FIZIKA, 5 (1973) 37—42

PROMPT γ-RAY SPECTRA FROM THE RADIATIVE CAPTURE OF 14.1 MeV NEUTRONS IN Cu, Se, Br, In, AND I

M. BUDNAR, F. CVELBAR, V. IVKOVIĆ, A. PERDAN and M. POTOKAR

J. Stefan Institute and Faculty for Natural Sciences and Technology, University of Ljubljana, Ljubljana

Received 24 October 1972

Abstract: Spectra of primary γ-transitions to bound states from the 14,1 MeV neutron radiative capture process in natural targets of Cu, Se, Br, In and I are presented together with the corresponding integrated cross sections. Because of the spherical geometry of the experiment, spectra are integrated over a solid angle of 4π for Cu, Se, Br, and I and over 2π for In. The energy spread of the initial neutrons is 1.35 MeV.

1. Introduction

In recent papers[1-7] it was shown that the study of γ-ray spectra from the radiative capture of 14 MeV neutrons represents a rather effective tool for the analysis of the effect of the giant dipole resonance state on this reaction. Comparing the experimental and calculated spectra, one can establish the adequacy of different theoretical models. For this purpose nuclei having a rather simple level structure are appropriate. Some further insight into the capture process can be obtained from the mass dependence of the capture cross section, integrated over primary transitions to the bound states of final nuclei[6, 7]. These data should preferably be collected for monoisotopic targets, but monoisotopic natural elements are too rare to yield enough data. Separated isotope targets on the other hand cannot be used because the target samples are large, containing a few hundred grams of material.

In our previous measurements on light and medium weight nuclei it was found that the integrated cross sections depend very smoothly on mass number, such behaviour was also explained theoretically. This was expected to be found also for heavier nuclei and could be checked by the measurement of the cross section on either monoisotopic or polyisotopic natural samples. In our program we therefore introduced measurements on polyisotopic targets.

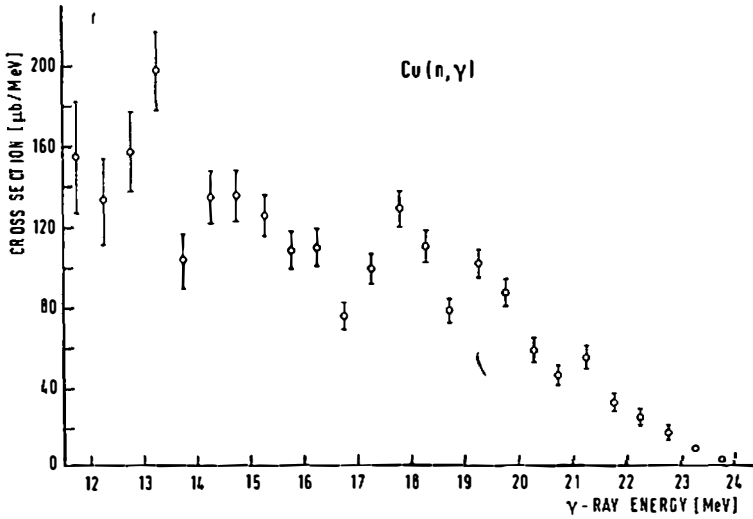

Fig. 1. Corrected γ-ray spectrum from the radiative capture of 14.1 MeV neutrons in natural copper, containing 69% of ^{63}Cu and 31% of ^{65}Cu.

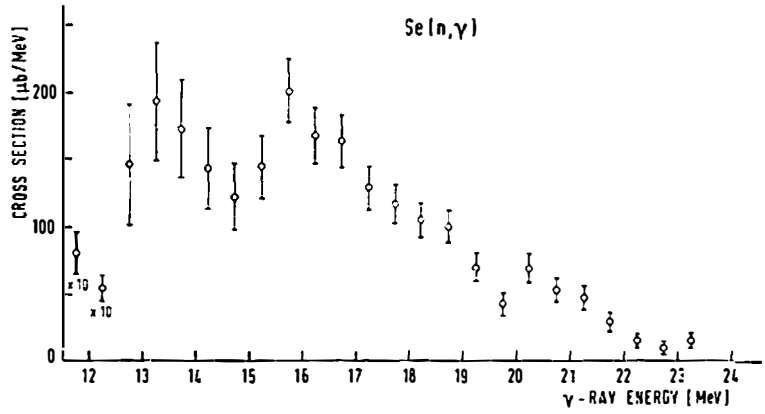

Fig. 2. Corrected γ-ray spectrum from the radiative capture of 14.1 MeV neutrons in natural selenium, containing mainly ^{78}Se (23,6%) and ^{80}Se (50%).

