Study of the Spin-Memory Effect with Low-energy Gamma-rays in ^{177}Hf$(n,\gamma)^{178}$Hf Reaction Measurement

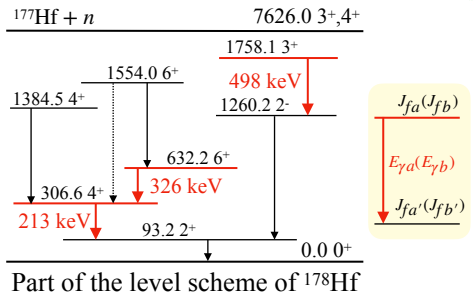
Shiori Kawamura[1,2], Shunsuke Endo[1,2], Osamu Iwamoto[2], Nobuyuki Iwamoto[2], Atsushi Kimura[2], Masaaki Kitaguchi[1], Shoji Nakamura[2], Takuya Okudaira[1,2], Gerard Rovira[2], Hirohiko Shimizu[1], Tatsushi Shima[3] and Hiromoto Yoshikawa[3]
[1]Nagoya University, [2]Japan Atomic Energy Agency, [3]Research Center for Nuclear Physics, Osaka University
Contact；kawamura@phi.phys.nagoya-u.ac.jp

Introduction

- The total angular momentum J of a resonance is one of the most important parameters in understanding nuclear reactions.
- Several methods have been proposed to measure J; one of them is on the basis of a "**Spin-Memory Effect (SME)**".

SME is that the spin information of the resonance remains after gamma-ray cascades [1].

→ J of resonances is deducible by taking the intensity ratio of two low-energy gamma-rays emitted through cascades [2].



Part of the level scheme of ^{178}Hf

The study by Olejniczak et al. [3] suggested that SME appears stronger in the following cases:
when a spin difference between levels of gamma-ray emission is large, and **when the atomic number Z of the nuclide is near the magic number, $Z = 50$.**

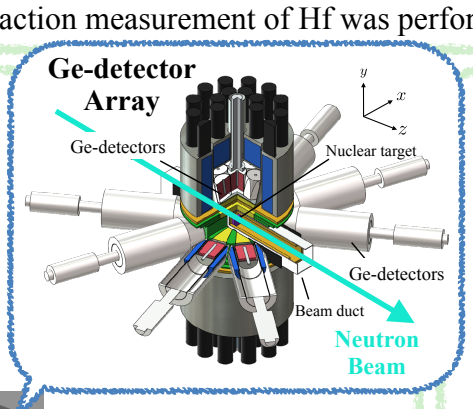
The present purpose is to examine the strength of SME for a nuclide far from $Z = 50$.

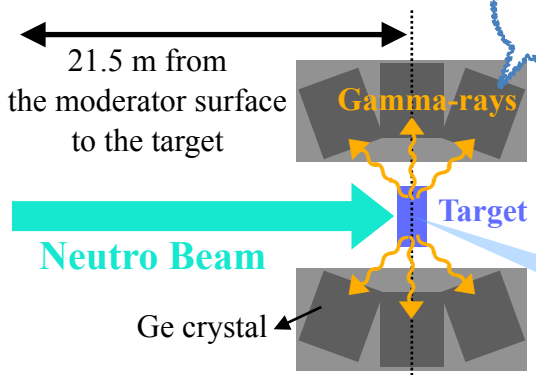
In this study, a neutron capture reaction measurement of Hf was performed with a time-of-flight method and the intensity ratios of gamma-rays were analyzed.

Experiment

J-PARC MLF ANNRI (BL04)

- High-intensity pulsed neutron beam
- Ge-detector array covering a large solid angle with high resolution



