Measurement of resonance integral of ^{138}Ba (n,γ)^{139}Ba reaction using an Am-Be neutron source

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Introduction

Resonance integrals are the effective reaction probability due to neutron flux in isothermal region (0.55 ev < E < 100keV) and it gives the probability of a neutron getting captured before reaching the thermal energies. These values are used for integral tests of resonance parameters and for validating various evaluated capture cross sections. Neutron activation analysis using epithermal neutrons also requires precise resonance integrals [1].

Generally, capture resonance integrals are measured experimentally by activation method using reactor neutron beam or D-T neutron beam. The present experiment is an attempt to ascertain the ability of a low flux neutron source facility to measure the resonance integral of ^{138}Ba(n,γ)^{139}Ba in the isothermal region.

Materials and methods

$BaCl_2$ powder procured from Sigma Aldrich was used for resonance integral measurements. Activation foils of Mn (Mn(83%)-Cu) and Au procured from Shieldwerx with purity 99.9% were used as comparator isotopes. Two sets of each sample were used in the experiment; one of each was irradiated by enclosing in a Cd cover and another set without Cd cover. This Cd-cut off method is used to separate the contribution from epithermal neutrons (>0.5eV). Nuclear data of the selected samples used in the calculations are listed in Table.1. All the samples were irradiated at the neutron source facility available at Manipal Centre for Natural Sciences. The Am-Be source emits 4×10^7 neutrons per second in 4π direction. The samples were placed in the irradiation channel where the isothermal flux is maximum (≈10^3 n/s). All the foils were irradiated for 6 days. After irradiation the induced activity in each foil were counted using a well shielded 30% HPGe (Bruker Baltic) detector having an energy resolution of 0.25% at 1.33MeV. The energy and efficiency of the detector was pre calibrated using the gamma lines from ^{152}Eu. Gamma lines of interest from the capture products ^{139}Ba, ^{198}Au and ^{56}Mn are 165.9 keV, 411.6 keV and 846.8 keV respectively.

Table.1. Nuclear Data of the selected isotopes [2, 3].

Foil	Effective Energy, E_γ (eV)	Thermal cross section σ_0 (b)	Resonance Integral, RI (b)
^{115}In *****	1.51	205	3271
^{197}Au	5.47	98.71	1563
^{55}Mn	468	13.41	11.76
^{138}Ba	15700	0.359	

***** Used only for spectrum parameter estimation

Resonance integral ($I_0(\alpha)$) for a real epithermal spectrum (neutron flux varies as $1/E^{(1+\alpha)}$ instead of ideal 1/E behavior) can be obtained from measured reaction rates as given below:

$$I_0(\alpha)_s = \frac{I_0(\alpha)_R \sigma_{0,S}(R-1)_R}{\sigma_{0,R}(R-1)_S}\left(\frac{G_{epi}}{G_{th}}\right)_R\left(\frac{G_{th}}{G_{epi}}\right)_S \quad (1)$$

In Eq (1), cadmium ratio of the foil obtained from the ratio of specific activities of bare and cadmium covered foils corrected with F_{Cd} is represented by R (subscript S and R indicate sample and reference respectively). G_{th} and G_{epi} are thermal and epithermal self shielding factors respectively. $I_0(\alpha)$ can be related to the ideal resonance integral, I_0 as below .

$$I_0(\alpha) = (1eV)^\alpha\left[\frac{I_0 - 0.426\sigma_0}{(\overline{E\gamma})^\alpha} + \frac{0.426\sigma_0}{(2\alpha+1)(E_{Cd})^\alpha}\right] (2)$$

This relation is valid for E_{Cd} =0.55 eV since the value 0.426 is obtained from $2(E_0/E_{Cd})^{0.5}$, where E_0 =0.025 eV. E_γ is the effective resonance energy and σ_0 is the thermal cross section.

Results and Discussions

Spectral parameter α, i.e., the deviation of neutron spectrum from 1/E behavior in the epi cadmium region of the neutron spectrum at the irradiation location, is measured experimentally using foils In-Au and In-Mn whose resonance integrals are known. Eq (1) and Eq (2) are used to estimate α. The measured α values for this AmBe experimental facility are -0.39±0.02 and -0.45±0.02 respectively with respect to In-Au and In-Mn measurements.

A comparison of the present studies with respect to the previous reported values are given in Table 2 and other evaluated data can be found in Ref [2]. Resonance integral for ^{138}Ba (n,γ)^{139}Ba reaction is estimated with respect to that of ^{55}Mn(n,γ)^{56}Mn and ^{197}Au(n,γ)^{198}Au. The estimated values without considering self shielding factors are 0.333±0.023 b and 0.316±0.016 b respectively. Thermal self shielding and epithermal self shielding factors are taken from literature [3,4]. After incorporating the above factors the estimated cross sections are 0.330±0.023 b and 0.329±0.016 b respectively with respect to that of ^{55}Mn(n,γ)^{56}Mn and ^{197}Au(n,γ)^{198}Au.

Table.2: Resonance integral of ^{138}Ba (n,γ)^{139}Ba along with the reference isotope used in brackets.

Reference	Resonance Integral, RI (b)
Present work	0.330±0.023 (^{55}Mn) 0.329±0.016 (^{197}Au)
Dauenhauer, A.Y [4]	0.382±0.020(^{197}Au)
Agbemava, S.E [5]	0.380±0.007(^{55}Mn)
Heft, R.E [6]	0.256±0.050(^{45}Sc)
Mughabghab, S.F [7]	0.320±0.040
EAF-2010[8]	0.263
ENDF-B.VII.1[9]	0.265

The present results are in reasonable agreement within the uncertainty with the recommended data 0.320±0.040 [7]. However they are greater than evaluated data [8,9] by approximately 22% and lower than recent experimental measurements using reactor neutron spectrum [4,5] by 13%. Various parameters affecting the uncertainty of the data are counting statistics (2-5%), detector efficiency (2-3%), sample mass (0.5-1%), nuclear data (cross section (0.1-0.9%) and resonance integral (1.8-3.7%)). Experimental activity with different irradiation and counting times were found to be within 2.6%.

Conclusions

The resonance integral of ^{138}Ba(n,γ)^{139}Ba is measured with ^{55}Mn and ^{198}Au as reference monitor using Cd-cut off method. The measured values after incorporating self shielding factors are 0.330±0.023 b and 0.329±0.016 b and are in reasonable agreement within the uncertainty with evaluated data as well as measurements. Thus, the present measurement establishes the feasibility of measuring RI using an isotopic neutron source facility.

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