In the following, the γ-ray spectra and corresponding integrated cross sections due to the radiative capture of 14.1 MeV neutrons in monoisotopic In and I, and polyisotopic Cu, Se, and Br are presented.

2. *Experimental technique*

The experimental technique has been previously described[1–3]. Neutrons were produced by bombarding a tritium target with 100 keV deuterons from a Cockcroft-Walton accelerator. Neutron energy was 14.1 MeV and the

energy spread 1.35 MeV. Samples were spheres or hemispheres (Indium) with a cylindrical hole or channel 1 cm diameter, fitting into the tritium target holder. The copper sample was turned out of a metalic block and the indium one was cast into a hemispherical mold. Samples of other elements were prepared by filling thin walled (0.5 mm) glass capsules with powdered materials (Selenium, Iodine) or liquid (Bromine). The indium sample was made hemispherical because for the minimum experimentally acceptable radius (2 cm) the absorption of γ-rays in a sphere was too high. Gamma--rays were detected by a special telescopic scintillation pair spectrometer[1], having an energy resolution of about 10 %. As the neutron source lies in the centre of the sample, measured spectra are integrated over a solid angle of 4π and 2π for spherical and hemispherical samples, respectively.

3. *Results*

Unfolded γ-ray spectra from the radiative capture of 14.1 MeV neutrons in Cu, Se, Br, In, and I are shown in Figs. 1—5. Corrections due to the absorption of γ-rays and the scattering of neutrons in samples were taken into account. The error bars include the statistical fluctuation of counts, the uncertainties due to the background corrections, and the error introduced by the unfolding procedure.

Integrated cross section data presented in the Table are obtained by the integration of γ-ray spectra over all γ-ray energies higher than E_n, the relative energy in the C. M. system. The errors of the integrated cross section values include besides the errors of the spectral intensity, also the uncertainty of the spectrometer efficiency and the uncertainty of the flux determination.

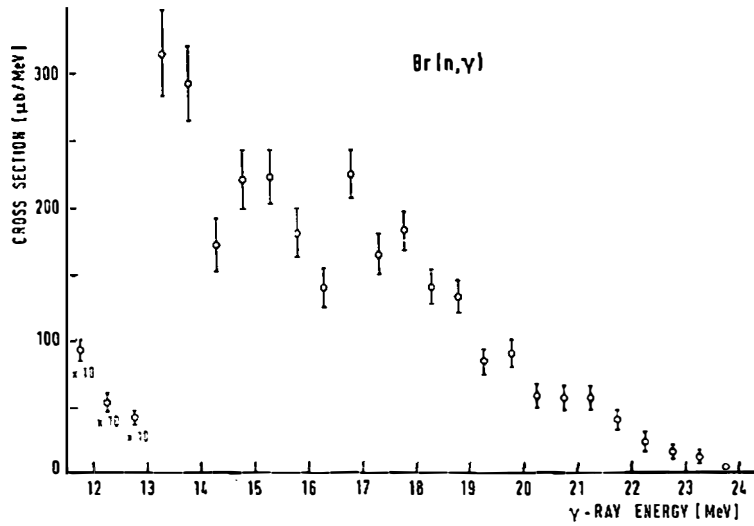

Fig. 3. Corrected γ-ray spectrum from the radiative capture of 14.1 MeV neutrons in natural bromium, containing 50.6% of ^{79}Br and 49.4% of ^{81}Br.

