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Evaluation of the 1077 keV γ-ray emission probability from ^{68}Ga decay

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Abstract: ^{68}Ga decays to the excited states of ^{68}Zn through the electron capture decay mode. New recommended values for the emission probability of 1077 keV γ-ray given by the ENSDF and DDEP databases all use data from absolute measurements. In 2011, JIANG Li-Yang deduced a new value for 1077 keV γ-ray emission probability by measuring the ^{69}Ga(n,2n) ^{68}Ga reaction cross section. The new value is about 20% lower than values obtained from previous absolute measurements and evaluations. In this paper, the discrepancies among the measurements and evaluations are analyzed carefully and the new values are re-recommended. Our recommended value for the emission probability of 1077 keV γ-ray is (2.72±0.16)%.

Key words: decay data, γ-ray emission probability, cross section, evaluation, ^{68}Ga

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1 Introduction

Accurate decay data for ^{68}Ga are necessary for various applications in nuclear physics and technology. The radionuclide ^{68}Ga is mainly a positron emitter and is often used in nuclear medicine. It mainly emits annihilation radiation. For its gamma transitions, only the 1077 keV γ-ray is important, because the other γ-rays are very weak. The emission probability for 1077 keV γ-ray from ^{68}Ga decay is frequently used to measure the sample activity in activation cross section measurements. Also, GaAs is an important semiconductor with extensive application possibilities in research and industry. Cross section measurements of neutron-induced reactions on GaAs are thus important for characterization of the semiconductor.

The ^{69}Ga(n,2n) ^{68}Ga reaction is an important reaction, and has been studied for many years. Most of the experiments use high-resolution γ-ray spectroscopy to count the 1077 keV γ-ray from activated samples. Bormann et al. [1], however, have performed a study using a coincidence setup with two NaI(Tl) detectors to count the annihilation γ-rays of the positrons from the $\beta+$ decay of the ^{68}Ga product nucleus. Among these experiments, a large difference was found between the cross section values that were deduced with annihilation radiation and direct γ-ray spectroscopy, respectively (see Figs. 1 and 2). Raut's [2] measurements are lower than all other measurements. It is noted that the experimental measurements for the ^{75}As(n,2n) ^{74}As reaction show the same behaviour (see Fig. 5 in Ref. [2]). Using the ratio of values evaluated with ENDF/B-Ⅱ to the measured values in ^{75}As(n,2n) ^{74}As reaction, the measured values for the ^{69}Ga(n,2n) ^{68}Ga reaction were adjusted, as shown in Fig. 2. The adjusted values are in agreement with the values measured using the 1077 keV γ-ray, but are still lower than the values measured by Bormann et al. [1].

In this work, those factors that can induce a difference between these measurements are analyzed. It is found that the most likely reason is due to inadequacies

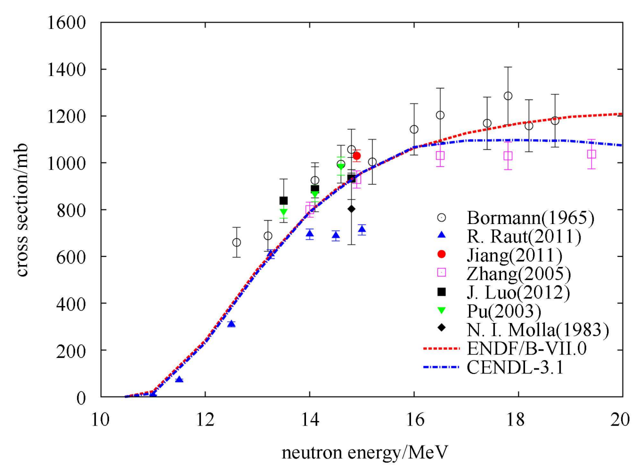

Fig. 1. (color online) Measured and evaluated cross section for ^{69}Ga(n,2n) ^{68}Ga reaction.

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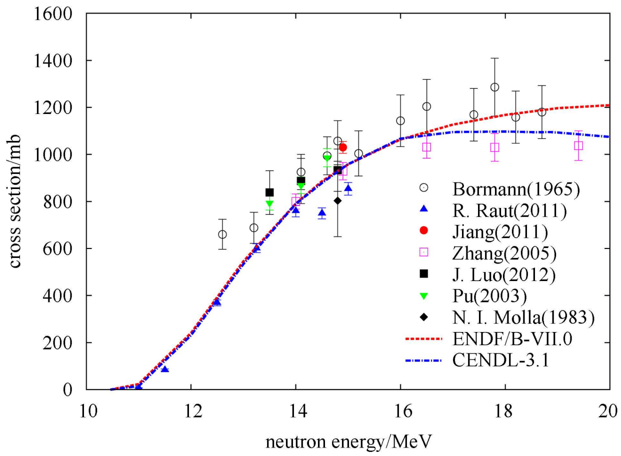

Fig. 2. (color online) Adjusted and evaluated cross section for ^{69}Ga(n,2n) ^{68}Ga reaction.

in the current decay data for ^{68}Ga. Such a difference demands re-evaluation of the 1077 keV γ-ray emission probability.