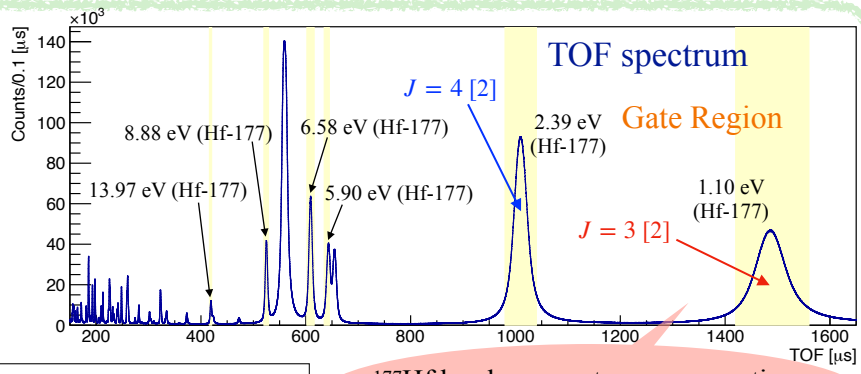


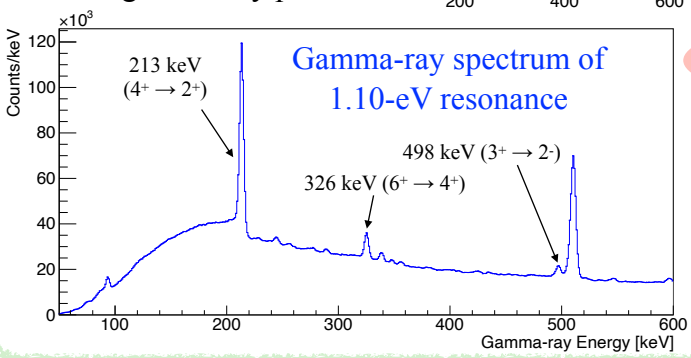
Acquire gamma-ray energy and time-of-flight (TOF) corresponding to neutron energy.

Natural metal Hf target 10 mm × 10 mm × 0.25 mmt

Analysis

The gamma-ray spectra were obtained from TOF ones gated at resonance regions. The background was extrapolated from the region on both sides of the gamma-ray peak.





^{177}Hf has large capture cross sections in a low neutron energy region.

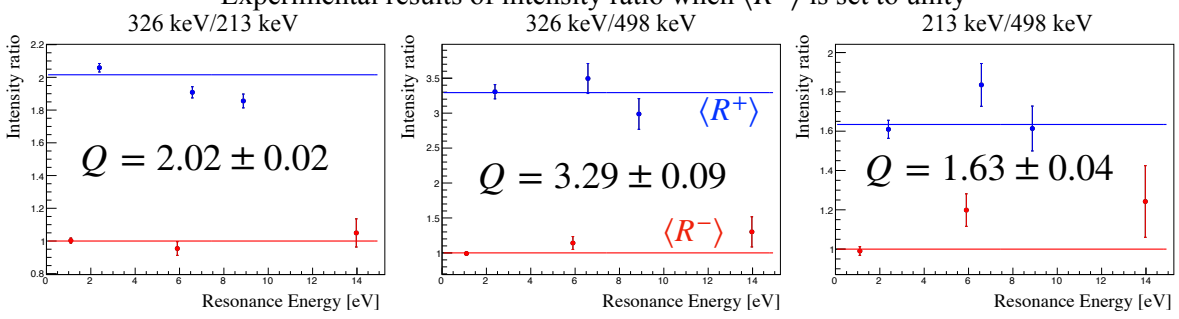
Background was subtracted from peak gross counts to get the intensity of gamma-ray peak. The intensity ratio R of two gamma-rays was taken. In this study, 213-keV, 326-keV, and 498-keV gamma-rays were adopted.

Results and Discussion

1. Experimental results

The strength of SME is quantitatively evaluated from the difference of the intensity ratio of low-energy gamma-rays. The obtained intensity ratios were classified into two groups, $J = 3$ and $J = 4$, depending on whether the values were closer to those of 1.10-eV or 2.39-eV resonance. The weighted averages of the $J = 4$ and $J = 3$ groups were defined as $\langle R^+ \rangle$ and $\langle R^- \rangle$, respectively, and $Q = \langle R^+ \rangle / \langle R^- \rangle$. A larger Q would mean that SME appeared stronger.

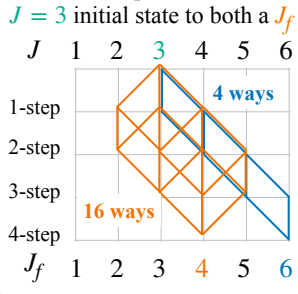
Experimental results of intensity ratio when $\langle R^- \rangle$ is set to unity



2. The simple model calculation

In a simple model calculation [2], the probability of populating a low-lying level J_f after an n-step cascade is approximately proportional to the number of independent ways by which the capture state J can decay to a final level under the restriction of dipole transitions.

