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# INELASTIC SCATTERING OF 275 keV NEUTRONS BY SILVER

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## ABSTRACT

Neutron total, elastic and inelastic scattering cross-sections of Ag at the $E_n$ = 275 keV neutron energy were measured by using the filtered neutron beam of the WWR-M reactor in Kiev. The d-neutron strength function $S_{n2}$ of Ag was determined from the analysis of all available data in the $E_n \leq 600$ keV energy region on neutron inelastic scattering cross-sections with excitation of the first isomeric levels $I_m^\pi = 7/2^+$, $E_m \sim 90$ keV of $^{107,109}$Ag: $S_{n2} = (1.03 \pm 0.19) \cdot 10^{-4}$.

## Introduction

The two stable isotopes of silver $^{107,109}$Ag, which constitute a natural mixture, have very similar systems of lower excited states, including the isomeric state $I_m^\pi = 7/2^+$ which differs strongly with regard to spin from the ground state $I_g^\pi = 1/2^-$ (Fig. 1). As has been shown in Ref. [1], the presence of a low-lying isomeric level means that one can reliably determine the d-neutron strength function $S_{n2}$ from an analysis of the neutron inelastic scattering cross-section $\sigma_{in}^m$ near the excitation threshold of this isomer. In contrast to the s- and p-neutron strength functions, the currently available experimental information on $S_{n2}$ is extremely limited [2]. The conventional method for determining $S_{n2}$ consists in analysing the total neutron cross-sections $\sigma_{tot}$ and the neutron radiative capture cross-sections $\sigma_\gamma$ [3]. As was noted in Ref. [1], a major disadvantage of the conventional approach is the strong correlation between the values of $S_{n2}$ to be determined and the average resonance parameters of the s- and p-partial neutron waves. The method proposed in Ref. [1] for determining $S_{n2}$ from an analysis of $\sigma_{in}^{m}$ does not have this disadvantage; however, for a wide range of nuclei the use of this method is restricted both by the absence of a low-lying isomeric state in the majority of nuclei and the methodological complexity of measuring $\sigma_{in}^{m}$.

Owing to the large difference in spin from the ground state, the low-lying isomeric levels have a comparatively large half-life. As a result, $\sigma_{in}^{m}$ can be measured with the use of the activation method - by producing the isomer in the neutron beam and then measuring discharge photons outside the beam. However, proper account must be taken in this method of a number of corrections (for self-absorption of photons by the sample, conversion decay, etc.) the ambiguity of which may result in a large systematic error in the determination of $\sigma_{in}^{m}$.

Where the difference in the spins of the ground and isomeric states is $\Delta I \geq 3$, the cross-section $\sigma_{in}^{m}$ near the threshold is of the order of tens of millibarns. Since the elastic scattering cross-section $\sigma_{el}$ is ~ 10 b, measurement of $\sigma_{in}^{m}$ by the direct recording of inelastically scattered neutrons is difficult owing to the high elastic scattering background $\sigma_{in}^{m}/\sigma_{el} \leq 10^{-3}$. Also, in Ref. [4] using $^{103}Rh$ as an example, we demonstrated the possibility of measuring $\sigma_{in}^{m}$ near the threshold by direct recording of inelastically scattered neutrons, employing intensive filtered reactor neutron beams (flux at sample location $\Phi \sim 10^{6}$ n/s·cm$^{2}$), to an accuracy of ~ 7 mb.

**Experimental method**

The total neutron cross-section $\sigma_{tot}$ was measured by the transmission method; $\sigma_{el}$ and $\sigma_{in}$ were measured by direct recording of elastically and inelastically scattered neutrons. The measurement method for $\sigma_{tot}$, $\sigma_{el}$ and $\sigma_{in}$ has been described in detail in Refs [5, 6]. The beam of quasimonoenergetic neutrons with an average energy of $E_n$ = 275 keV was produced from a reactor beam using an Mn- (thickness 270 g/cm$^2$), V- (50 g/cm$^2$), S- (54 g/cm$^2$) and $^{10}$B-based (0.2 g/cm$^2$) filter placed in the outlet discs of the channel gate [7]. The relative contribution of the group of quasimonoenergetic neutrons with an energy of $E_n$ = 275 keV was 65.4%; the neutron flux at the sample location in the scattering experiment was $\Phi \sim 3 \cdot 10^5$ n/cm$^2$. In the transmission and scattering experiments, we used an elliptical metallic Ag sample (weight 110.06 g, thickness 2.92 mm, semiminor axis 29.32 mm and semimajor axis 38.55 mm). An SNM-38 spectrometric proportional hydrogen counter was used for the neutron recording; in the scattering experiments, this instrument made it possible to separate the groups of elastically and inelastically scattered neutrons. The scattering cross-sections were measured at an angle of $\theta$ = 90°. The method used for processing the primary experimental data and calculating the corrections for multiple processes in the sample has been described in detail in Refs [6, 8].

