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Neutron capture cross sections at 25 keV

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Abstract. The radiative capture cross sections for eight even–even nuclei in the mass region $80 < A < 160$ have been investigated using the activation method and gamma counting technique. The cross sections for the three isotopes ^{84}Kr, ^{110}Cd and ^{146}Nd are reported for the first time and in the rest of the cases a comparison is made with previously reported values. The case of ^{115}In(n, γ)^{116m}In is reinvestigated as there is a discrepancy between the values reported using beta and gamma counting methods. The present results are in better agreement with gamma counting values.

The capture cross sections of keV neutrons are of great use in the understanding of the nucleosynthesis occurring in stars. The design of fast reactors as well as their control and maintenance is critcally influenced by the availability of precise data on the keV neutron capture cross sections of the various materials used in the reactors. Thus from both practical and theoretical points of view, there is a great need for systematic and accurate data on the keV neutron capture cross sections. Owing to the easy availability of keV neutrons from an antimony–beryllium source, the bulk of such data (Hummel and Hamermesh 1951, Kimbal and Hamermesh 1953, Macklin *et al* 1957, Booth *et al* 1958, Kononov *et al* 1959, Vervier 1959, Chaubey and Seghal 1965, 1966, Hasan *et al* 1968 and Chaubey and Seghal 1968) are available at 25 keV although they are by no means complete or well established. There exist several even–even nuclei uninvestigated while a few of them have recently been studied using the activation technique and beta counting method. However, for measuring such small cross sections, the gamma counting technique offers several advantages. Hence the present work is undertaken to study eight even–even isotopes. The cross section for ^{115}In(n, γ)^{116m}In is also reinvestigated since there is a considerable discrepancy between the values reported by Kononov *et al* (1959) and Chaubey and Seghal (1965) using beta counting and the values reported by Macklin *et al* (1957) and Booth *et al* (1958) employing the gamma counting technique.

For the present work, the 25 keV neutrons are obtained from a 16 Ci antimony–beryllium source. The photoneutron spectrum from this source was recently investigated by Lalovic and Werle (1970). There is a most intense group of energy $26 \pm 1{\cdot}3$ keV, a second neutron group of energy 363 ± 15 keV having an intensity of 5% of the former and a very weak third group of energy about 550 keV. Taking into account the softening of the neutron spectrum due to elastic collisions in beryllium, the average energy of neutrons emitted by this source is estimated to be 25 ± 5 keV. Thermal neutrons are obtained from a 500 mCi Ra–α–Be source moderated in a howitzer. Suitable corrections are applied for the presence of epicadmium neutrons. For gamma ray counting a

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$1\frac{3}{4}\times 2\ \text{in}^2$ NaI(Tl) crystal scintillation spectrometer with a 100 channel analyser was employed.

The experimental method followed was essentially the same as that of Booth *et al* (1958) except that in seven cases where the product nucleus could be identified by a unique gamma ray, the photopeak of the latter was recorded in the 100 channel analyser. In the remaining two cases, where the gamma spectrum was complex, the saturation activity was determined following the halflife as was done by Booth *et al* (1958). The 'double comparison ratio' R was defined in a similar way as

$$R = \frac{A^{x}_{keV} A^{I}_{th}}{A^{x}_{th} A^{I}_{keV}}$$

where the A represent the areas of the characteristic photopeaks (or the saturation activities) of the sample substance (x) and iodine (I) irradiated with 25 keV and thermal neutrons respectively. The capture cross section σ^{x}_{keV} of the sample for 25 keV neutrons was obtained from the relation

$$\sigma^{x}_{keV} = R\sigma^{x}_{th}\frac{\sigma^{I}_{keV}}{\sigma^{I}_{th}}$$

where σ^{I}_{th} and σ^{I}_{keV} are the standard cross sections of iodine at thermal energies and 25 keV taken as $6{\cdot}17 \pm 0{\cdot}2$ b (BNL supplement no 2 1967) and 832 mb (Robertson 1965) respectively. Thermal neutron capture cross sections of the samples σ^{x}_{th} are taken from the latest literature (BNL supplement no 2 1967, Kondaiah *et al* 1968).

The overall error associated with the cross section measurement can be resolved into two parts: (i) experimental error incurred in the determination of factor R and (ii) the compound error of the three assumed cross sections. The main contribution to the experimental error comes from the statistics of counting, particularly in view of the small cross sections which we tried to measure in the present investigations. In the cases where the characteristic photopeaks are measured this error varied between 2 and 10%.

Table 1.

Target nucleus	Halflife	Gamma ray selected	R	σ^{x}_{th}(b)	σ^{x}_{keV}(mb)	Literature value
^{84}Kr	4·4 h	150 keV	0·469 ± 0·018	0·090 ± 0·013[k]	57 ± 10	—
^{110}Cd	49 min	150 keV	0·951 ± 0·038	0·132 ± 15 %[i]	17 ± 3	—
^{115}In	54 min	1·27 MeV	0·47 ± 0·01	145 ± 15[h]	918 ± 100	805 ± 80[a] 980 ± 220[b] 580 ± 40[c] 590 ± 20[d]
^{130}Te	25 min	145 keV	0·47 ± 0·02	0·271 ± 0·06[j]	15 ± 4	72 ± 12[g]
^{146}Nd	11 day	530 keV	0·279 ± 0·17	1·8 ± 0·6[h]	68 ± 23	—
^{148}Nd	1·9 h	halflife	0·778 ± 0·134	3·7 ± 1·2[h]	388 ± 144	165 ± 35[f]
^{150}Nd	12 min	halflife	0·42 ± 0·07	1·5 ± 0·2[i]	85 ± 19	125 ± 25[f]
^{58}Gd	18 h	363 keV	1·16 ± 0·03	4 ± 2[h]	626 ± 350	710 ± 71[a] 545 ± 120[e]
^{160}Gd	3 min	361 keV	0·133 ± 0·015	0·8 ± 0·015[h]	15 ± 7	110 ± 20[e]

a Macklin *et al* (1957); b Booth *et al* (1958); c Kononov *et al* (1959); d Chaubey and Seghal (1965); e Chaubey and Seghal (1966); f Hasan *et al* (1968); g Chaubey and Seghal (1968); h *BNL Suppl.* no. 2 (1967); i Seghal *et al* (1959); j Seghal (1962); k Kondaiah *et al* (1965).

In other cases an error of the order of 15 % is incurred due to the presence of appreciable background in the counting channels. A minor error ($\simeq 1$ %) is due to the possibility of sight alternations in the geometry of irradiations. The errors associated with the thermal neutron cross sections are taken, as they are, from the literature. The overall accuracy of the measured cross section is specified in terms of the root mean square projection of all the errors stated above. The values of the cross sections are presented in table 1 together with other relevant data.

It can be seen from table 1 that the present experimental value for the cross section of $^{115}In(n, \gamma)^{116m}In$ confirms that obtained by the gamma counting method (Macklin *et al* 1957, Booth *et al* 1958). There is approximate agreement within errors between the present values and those reported by Chaubey and Seghal (1968) for ^{148}Nd and ^{150}Nd. However, in ^{130}Te and ^{160}Gd the beta counting values reported by Chaubey and Seghal (1966) are surprisingly larger than the present values obtained by the gamma counting method.

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