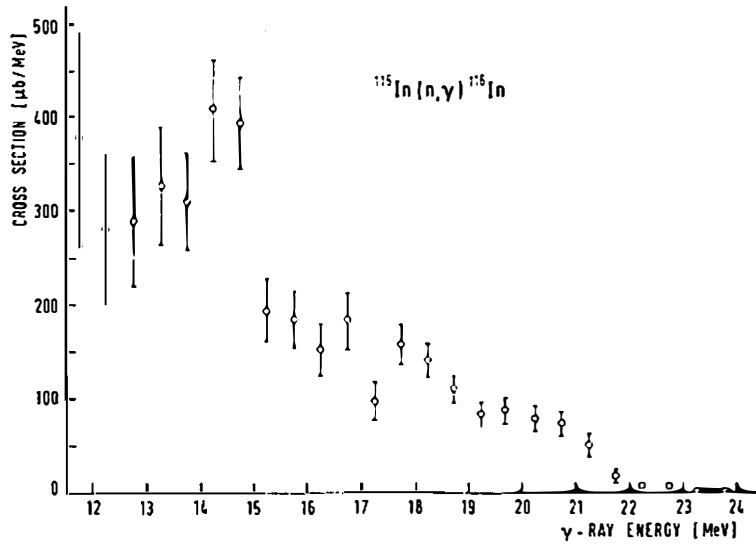

Fig. 4. Corrected γ-ray spectrum from the radiative capture of 14.1 MeV neutrons in natural indium, containing mainly ^{115}In (95,8%).

4. Discussion

According to the direct-semidirect capture model[7, 8] the shape of fast neutron capture γ-ray spectra is determined by the distribution of single particle transition strengths, modulated by the resonance like enhancement function, describing the effect of the dipole resonance state on the capture process. In the γ-ray energy region below the peak energy of the giant dipole resonance, this function is rather steep due to the destructive interference between the direct and semi-direct part of the transition amplitude. Though sometimes transitions to some nuclear states are exceptionally strong and the effect of the enhancement function is not always clearly visible, spectral intensity must be at least on the average very much depressed due to this interference effect. In light nuclei this effect could be overshadowed by the contribution of the statistical process[9] which can be of the order of the experimentally observed cross section. As this contribution reduces to 10 %, 1 %, and 0.1 % at mass numbers 80, 12, and 200, respectively, there was some hope to find the mentioned interference effect in the capture γ-ray spectra from medium and heavy nuclei.

Contrary to expectation, in the spectra reported here this effect has not been observed. Only in the spectrum of Se a small dip at about 14 MeV γ-ray energy could be perhaps ascribed to this effect. The reason that the interference effect is not visible probably lies in the fact that the spectra rise steeply for γ-ray energies below E_n. In this region we have γ-rays corresponding to primary transitions to unbound states which decay preferably

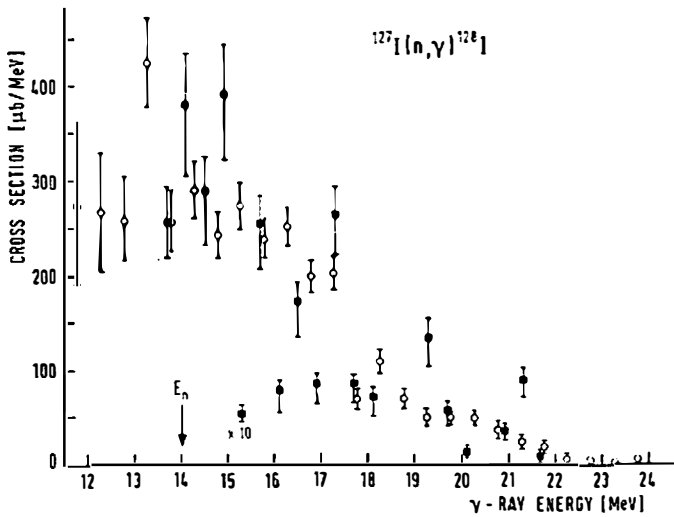

Fig. 5. Corrected γ-ray spectrum from the radiative capture of 14.1 MeV neutrons in ^{127}I. ■ Dinter's result[11], ○ present result.

by particle emission, the (n, γ, particle) reaction, and also γ-rays from the (n, n', γ) reaction. Due to the large energy spread of incident neutrons these γ-rays appear also in the region above E_n, which otherwise should be populated only by the primary radiative capture γ-rays. To study the above mentioned interference effect, spectra should be measured with better neutron energy resolution and possibly with about 16 MeV neutrons.