The values obtained for $\sigma_{tot}$ and $\sigma_{in}^m / \sigma_{el}$ at $E_n$ = 275 keV in the present work were:

$$\sigma_{tot} = 7.59 \pm 0.19 \qquad (1)$$

$$\sigma_{in}^m / \sigma_{el} = (9.0 \pm 7.6) \cdot 10^{-3}. \qquad (2)$$

The absolute values of $\sigma_{in}^m$ and $\sigma_{el}$ were determined by normalizing their sums to the difference between $\sigma_{tot}$ and the neutron radiative capture cross-section $\sigma_\gamma$. The evaluated data from Ref. [9] were used for $\sigma_\gamma$: $\sigma_\gamma = 0.30 \pm 0.03$ b at $E_n$ = 275 keV. The values obtained for $\sigma_{el}$ and $\sigma_{in}^m$ were:

$$\sigma_{el} = 7.29 \pm 0.21\,\text{b} \qquad (3)$$

$$\sigma_{in}^m = 65 \pm 55\,\text{mb}. \qquad (4)$$

## Analysis of the inelastic scattering cross-section

The data on $\sigma_{in}^{m}$ near the excitation threshold of the isomeric states $I_m^{\pi} = 7/2^+$ $E_m \sim 90$ keV of the $^{107,109}Ag$ nuclei were obtained first. Among the data available in the literature, those for $\sigma_{in}^{m}$ which were closest to the threshold were obtained in Ref. [5] at energies of $E_n = 500$ and 600 keV (Fig. 2). These data, together with the results of the present work, were analysed with a view to determining the d-neutron strength function $S_{n2}$ for Ag.

The parametrization formalism for $\sigma_{in}^{m}$ has been described in detail in Ref. [1]. The inelastic scattering cross-section was parametrized with the help of an expression which takes the form of the well-known Hauser-Feshbach-Moldauer formula:

$$\sigma_{in} = \frac{2\pi^2}{k^2}\sum_{J\pi}\frac{g(J)}{D_J}\sum_{ll'}\frac{\Gamma_n^{Jl}\Gamma_{n'}^{Jl'}}{\Gamma_J}F, \qquad (5)$$

where $D_J$ is the average distance between resonances with spin J; $\Gamma_j$, $\Gamma_n^{jl}$ and $\Gamma_{n'}^{jl'}$ are the average values of the total resonance width and the partial neutron widths in the elastic and inelastic scattering channels; F is the fluctuation factor. The neutron widths, $\Gamma_n^{jl}$, $\Gamma_{n'}^{jl'}$ were parametrized in terms of the neutron strength functions $S_{nl}$:

$$\Gamma_{n(n')}^{Jl} = \frac{S_{nl}}{d_l}\nu_l D_J n_{Jl}\sqrt{E_{n(n')}}, \qquad (6)$$

where $d_l$ and $\nu_l$ are the renormalization factor and the optical transmission for the neutron wave with the orbital momentum l; $n_{Jl}$ is the degree of degeneracy of the total momentum of the system J; $E_{n(n')}$ is the neutron energy in the elastic (inelastic) scattering channel.

For the calculations, we used the data from Ref. [2] on the average resonance parameters of Ag for the s- and p-partial waves. The contributions of the s-, p-, d- and f-partial neutron waves to $\sigma_{in}^{m}$ for Ag are shown in Fig. 2. It will be seen from the figure that $\sigma_{in}^{m}$ is chiefly sensitive to the d-neutron strength function $S_{n2}$, as is concluded in Ref. [1]. The experimental data in Ref. [5] and in this paper were approximated using the method of least squares by expression (5) with the variation of $S_{n2}$. The result of the approximation is shown in Fig. 2 as a continuous line. The value of $S_{n2}$ obtained is

$$S_{n2} = (1.03 \pm 0.19) \cdot 10^{-4} . \tag{7}$$

Prior to this paper, there were no experimental data on $S_{n2}$ for Ag. The value obtained for $S_{n2}$, which is shown in expression (7), does not contradict the systematics of the data for neighbouring nuclei [1] (Fig. 3).

