Thermal neutron capture branching ratio of ^{209}Bi using a gamma-ray technique

A.Letourneau [1] , E.Berthoumieux, O.Déruelle, M.Fadil, G.Fioni, F.Gunsing, F.Marie, L.Perrot, D.Ridikas

DSM/DAPNIA/SPhN - CEA/Saclay, 91191 Gif-sur-Yvette, France

H.Boerner, H.Faust, P.Mutti, G.Simpson

Institut Laue-Langevin, 38000 Grenoble, France

P.Schillebeeckx

IRMM, 2440 Geel, Belgium

Abstract

A new experimental program concerning the measurement of the neutron capture branching ratio of ^{209}Bi as a function of neutron energy has been proposed recently. The preliminary results obtained at the high neutron flux reactor of ILL with a thermal neutron flux are presented in this paper. The neutron capture cross section and the corresponding branching ratio are measured with an on-line gamma-ray spectroscopy method. We find for the capture cross section 35±1.75 mb, what is in a good agreement with existing results. For the partial cross sections we get σ_{210gs}=17.9±2 mb and σ_{210m}=17.1±2 mb giving a branching ratio of 51%±5%. This value is by 25% smaller than values from evaluated libraries.

1 Introduction

The ^{209}Bi(n,γ)^{210gs}Bi and ^{209}Bi(n,γ)^{210m}Bi reaction cross sections are very important in the context of using the Pb-Bi eutectic as a material for spallation target to build very intense neutron sources for accelerator-driven transmutation or research. These two reactions contribute significantly to the short-term and long-term radiotoxicity of the target via the production of ^{210}Po ($T_{1/2}$=138.376 days) and ^{210m}Bi ($T_{1/2}$=3.04×10^6 years), both alpha-emitters.

[1] Corresponding author : E-mail address: aletourneau@cea.fr

Existing data are very scarce, in particular the branching ratio for the fundamental (G) and metastable (M) state population of the compound nucleus. Therefore, an experimental program has been proposed to measure the neutron capture cross section (σ_c) and the corresponding branching ratio as a function of neutron energy by using on-line γ-ray spectroscopy.

In this technique all γ-rays coming from the deexcitation of the compound nucleus are recorded. An advantage of it is to offer a direct measurement of both total neutron capture cross section and corresponding branching ratio for the G and M final states even with a low neutron flux.

The preliminary results with a pure thermal neutron flux are presented in this paper.

2 Description of the experiment

The ^{209}Bi(n,γ)^{210gs}Bi and ^{209}Bi(n,γ)^{210m}Bi cross sections were measured at the Institut Laue-Langevin (ILL - Grenoble) using the ultra-cold neutron beam facility (PF1) of the high flux reactor. The neutron beam had a Maxwellian energy distribution with a mean temperature of 30^o K and was collimated either to 2 mm or 3.8 cm in diameter by 5 mm thick B_4C apertures.

The Bi sample was placed 1 m upstream of the collimator. It consisted of 80 mm in diameter of pure (99.99%) ^{209}Bi with a thickness of 2 mm (87.795 g). The sample was oriented at 45^o relative to the incident neutron beam axis. The absolute cross sections were determined by normalizing the observed γ-ray yields to those from the standard ^{35}Cl(n,γ)^{36}Cl reaction[1]. A NaCl sample enclosed in 0.4 mm thick and 90 mm in diameter Al container was used for this purpose. Normalisation runs were done with the smaller aperture and by replacing Bi sample with NaCl sample. The neutron absorption in Al plates was negligible (less than 0.1%).

Prompt capture γ-rays were detected with a 60% efficiency Ge detector of EUROBALL with a BGO-anticompton shielding. It was placed at 51 cm from the centre of the target. The γ-ray background and diffused neutrons were reduced by shielding the detector with B_4C and Pb bricks, except for the line-of-sight to the sample where a 5 mm thick ^{6}LiF slab was placed. The photopeak efficiency (Fig.1 left) of the detector was determined for 25 γ-ray energies between 100 and 8578 keV from a calibrated ^{152}Eu source and from the standard ^{35}Cl(n,γ)^{36}Cl reaction[1]. A logarithmic polynomial function was used to interpolate the efficiency intensities between these energies.

The self-attenuation in the Bi target (Fig.1 right) was measured as a function

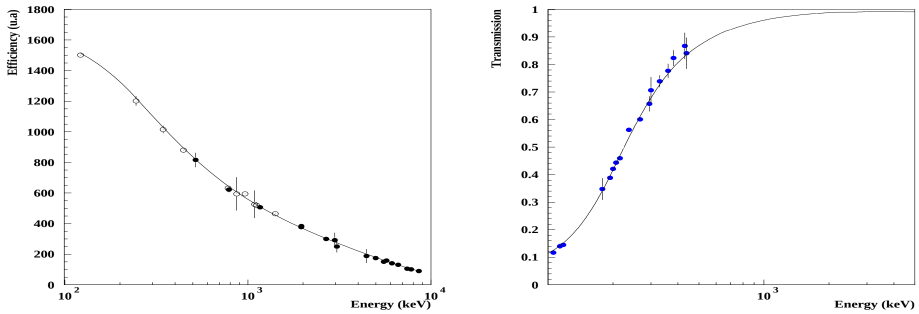

Fig. 1. Left : Relative efficiency of the Ge detector deduced from a Eu source (open circles) and ^{35}Cl(n,γ) standard (full circles). The continuous line is a fit with a polynomial function. Right : Self-attenuation of γ-rays in the target deduced from Ag and Bi-Ag targets (symbols). The continuous line is given by tabulated absorption cross sections when integrated over the thickness of the target (see text).

