Measurement of the Thermal Neutron Capture Cross Section andthe Resonance Integral of the $^{109}Ag(n,\gamma)^{110m}Ag$ Reaction

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The thermal neutron capture cross section (σ_0) and the resonance integral (I_0) of the $^{109}Ag(n,\gamma)$ reaction were measured by the activation and γ-ray spectroscopic methods to develop a neutron flux monitor for the long irradiation.

1. Introduction

To know neutron fluxes by multi neutron flux monitors, the cross section data of monitors are needed to be precisely measured. The nuclides, ^{197}Au and ^{59}Co, are popularly used as monitors because their cross sections are well known. However, the daughter nuclide ^{198}Au after neutron irradiations have short half-live as 2.69 days, therefore it is not adequate to use ^{197}Au as the flux monitor in the long neutron irradiation. If there are some nuclides which have longer half-lives than that of ^{198}Au and have the same sensitivities to epi-thermal neutrons as that of ^{198}Au, they can be used as flux monitors. Then, ^{109}Ag was one of candidates for flux monitors instead of ^{197}Au. Its daughter nucleus ^{110m}Ag has relatively long half-life as 249.9 day, and also the intensities of γ-rays emitted from ^{110m}Ag are precisely obtained. The reported data of ^{109}Ag cross section are σ_0=4.7±0.2 (b) and I_0=72.3±4.0 (b), of which errors are large. To develop the neutron flux monitors for the long irradiation, the σ_0 and I_0 of ^{109}Ag were measured precisely.

2. Brief Outline of Analysis

Since the details of Westcott's convention [1] that we used to determine the cross sections and neutron fluxes were described elsewhere [2], here we present only a brief outline of the analysis. Equations based on Westcott's convention can be rewritten by using simplified flux notation [2] as follows:

$$R/\sigma_0 = \phi_1 G_{th} + \phi_2 s_0 G_{epi}, \quad (1)$$

for irradiation without a Cd shield capsule,

$$R'/\sigma_0 = \phi_1' G_{th} + \phi_2' s_0 G_{epi}, \quad (2)$$

for irradiation with a Cd shield capsule. Here, the R (or R') is the reaction rate and σ_0 the thermal neutron (2,200m/s neutron) capture cross section; ϕ_1 and ϕ_1' are neutron flux components in the thermal energy region, and ϕ_2 and ϕ_2' are those in the epithermal energy region. The neutron flux components were obtained with flux monitors. The G_{th} and G_{epi} are self-shielding factors to thermal and epi-thermal neutrons, respectively. The G_{th} and G_{epi} were estimated as 0.9985 and 0.9236, respectively. In this analysis, the parameters for 0K were used to calculate the factors G_{th} and G_{epi}. The s_0 is the parameter defined by

$$s_0 = \frac{2}{\sqrt{\pi}} \frac{I_0'}{\sigma_0}, \quad (3)$$

where I_0' is the reduced resonance integral, i.e. the resonance integral after subtracting the 1/υ components. The resonance integral I_0 is calculated as follows:

$$I_0 = I_0' + 0.45\sigma_0 , \quad (4)$$

where $0.45\sigma_0$ is the 1/υ contribution given by assuming the Cd cut-off energy to be 0.5eV.

Eqs.(1) and (2) give the relation,

$$s_0 = -\frac{\phi_1 - \phi_1'(R/R')}{\phi_2 - \phi_2'(R/R')} \cdot \frac{G_{th}}{G_{epi}} , \quad (5)$$

so that the value of s_0 is obtained from R/R' value of each irradiated target. The σ_0 is derived by substituting the s_0 into Eq.(1), and then the values of I_0' and I_0 are calculated from Eqs.(3) and (4).

3. Experiment

The cross section measurements were performed by the activation and γ-ray spectroscopic methods.

Targets were high purity(99.97%) Ag foils which were 0.001mm in thickness to reduce effects of impurities and self-shielding. The target amount was 1mg. The neutron irradiation was performed at rotary specimen rack(RSR) in Rikkyo Univesity Reactor. The irradiation of the Ag foil was performed for 1 hour, and for 5hours within a Cd capsule. The Cd capsule was 20mm in diameter, 26mm in length and 1mm in thickness. The wires of 0.112wt% Au/Al alloy (0.510mm in diameter) and 0.46wt% Co/Al alloy (0.381mm in diameter) were irradiated together with the Ag targets to monitor the neutron flux at the target position. The method of measuring the neutron flux was the same as that for the cross section measurements. Using the well-known data of both the cross sections σ_0 and the parameter s_0 for cobalt and gold, the values of the flux terms, i.e. $\phi_{1,2}$ and $\phi'_{1,2}$, were determined by solving the simultaneous equations for cobalt and gold from Eqs. (1) and (2) in Sec.2. For example, **Table 1** summarizes the experimental results of the neutron fluxes in the case of Rikkyo Reactor together with the R and R' values of the flux monitors.