Spectra reported here have not been previously measured, except the spectrum of Iodine[11]. In this experiment the γ-ray spectrum was measured with a NaI (T1) crystal at 90° to the neutron beam and is therefore not directly comparable with our spectrum which is integrated over a solid angle of 4π. However, both data are presented in Fig. 5 without any correction. The average agreement is better than the experimental error. This can be seen from the comparison of Dinter's value of 1090 ± 80 μb for the integrated cross section with our value of 1130 ± 170 μb. It would therefore appear that the angular distribution is rather isotropic.

Integrated cross section values are presented in Table 1. Their values lie around 1 mb and agree with the expected smooth mass dependence[6].

From the comparison of integrated cross section values with the older data[12, 13] obtained by the activation technique (σ_{act}) follows that the two cross sections agree only for Se, for other elements the σ_{act} are higher than σ_{int}. Such a behaviour was qualitatively discussed in Refs.[6, 7]. However very recently Kantele and Valkonnen reported[14] that the activation technique has been improved and for 8 nuclei in which previous σ_{act} values appreciably exceeded the σ_{int} data, new σ_{act} results agree with σ_{int} values within the

Table
Cross sections for the radiative capture of 14.1 MeV neutrons and parameters of the samples.

	Density of the sample (g/cm³)	Radius (cm)	Integrated cross section (μb)	Isotopes	Activation cross section (μb)
Cu	8.92	2.0	770 ± 110	^{63}Cu (69.1%) ^{65}Cu (30.9%)	2560 ± 380[a] 6300 ± 1900[b]
Se	1.42	3.0	860 ± 130	^{80}Se (50.0%) ^{78}Se (23.6%) ^{76}Se (9.1%) ^{82}Se (8.8%) ^{77}Se (7.5%) ^{74}Se (1.1%)	650 ± 200[a]
Br	3.09	3.0	1100 ± 160	^{79}Br (50.6%) ^{81}Br (49.4%)	3500 ± 850[b]
In	7.28	2.0	1200 ± 200	^{115}In (95.8%) ^{113}In (4.2%)	5970 ± 810[a]
I	3.10	3.0	1100 ± 160	^{127}I (100%)	2500 ± 500[a] 900 ± 300[c]

[a] Data taken from Ref.[12],
[b] Data taken from Ref.[13],
[c] Data taken from Ref.[14].

experimental error. The same applies for the iodine cross sections shown in the Table. We believe that future σ_{act} measurements will remove the $\sigma_{act} - \sigma_{int}$ discrepancy for other nuclei reported here.

Acknowledgement

We are indebted to Dr. E. Hodgson and Dr. M. Najžer for helpful comments.

References

1) F. Cvelbar, A. Hudoklin, M. V. Mihailović, M. Najžer and V. Ramšak, Nucl. Phys. **A130** (1969) 401;
2) F. Cvelbar, A. Hudoklin, M. V. Mihailović, M. Najžer and M. Petrišič, Nucl. Phys. **A130** (1969) 413;
3) F. Cvelbar, A. Hudoklin and M. Potokar, Nucl. Phys. **A138** (1969) 412;
4) F. Cvelbar and A. Hudoklin, Nucl. Phys. **A159** (1970) 555;
5) F. Rigaud, J. Roturier, J. L. Irigaray, G. Y. Petit, G. Longo and F. Saporetti, Nucl. Phys. **A154** (1970) 243;
6) F. Cvelbar, A. Hudoklin and M. Potokar, Nucl. Phys. **A158** (1970) 251;
7) F. Rigaud, J. L. Irigaray, G. Y. Petit, G. Longo and F. Saporetti, Nucl. Phys. **A173** (1971) 551 and **A176** (1971) 545;
8) G. E. Brown, Nucl. Phys. **57** (1964) 339;
9) A. A. Lushnikov and D. F. Zaretsky, Nucl. Phys. **66** (1965) 35;
10) A. M. Lane and J. E. Lynn, Nucl. Phys. **11** (1959) 646;
11) H. Dinter, Nucl. Phys. **A111** (1968) 360;
12) J. L. Perkin, L. P. O'Connor and R. F. Coleman, Proc. Phys. Soc. **72** (1958) 505;
13) H. O. Menlove, K. L. Coop and H. A. Grench, Phys. Rev. **163** (1967) 1299;
14) J. Kantele and M. Valkonen, Phys. Lett. **39B** (1972) 625.