
<td>1381.42</td>
<td>3/2</td>
</tr>
<tr>
<td>3</td>
<td>6419.04</td>
<td>1723.46</td>
<td>3/2</td>
</tr>
<tr>
<td>4</td>
<td>3260.38</td>
<td>0</td>
<td>7/2</td>
</tr>
<tr>
<td>5</td>
<td>3175.64</td>
<td>0</td>
<td>7/2</td>
</tr>
</tbody>
</table>

![Graph of the sum spectrum](image)

Fig. 2. A part of sum spectrum
Table 2. Some experimental data obtained from the $^{48}$Ti(n,2$\gamma$)$^{50}$Ti reaction

<table>
<thead>
<tr>
<th>$E_{1}$ (keV)</th>
<th>$E_{2}$ (keV)</th>
<th>$E_{\gamma}$ (keV)</th>
<th>$I_{\gamma}$ ($\Delta I_{\gamma}$) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1+E2 = 8142.50 keV, $E_{\gamma} = 0$ keV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6761.08(101)</td>
<td>1381.42</td>
<td>1381.42(070)</td>
<td>46.300(269)</td>
</tr>
<tr>
<td>6556.06(79)</td>
<td>1586.44</td>
<td>1585.44(083)</td>
<td>5.919(312)</td>
</tr>
<tr>
<td>E1+E2 = 6761.08 keV, $E_{\gamma} = 1381.42$ keV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6419.04(078)</td>
<td>1723.46</td>
<td>341.29(050)</td>
<td>4.145(437)</td>
</tr>
<tr>
<td>4966.86(098)</td>
<td>1793.47(089)</td>
<td>2046.50(092)</td>
<td>2.703(213)</td>
</tr>
<tr>
<td>4713.83(122)</td>
<td>3428.67</td>
<td>2405.54(105)</td>
<td>0.494(231)</td>
</tr>
<tr>
<td>4353.78(133)</td>
<td>3788.72</td>
<td>2839.60(121)</td>
<td>1.561(311)</td>
</tr>
<tr>
<td>4713.83(122)</td>
<td>3482.67</td>
<td>2045.54(105)</td>
<td>0.494(231)</td>
</tr>
<tr>
<td>E1+E2 = 6419.04 keV, $E_{\gamma} = 1723.46$ keV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3920.73(164)</td>
<td>4221.77</td>
<td>2839.60(121)</td>
<td>1.561(311)</td>
</tr>
<tr>
<td>3475.68(164)</td>
<td>4666.82</td>
<td>2943.61(132)</td>
<td>2.175(78)</td>
</tr>
<tr>
<td>3026.62(135)</td>
<td>5115.88</td>
<td>3389.66(154)</td>
<td>1.045(94)</td>
</tr>
<tr>
<td>E1+E2 = 3260.38 keV, $E_{\gamma} = 0$ keV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1498.43(077)</td>
<td>1761.95</td>
<td>2498.55(113)</td>
<td>0.999(102)</td>
</tr>
<tr>
<td>1674.45(054)</td>
<td>1761.46(071)</td>
<td>3389.66(154)</td>
<td>1.045(94)</td>
</tr>
<tr>
<td>E1+E2 = 3175.64 keV, $E_{\gamma} = 0$ keV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1793.47(089)</td>
<td>1381.67</td>
<td>1381.42(070)</td>
<td>7.324(209)</td>
</tr>
</tbody>
</table>

Note: $E_{1}$ (keV) was the energy of primary gamma rays; $E_{2}$ (keV) was the energy of the secondary gamma rays; $E_{\gamma}$ (keV) was the energy of the intermediate level; $I_{\gamma}$ (%) and $\Delta I_{\gamma}$ (%) were intensity and intensity error of cascade gamma transfer.

Gamma width and transition strength

From the experimental data of gamma intensity and electromagnetic transfer selection, the lifetime level, width level and gamma transition strength calculated for some levels of $^{49}$Ti nucleus at compound state as capturing neutron. The result showed on the table 3.

Table 3. The lifetime, width level, spin and transition strength of some level

<table>
<thead>
<tr>
<th>Level (keV)</th>
<th>$\tau_{1/2}$ (s)</th>
<th>$\Gamma_{\gamma}$ (eV)</th>
<th>$E_{\gamma}$ (keV)</th>
<th>$J_{\gamma}^{\pi} \rightarrow J_{\gamma}^{\pi}$</th>
<th>$J_{\gamma}^{\pi} \rightarrow J_{\gamma}^{\pi}$</th>
<th>Transition Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>1842.50</td>
<td>4.89599E-16</td>
<td>1.34</td>
<td>6761.08</td>
<td>1/2$^+\rightarrow$3/2</td>
<td>1/2$^+\rightarrow$3/2</td>
<td>$M(E1)^2$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6556.06</td>
<td>1/2$^+\rightarrow$3/2</td>
<td>1/2$^+\rightarrow$3/2</td>
<td>$M(M1)^2$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6419.04</td>
<td>1/2$^+\rightarrow$1/2</td>
<td>1/2$^+\rightarrow$1/2</td>
<td>$M(E2)^2$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4966.86</td>
<td>1/2$^+\rightarrow$1/2</td>
<td>1/2$^+\rightarrow$1/2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4392.73</td>
<td>1/2$^+\rightarrow$1/2</td>
<td>1/2$^+\rightarrow$1/2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3475.68</td>
<td>1/2$^+\rightarrow$1/2</td>
<td>1/2$^+\rightarrow$1/2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3026.62</td>
<td>1/2$^+\rightarrow$1/2</td>
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<td></td>
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<td>1/2$^+\rightarrow$1/2</td>
<td>1/2$^+\rightarrow$3/2</td>
<td></td>
</tr>
</tbody>
</table>
In this result, spin and parity of some levels were different from LANL [3]. Especially, two gamma rays: 4713.83 keV and 4353.78 keV emitted from Bi to intermediate level, they were not electronic dipole, and they were must magnetic dipole. The results used to calculate the single particle model of nuclei which compared to experimental data. Thus, we concluded that $^{49}$Ti nucleus could be explained by the single particle model. A comparison of ratio between theoretical result with experimental result was about 12 times (for electronic dipole), while the ratio between theoretical result with experimental result was about 1.3 times (for magnetic dipole).

V. CONCLUSIONS

By the empirical study of the cascade transfers of $^{49}$Ti nucleus from $^{48}$Ti(n, 2$\gamma$)$^{49}$Ti reaction, we measured 14 pairs of cascade transfer and arranged into nuclear scheme; in addition, the relative intensities of the transfers were presented. Using the rules of calculation of spin and parity, the possible spin and parity were calculated for experimental levels. The spins, the parities were up to date for unsuitable levels. The results also showed lifetime level, width level and gamma transition strength of some levels.

REFERENCES