of γ-energy with a set of Ag and Bi-9%Ag targets containing equivalent masses of Ag (9 and 11 g respectively). The mixed Bi-9%Ag sample had the same geometry as Bi.

3 Results and discussion

In total 8 hours and 17 hours with low (2×10^6 n/cm^2/s) and high (1×10^9 n/cm^2/s) neutron beam intensity were used to collect γ-ray energy spectra (Fig.2). A four Gaussian sum shape with only two free parameters (the height and the width) were used to determine the count number in the photo-peak. Other dependent parameters were adjusted on standard Cl to reduce systematic errors.

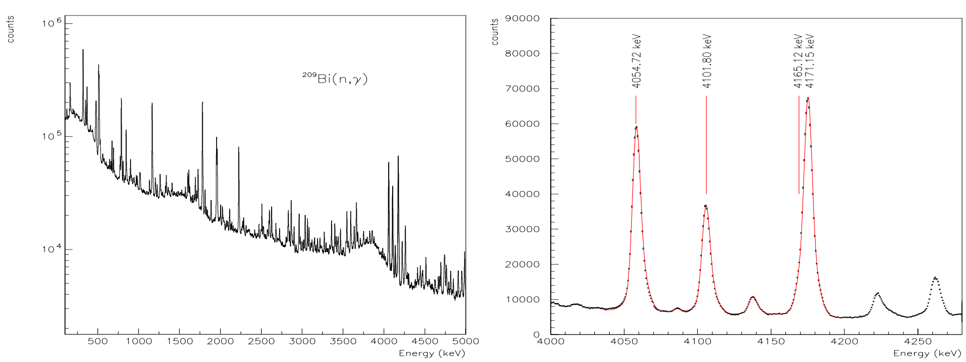

Fig. 2. Left : Total γ-ray energy spectrum collected with Bi sample and high intensity beam. Right : Enlargement of the previous figure on the most intense primary γ-rays (indicated energies). The four gaussian shape adjustement is shown as a continous line.

The primary γ-rays[3] intensity that has been measured account for 98% of the total intensity. Assuming the same neutron flux for Cl and Bi, we obtained σ_c=35±1.75 mb at 0.025 eV for neutron capture of ^{209}Bi. The uncertainty is mainly related to systematic errors as the effective thicknesses of Bi and normalisation samples. This result is in a good agreement with previous "in pile" measurements (see ref.[5] for instance). The evaluated libraries JENDL-3.2, ENDF/B-VI and EAF-4.1 give a cross section of 33.8 mb whereas JEF-2.2 and BROND-2 give 37.2 mb and 34.4 mb.

Only 9 of the 18 known low-lying[2,4] γ-rays populating the G and M states have been measured, however the missing γ-rays make only a few percents to the total population. The main uncertainties came from the efficiency, self-attenuation and internal conversion corrections. In some cases the multipolarity of the transition is not clearly established, thus a favorable (mixed 0.5 M1 + 0.5 E2 transition) and defavorable (pure M1 transition) internal conversion coefficient has been chosen. Two extreme values are thus given for the branching ratio, namely 50% and 52.5%. The sum of final γ-rays intensities are 3% or 8% greater than the sum of primaries which are determined with less corrections. Thus an error of 10% has been added to the mean value of the branching ratio : 51%±5%. The ^{209}Bi(n,γ)^{210gs}Bi and ^{209}Bi(n,γ)^{210m}Bi deduced cross sections are then 17.9±2 mb and 17.1±2 mb, respectively. These preliminary results disagree with evaluation libraries where the values of 24.2±0.2 mb [6] and 9.6±1 mb are taken. Our results are in a better agreement with older activation measurements [7,8] : 15±3 and 20.5±1.5 mb for the ^{209}Bi(n,γ)^{210gs}Bi reaction.

4 Conclusion

A prompt gamma-ray technique has been used for the first time with a isomeric final state to determine both the total neutron capture cross section and the corresponding branching ratio with reasonable uncertainties. The branching ratio obtained for thermal neutrons (51%) is in disagreement with the evaluated libraries (67%) whereas the total neutron capture cross section (35 mb) is compatible. The next step of the program will be to use this technique to evaluate the neutron capture branching ratio as a function of the neutron energy at the Gelina neutron source (Geel-IRMM).

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