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THE SPIN OF THE 2 sec ISOMERIC STATE OF In

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Abstract: The cross section ratios for the formation of the 2 sec and the 54 min isomeric states of In^{116} due to neutron capture in the three lowest resonances of the In^{116} compound nucleus were measured. A comparison of the results with the isomeric cross section ratios calculated by the γ-ray cascade statistics yields for the spin of the 2 sec state, a value $J_{m2} = 5$. The activation cross section for thermal neutrons was calculated from the isomeric cross section ratio in the 1.46 eV resonance to be $\sigma_{m2}(0.0253 \text{ eV}) = 81 \pm 8$ b.

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NUCLEAR REACTIONS In^{115}(n, γ), $E = 1.4$, 3.9, 9.1 eV; measured I_γ. In^{115} deduced σ(In^{116} isomers). In^{116} deduced J. Natural target.

1. Introduction

Two isomeric states of indium 116 are known. The first isomeric state In^{116m1} ($T_{\frac{1}{2}} = 54.12$ min) is a 5^+ state [1,13]) with an excitation energy [2]) of about 108 keV. This state decays by β-radiation to excited states of Sn^{116}. The second isomeric state [3,4]) In^{116m2}($T_{\frac{1}{2}} = 2.16$ sec) decays by 163 keV γ-transitions to In^{116m1}. From the E3 character of this isomeric transition it has been concluded that this is a 8^- state. The spin value 8 was confirmed by the agreement between the excitation cross section of the 2 sec state for thermal neutrons measured by Fettweis [5]) and the calculated one obtained by the cascade statistics theory from Huizenga and Vandenbosch [6]). However, the approximately 20 times larger cross section measured by Alexander *et al.* [4]) is only compatible with smaller spin values. In order to determine which of the two measured cross sections σ_{m2} is more accurate and to get further information on the spin value of the second isomeric state of indium 116, the cross section ratios σ_{m2}/σ_{m1} in the three lowest resonances of the indium 116 compound nucleus were measured in the present work. In the first resonance [7]) ($E = 1.46$ eV), σ_{m2}/σ_{m1} was determined by two different methods. For the second and third resonances [7]) ($E = 3.9$ and 9.1 eV), the isomeric cross section ratios were measured relative to that in the first resonance.

2. Experimental Procedure and Results

Metallic indium foils were irradiated with neutrons of ≈ 1.4, 3.9 and 9.1 eV using crystal spectrometer at the Karlsruhe reactor FR2. The γ-activity of the foil was counted in a 10.2 cm × 15.2 cm NaI(Tl) crystal either with a single- or a 256-channel analyser.

2.1. DETERMINATION OF $(\sigma_{m2}/\sigma_{m1})_{1st\ res}$

For the determination of $(\sigma_{m2}/\sigma_{m1})_{1st\ res}$, the γ-ray spectra after irradiation times of 10 sec or 20 min were measured for several runs. The cross section ratio can be obtained from the counting rates N in the photopeaks of the 163 keV γ-rays and the γ-rays of one transition in the Sn^{116} spectrum in the following way:

$$\sigma_{m2}/\sigma_{m1} = \left(\frac{N}{\eta_\gamma P_\gamma \varepsilon f T}\right)_{2\,sec} \Bigg/ \left(\frac{N}{\eta_\gamma P_\gamma \varepsilon f T}\right)_{54\,min} . \tag{1}$$

Here f is the γ-ray intensity per decay for the transition considered, η_γ the total detection efficiency of the NaI(Tl) crystal and P_γ its peak-to-total ratio [8]). The factor ε represents the γ-absorption in the foil [9]) and T is a factor dependent on irradiation and counting time. From the internal conversion coefficients [10]) for the isomeric transition a value of f equal to 0.37 ± 0.03 was calculated. Eq. (1) was evaluated for the 408, 1085 and 1270 keV γ-peaks of the 54 min spectra. This yields the average value

$$(\sigma_{m2}/\sigma_{m1})_{1st\ res} = 0.52 \pm 0.05.$$

The error is mainly due to the errors of f.

Another determination of the cross section ratio was made by observing the increase of the Sn^{116} γ-activity in the first few seconds after a short-time irradiation due to the decay of the second to the first isomeric state. The counting rate of the 1085 and 1270 keV peaks after a 2 sec activation was measured. Thus the counting rate is

$$N(t) \approx A e^{-\lambda m1 t} - e^{-\lambda m2 t}, \tag{2}$$

where A is related in a straightforward manner with σ_{m2}/σ_{m1}. The evaluation of eq. (2) yields

$$(\sigma_{m2}/\sigma_{m1})_{1st\ res} = 0.49 \pm 0.05.$$

In this case the error depends mainly on statistical fluctuations of the counting rate.