2 Brief introduction to Jiang's measurements of the ^{69}Ga(n,2n) ^{68}Ga reaction

About 1 g of Ga_2O_3 powder of natural isotopic composition was pressed to obtain a pellet of diameter 2.0 cm. Monitor foils of Nb (99.9% pure) of the same diameter as the pellets but of weight 0.1 g were then attached to the front and back of each sample. Irradiation of the samples was carried out at the Cockcraft-Walton accelerator in the China Institute of Atomic Energy (CIAE), which lasted 40 minutes. Neutrons were produced by the T(d,n)^{4}He reaction. The groups of samples were placed at an angle of 0° relative to the beam direction and centered about the T-Ti target at distances of ∼3.5 cm. The γ-ray activity of ^{68}Ga were determined by a high-purity germanium (HPGe) detector.

The cross section of ^{69}Ga(n,2n) ^{68}Ga reaction at E_n=14.9 MeV was measured. A large difference was found between the cross section values that were deduced with annihilation radiation and direct γ-rays. Factors which could induce the difference were then analyzed, with the most likely reason being the current decay data for ^{68}Ga. Using the measured relative counting rates of the characteristic rays, as well as the existing experimental reports, the emission probability for 1077 keV γ-ray in ^{68}Ga decay were adjusted to $P_γ$(1077 keV)=(2.56±0.09)%. The adjusted decay data makes the cross section values deduced with different detection methods agree with each other better. The relevant results are presented in Table 1.

The finial result for the ^{69}Ga(n,2n) ^{68}Ga reaction cross section at E_n=14.9 MeV was (1030±31)mb with $P_γ$ (1077 keV)=(2.56±0.09)%.

Table 1. Measured cross sections from various decay data for the ^{69}Ga(n,2n) ^{68}Ga reaction.

E_n/MeV	cross section/mb	$E_γ$/keV	$P_γ$(%)
14.9±0.5	897±94	1077	3.0±0.3 [3]
14.9±0.5	1040±27	511	89.3±1.6 [3]
14.9±0.5	1035±32	1077	2.56±0.09 [4]
14.9±0.5	1029±25	511	89.4 [4]

3 Status of experimental data on relative values of γ-ray intensities

In order to clarify the discrepancies in measurements of 1077 keV γ-ray emission probability, all of the available relative intensities, including Jiang's [4] measurements, are compiled and listed in Table 2, as well as the LRSW results. It is noted that the LRSW results are in good agreement with Jiang's [4] measurements and with the NDS evaluations [5]. This means that the present experimental data on relative value of γ-ray intensities are good.

4 Evaluation of the 1077 keV γ-ray emission probability

There is only one absolute measurement of the emission probability of 1077 keV γ-ray from ^{68}Ga ε decay [10]. The $I_{β+}$ value was also determined to be (89.14±0.11)% in this work. This value is in good agreement with other measured values: $I_{β+}$=(88±11)% [13], $I_{β+}$=89.2% [7]. There is little difference in the available measured $I_{β+}$ values.

From LOGFT code, the theoretical ratio of $ε/β^+$ can be determined as $ε/β^+$(1077 keV level)=1.505±0.017, and $ε/β^+$(ground state)=0.1017±0.0011. If the measured value $I_{β+}$=(89.14±0.11)% [10] and the relative γ-ray intensities from the LRSW results in Table 2 are used, then the emission probability of 1077 keV γ-ray can be determined to be $P_γ$(1077 keV)=(2.81±0.01)%. This deduced value is obviously different from the absolute measured value of (3.22±0.03)% [10] and Jiang's deduced value of (2.56±0.09)% [4].

In order to obtain a reasonable value for the 1077 keV γ-ray emission probability, the measured ratio of the total intensity for positrons (p_{ann}) and for 1077 keV γ-ray (p_{1077}) in the ^{68}Ga ε decay are compiled and listed in Table 3. The weighted average results are adopted because the measured values are inconsistent with each other.

From the theoretical ratio of $ε/β^+$(1077 keV level)= 1.505±0.017, $ε/β^+$(ground state)=0.1017±0.0011, the relative γ-ray intensities from the LRSW results in Table 2, and the recommended ratio P_{ann}/P_{1077}=65.6±0.4, the 1077 keV γ-ray emission probability of can be determined to be $P_γ$(1077 keV)=(2.72±0.16)%. The total

Table 2. Measured relative γ-ray intensities for ^{68}Ga.