Schematic representation of a 4-step dipole cascade from a $J = 3$ initial state to both a $J_f = 4$ and a $J_f = 6$ final state.



$R^-_{64} = 4/16 = 0.25$ $R^+_{64} = 10/19 = 0.53$

$\mathcal{R}_{64} = R^+_{64}/R^-_{64} = 2.11$

The relative population R_{ab} of two final levels J_{fa}, J_{fb} formed by cascade from the same initial state J is sensitive to J. The ratio $\mathcal{R}_{ab}$ between R^+_{ab} for $J = I + 1/2$ and R^-_{ab} for $J = I - 1/2$, is not necessary to consider the detection efficiency and many details.

It is possible to compare $\mathcal{R}_{ab}$ obtained by this model calculation and Q.

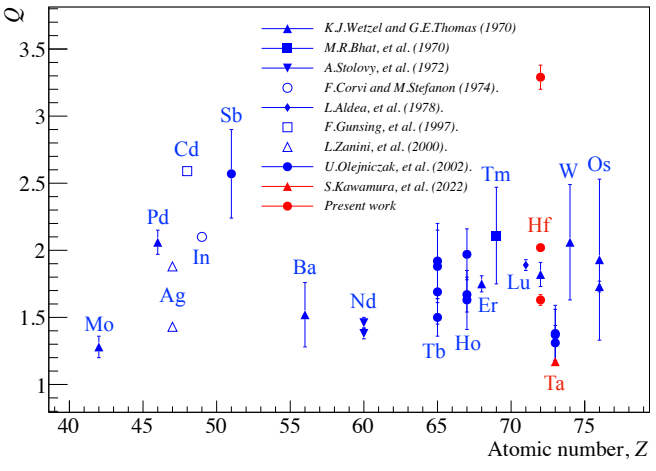
3. Discussion

Comparison of the simple model calculation results $\mathcal{R}_{ab}$ and experimental results Q

Gamma-ray information	Cascade step number 2-step	3-step	4-step	5-step	Present work
$E_{\gamma a}$ $(J_{fa} \to J_{fa'})$ / $E_{\gamma b}$ $(J_{fb} \to J_{fb'})$	$\mathcal{R}_{ab} = R^+_{ab}/R^-_{ab}$				$Q = \langle R^+ \rangle / \langle R^- \rangle$
326 keV (6⁺ → 4⁺) / 213 keV (4⁺ → 2⁺)	-	2.57	2.11	1.76	2.02±0.02
326 keV (6⁺ → 4⁺) / 498 keV (3⁺ → 2⁻)	-	3.50	2.97	2.27	3.29±0.09
213 keV (4⁺ → 2⁺) / 498 keV (3⁺ → 2⁻)	2.25	1.36	1.41	1.28	1.63±0.04

The experimental results are in rough agreement with the model calculations. Also, **as suggested by past study [3], the stronger SME was found when the gamma-ray pair with the larger spin difference was used**. In order to evaluate SME more accurately, it is necessary to create more accurate theoretical calculation methods and to consider how to evaluate the strength of SME.

Dependence of SME strength on atomic number Z



The SME appears **to be weak for Ta with $Z = 73$** [4] but **strong for Hf with $Z = 72$**, which is far from the magic number. This indicates that **the strength of SME does not depend on the atomic number Z.**

It is necessary to systematically evaluate SME.

Summary and Future Plan

- In this study, the strength of SME was obtained using low-energy gamma-rays emitted from the compound nucleus ^{178}Hf ($Z = 72$).
- The present results show that **the strength of SME is independent of the atomic number Z** and that, as suggested in past study [3], **when the difference in the spins of gamma-ray-emitting levels that account for the intensity ratio is larger, SME appeared stronger**.
- In the future, we will systematically evaluate SME by measurements using nuclides near and far from the magic number.
- It is necessary to construct more accurate theoretical calculation methods and to study methods for evaluating the strength of SME.

[1] J. R. Huizenga and R. Vandenbosch, Phys. Rev. 120, 1305 (1960). [2] K. J. Wetzel and G. E. Thomas, Phys. Rev. C 1,1501 (1970). [3] U. Olejniczak, et al., Phys. Atom. Nucl., 65, 2044, (2002). [4] S. Kawamura, et al., Proceedings of the 2022 Symposium on Nuclear Data