2.2. RELATIVE DETERMINATION OF $(\sigma_{m2}/\sigma_{m1})_{2nd\ res}$ AND $(\sigma_{m2}/\sigma_{m1})_{3rd\ res}$

In order to determine σ_{m2}/σ_{m1} in the second and third resonance relative to the first resonance, the γ-rays with energies above 100 keV were measured after an irradiation time of 20 sec. These data allow the deduction of the ratio of γ-ray intensities of the decays of the 2 sec and 54 min isomeric states, respectively. The counting probabilities are eliminated by relating the ratio to that in the first resonance. The results are

$$(\sigma_{m2}/\sigma_{m1})_{2nd\ res}/(\sigma_{m2}/\sigma_{m1})_{1st\ res} = 0.98 \pm 0.06,$$

$$(\sigma_{m2}/\sigma_{m1})_{3rd\ res}/(\sigma_{m2}/\sigma_{m1})_{1st\ res} = 0.93 \pm 0.09.$$

3. Discussion

It is possible to calculate the isomeric cross section ratios from the γ-ray cascade statistics [6]). For this cascade model it is assumed that only E1 transitions occur and that the transition probability is proportional to the spin-dependent part of the nuclear level density $\rho(J)$ only, where

$$\rho(J) = \rho(0)(2J+1)\exp(-(J+\tfrac{1}{2})^2/2\sigma^2), \tag{3}$$

where $\rho(0)$ is the level density at the spin $J = 0$, σ is the spin cut-off parameter. One assumes furthermore that after $\bar{N}_\gamma - 1$ transitions of E1 character the last one follows with the lowest spin differences to the final states ($\bar{N}_\gamma$ is the average multi-

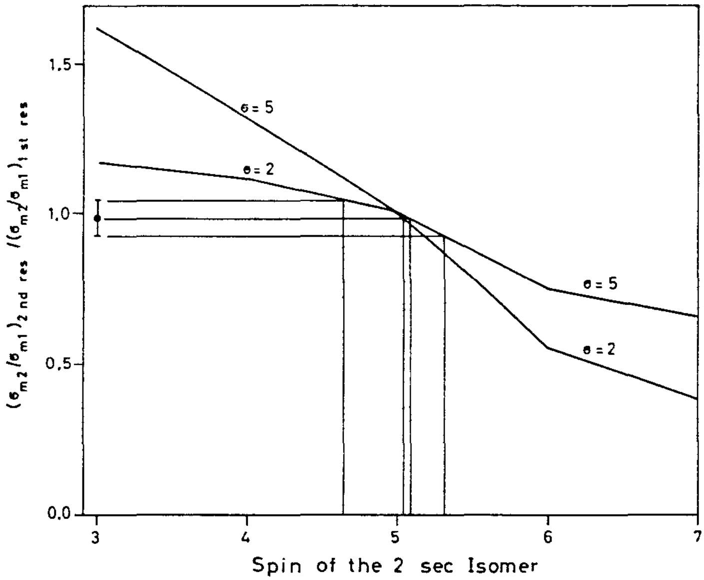

Fig. 1. Comparison of calculated and measured isomeric cross section ratios.

plicity of the γ-ray cascade). In order to compare the experimental results with those of the cascade theory, the values $\bar{N}_{\gamma\,1st\,res} = 4.4$ and $\bar{N}_{\gamma\,2nd\,res} = 5.6$ (ref. [11])), compound state spin values $J_{1st\,res} = 5$ and $J_{2nd\,res} = 4$ (ref. [12])) and the final state spin $J_{m1} = 5$ (refs. [13,14]) were used. The isomeric cross section ratios were calculated for the two limiting values $\sigma = 2$ and $\sigma = 5$ of the spin cut-off parameter [15]).

The ratio $(\sigma_{m2}/\sigma_{m1})_{2nd\,res}/(\sigma_{m2}/\sigma_{m1})_{1st\,res}$ thus calculated for various spin values of the 2-sec isomer is shown in fig. 1 and it is seen that the experimental value is compatible with a spin value $J_{m2} = 5$. The value of $(\sigma_{m2}/\sigma_{m1})_{1st\,res}$ itself allows us to determine the spin of the 2 sec state only by additional use of the value of $(\sigma_g/\sigma_{m1})_{1st\,res}$ measured by Albold [16]) where σ_g is the formation cross section [17,1]) for the ground state In^{116g}($T_{\frac{1}{2}}$ = 14.10 sec). By this alternative method, which was previously used by Alexander *et al.* [5]), $J_{m2} = 5$ was found, in agreement with the result of the method discussed above.

The spin value 5 was assigned with the aid of a statistical theory which does not take into account individual properties of states and transitions. It would be possible to consider the influence of the low-lying states of the compound nucleus as was done in calculations of γ-ray spectra [18]), but low-lying states of In^{116} and their γ-ray transitions have not been previously investigated. However, agreement between measured and calculated isomeric cross section ratios was observed in many cases [6, 19–21]). Furthermore, in this special case of equal final state spin values the assumption of E1 transitions in the γ-ray cascades is no restriction, as is easy to see.

Due to the overall constancy of the ratio σ_{m2}/σ_{m1} within experimental error, σ_{m2} for thermal neutrons can be calculated using σ_{m1} from earlier measurements with thermal neutrons [1]). The result is

$$\sigma_{m2}\ (0.0253\ \text{eV}) = 81 \pm 8\ \text{b}.$$

This is in agreement with $\sigma_{m2}(0.0253\ \text{eV}) = 92 \pm 14$ b measured by Alexander *et al.* [4]) and disagrees with $\sigma_{m2}(0.0253\ \text{eV}) = 4 \pm 1.5$ b measured by Fettweis [5])

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