E_γ/keV	I_γ							
	Carter [6]	Vaughan [7]	Lange [8]	Vo [9]	Schonfeld [10]	Schotzig [11]	Jiang [4]	LRSW
227				0.0037±0.0015				
483				0.0082±0.0009				
579	1.1±0.1	0.7±0.1	1.00±0.12	1.05±0.05	1.14±0.15		0.9±0.1	1.03±0.04
683				0.0097±0.0006				
806	2.8±0.2	2.2±0.2	2.95±0.12	2.81±0.14	2.90±0.31	2.97±0.07	2.8±0.2	2.92±0.05
939				0.0055±0.0005				
1077	100	100	100	100	100	100	100	100
1166				0.0005.±0.0003				
1261	2.9±0.2	3.1±0.2	3.00±0.07	2.75±0.14	3.06±0.31	2.91±0.06	3.0±0.2	2.93±0.04
1659*								
1744	0.28±0.04	0.5±0.01	0.30±0.04	0.295±0.015				0.294±0.013
1883	4.1±0.4	4.8±0.3	4.33±0.12	4.6±0.2	3.86±0.59	4.14±0.08	4.1±0.2	4.22±0.06
2338	0.04±0.02	<0.1	0.050±0.006	0.031±0.003				0.035±0.005
2821			0.015±0.002	0.0139±0.0011				0.0142±0.001

∗ from Slot [12]; a: (ce+γ)intensity [12].

Table 3. Measured and recommended ratio of P_{ann}/P_{1077} for ^{68}Ga ε decay.

P_{ann}/P_{1077}	References	comments
54.6±6.0	Horen [14]	
59.3±6.0	Carter [7]	
55.3±0.6	Schonfeld [10]	
69.83±0.38	JIANG Li-Yang [4]	
59.8±2.5		unweighted mean
65.6±0.4		weighted mean
62.6±0.7		LRSW weighted mean
65.6±0.4		recommended value, from weighted mean

emission probability for positrons can also be deduced to be $I_{\beta+}$=(89.2±0.2)%.

The final value for 1077 keV γ-ray emission probability is recommended to be P_γ(1077 keV)=(2.72±0.16)%, and $I_{\beta+}$=(89.2±0.2)%. These values are obviously different from the absolute measured value of (3.22±0.03)% [10] and Jiang's [4] deduced value of (2.56±0.09)%.

5 Discussion and conclusions

In order to verify the rationality of our present value for 1077 keV γ-ray emission probability, measured cross sections of the ^{69}Ga(n,2n) ^{68}Ga reaction around 14.8 MeV are adjusted using the present values. The adjusted and original measured reaction cross sections are listed in Table 4. It is clear that good agreement is obtained. Therefore, we consider our present value for 1077 keV γ-ray emission probability to be superior to other results, such as the NDS values [5].

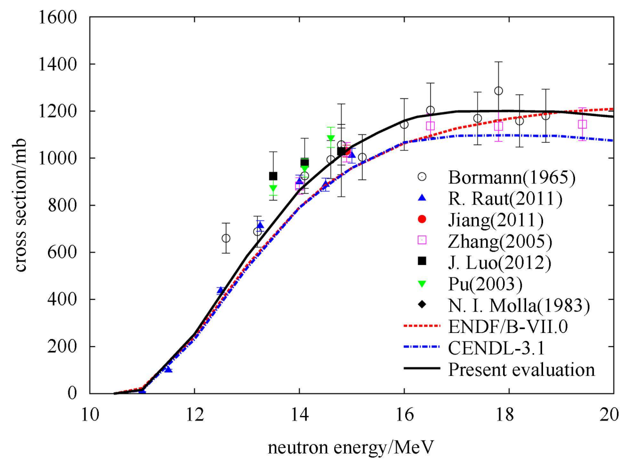

Fig. 3. (color online) Adjusted and re-evaluated cross section for the ^{69}Ga(n,2n) ^{68}Ga reaction.

Table 4. Comparsion of the original and adjusted measured data for the ^{69}Ga(n,2n) ^{68}Ga reaction at 14.8 MeV.

references	E_n/MeV	original cross section/mb	adjusted cross section/mb
Molla [15]	14.8	803±153(P_γ(γ1077 keV)=3.5%)	1033±197(P_γ(γ1077 keV)=2.72%)
Zhang [16]	14.9	929±37(P_γ(γ1077 keV)=3%)	1025±41(P_γ(γ1077 keV)=2.72%)
Luo [17]	14.8	933±90(P_γ(γ1077 keV)=3.2%)	1047±101(P_γ(γ1077 keV)=2.72%)
Bormann [1]	14.8	1057±86($I_{\beta+}$=88%)	1043±85($I_{\beta+}$=89.2%)
JIANG Li-Yang [4]	14.9	1030±31($I_{\beta+}$=89.4%)	1032±32($I_{\beta+}$=89.2%)

Using our present results, the measured cross sections of the $^{69}Ga(n,2n)\,^{68}Ga$ reaction were adjusted. The present recommended decay data makes the cross section values deduced with different detection methods agree with each other better, as shown in Fig. 3.

The excitation function of the $^{69}Ga(n,2n)^{68}Ga$ reaction were then re-evaluated based on the adjusted experimental data. The new values for the $^{69}Ga(n,2n)^{68}Ga$ reaction cross section are in agreement with the adjusted experimental data, but different from the other available evaluations, such as ENDF/B-Ⅶ and CENDL-3.1 (see Fig. 3).

We therefore suggest that the recommended value for emission probability of 1077 keV γ-ray from ^{68}Ga ε decay should be (2.72 ± 0.16) %. Further work will concentrate on obtaining more precise new measurements to establish the reasonableness of this evaluation.

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