In conclusion, it should be noted that the Mn-, V-, S- and $^{10}B$-based neutron filter used in the present work imposes a substantial limitation on the accuracy of the determination of $\sigma_{in}^{m}$ owing to the high admixture of background groups of quasimonoenergetic neutrons (~ 35%). The use of the filter proposed in Ref. [10] for an energy of $E_n$ = 317 keV, which does not have this disadvantage, will evidently ensure a much higher accuracy in subsequent measurements of $\sigma_{in}^{m}$ for a number of nuclei. Promising candidates for the study of the mass dependence of the d-neutron strength function $S_{n2}$ are the $^{77}Se$, $^{79}Br$ and $^{189}Os$ nuclei, which have relatively low-lying isomeric states and for which there are no data at present on $\sigma_{in}^{m}$.

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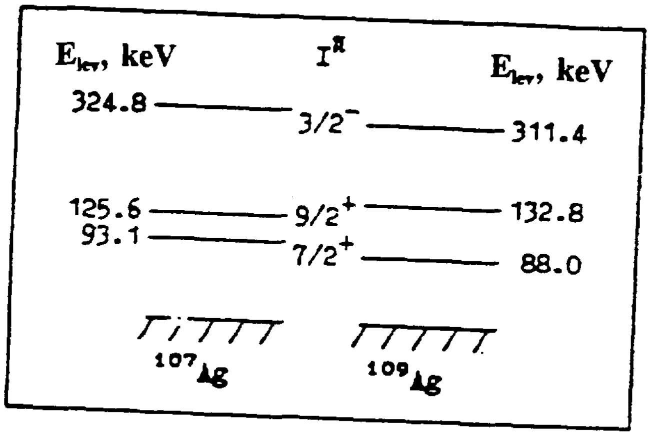


*FIG.1. The lower level schemes for $^{107,109}Ag$.*

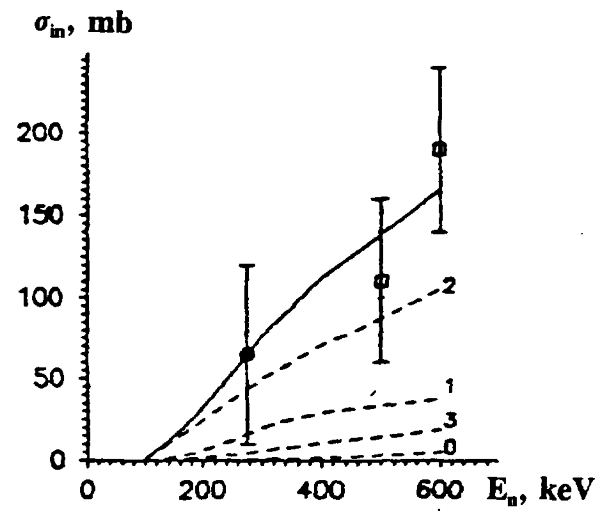


*FIG. 2. Neutron inelastic scattering cross-section for Ag. □ , • - data from Ref. [5] and this paper, respectively. Continuous line - approximation of the experimental data. Dashed lines - partial contributions of the s- (0), p- (1), d- (2) and f- (3) neutron waves.*

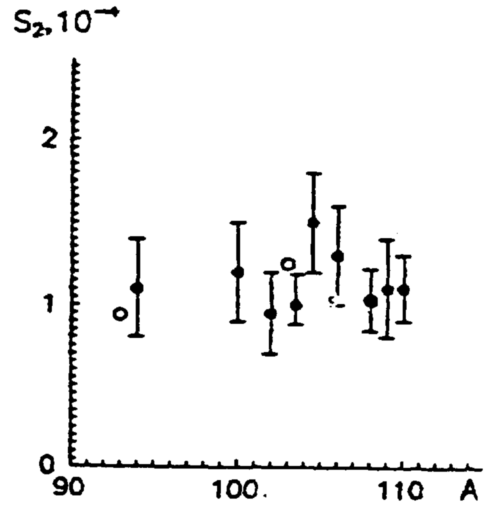


*FIG. 3. Mass dependence of the d-neutron strength function in the 90 ≤ A ≤ 110 region [1]. • - result from this paper.*

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