Table 1 Neutron fluxes at RSR in Rikkyo University reactor

	ϕ_1 of ϕ_1'	ϕ_2 of ϕ_2'
	(10^{11} n/cm^{2}sec)	
Without Cd	5.19±0.09	0.175±0.004
Within Cd	0.149±0.005	0.196±0.004

The yields of γ-rays emitted from the irradiated targets were measured by a high purity Ge detector with a 90% relative efficiency to a 7.6cm×7.6cmϕ(NaI) detector and an energy resolution of 2.1keV FWHM at 1.33MeV of ^{60}Co. The details of the data taking system were described elsewhere [2]. An example of the gamma-ray spectrum is shown in **Figure 1**.

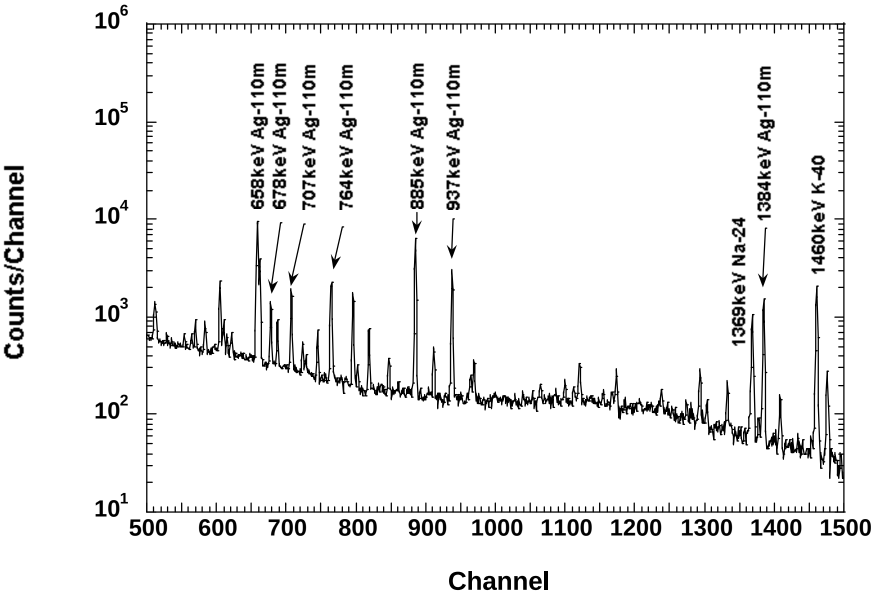

Fig. 1 Gamma-ray spectrum of Ag target irradiated without the Cd capsule

As can be seen in Fig.1, the 7 γ-rays originated from ^{110m}Ag, 658, 678, 707, 764, 885, 937 and 1384 keV γ-rays, were clearly measured These g-ray yields were used to calculated the reaction rates of the ^{109}Ag(n,γ)^{110m}Ag reaction.

4. Results and Discussion

The cross sections of ^{109}Ag were derived from the measured γ-ray yields based the Westcott's convention. The results obtained in this work are summarized in **Table 2** together with the previously reported data[3-9].

The σ_0 was 14% smaller than evaluated one, but the I_0 was in agreement with the evaluated one within the limits of error. The data of σ_0 were reported as 3~6 (b) for the period of 1960 - 70. The present adapted one(4.7±0.2(b)) might be evaluated from these data. F. D. Corte et al.[4] re-measured the cross sections of ^{109}Ag, and obtained 3.90 (b) for σ_0. Their result was in agreement with our result within the limit of error.

Table 2 Results of σ_0 and I_0 and the previously reported data

Authors	σ_0 (b)	s_0	I_0 (b)	$Q=I_0/\sigma_0$	Ref.
Present result	4.13±0.08	18.4±0.7	69.2±3.0	16.8±0.9	
HOLDEN('81)	4.7 ±0.2		72.3±4.0		[3]
CORTE('89)	3.90±0.08		69	17.5	[4]
RAO('78)	4.5 ±0.7				[5]
RYVES('71)	4.72±0.21				[6]
SIMS('68)	4.98±0.47				[7]
KEISH('63)	3.20±0.50				[8]
LYON('60)	5.78±0.58				[9]

5. Conclusions

To develop the flux monitor for the long irradiation, the cross section of ^{109}Ag were measured with the activation method. The σ_0 and I_0 for the $^{109}Ag(n,\gamma)^{110m}Ag$ reaction were obtained as 4.13±0.08(b) and 69.2±3.0(b), respectively. The sensitivities to the epi-thermal neutrons was estimated to be s_0=18.4, which was closed to 17.22 of ^{197}Au. It conclude that the ^{109}Ag is applicable to the flux monitor for the long irradiation instead of ^{197}Au monitor. However, it should be note that the problems remained is to evaluate the self-shielding factors more precisely.

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