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ABSTRACT

Using the time-of-flight method, the neutron total cross-sections for ^{80}Se were measured in the energy range below 10 keV. From the analysis of these data, the parameters of the s-wave neutron resonances were determined.

The available data on the neutron resonance parameters of ^{80}Se are restricted to the eleven lowest s-wave resonances and four p-wave resonances [1]. Information of this kind is needed not only for fundamental work in neutron physics but also for a number of applied tasks. For example, accurate data on the detailed energy dependence of the total cross-sections for this isotope are required for the construction of the high-flux interference filters used in nuclear physics experiments in research reactors [2]. Moreover, the resonance parameters of nuclei in the A ~ 80 range are needed for the correct estimation of the averaged cross-sections of those nuclei in stellar events in order to verify stellar nucleosynthesis models. The parameters of the isolated resonances of ^{80}Se are of special interest as the mean resonance parameters of the nucleus cannot be used to calculate averaged cross-sections owing to its low level density.

The Nuclear Research Institute of the National Academy of Sciences of Ukraine has studied the total neutron cross-sections of ^{80}Se in the 0-10 keV energy range. The cross-sections were measured using the time-of-flight technique in the ninth horizontal channel of the WWR-M reactor. A detailed description of the experimental methodology is given in Refs [3, 4]. The sample used for the measurements took the form of a powder highly enriched in the relevant isotope (99.2 ± 0.2%) in an aluminium container with a diameter 24.1 mm. The sample thickness was 10.846 ± 0.090 g/cm². The transmission values T which were obtained are represented by the points in the upper part of Fig. 1. Apart from these data, the value for the radiative capture cross-section at thermal point σ_γ^{th} = (0.610 ± 0.045) barn given in Ref. [1] was also used in the analysis.

The transmission value obtained for the i-th channel of the time-of-flight spectrum for a sample thickness n may be expressed as follows:

$$(E_i) = \int_{-\infty}^{\infty} f(E')\exp[-n\sigma_\gamma(E')]dE', \tag{1}$$

where E_i is the energy for the i-th channel, $\sigma_t(E)$ is the total neutron cross-section, and f(E) is the resolution function of the spectrometer which may be represented as follows:

$$f(E) = \frac{1}{\sqrt{\pi b}} \exp\left[-\left(\frac{E-E_1}{b}\right)^2\right] \tag{2}$$

with the constant b = $0.0015E^{3/2}$ [5].

The neutron cross-sections generated from the experimental dependence T(E) were parametrized using multilevel Reich-Moore formulae [6]. The contribution of distant resonances outside the energy range under consideration was taken into account by isolating the background component R^∞ in the R-matrix. The elements of the background matrix determine the potential scattering phases [7]:

$$\varphi_l = \phi_l - \arctan \frac{p_l R_l^\infty}{1 - R_l^\infty (s_l - B_l)} \tag{3}$$

where ϕ_l is the scattering phase for an impenetrable sphere, p_l and s_l are the penetrability and shift factors, and B_l is the parameter of the boundary condition imposed on the radial wave function of the system. In practical applications it is customary to use the potential scattering radius $R' = a(1-R_0^\infty)$, where $a = 1.35A^{1/3}$ fm instead of the potential scattering parameter for s-neutrons R_0^∞.

Since, in the energy range under consideration, the Doppler width is significantly smaller than both the effective width of resolution function b(2) and the mean resonance width for ^{80}Se [8], the Doppler effect was not taken into account when calculating the cross-sections.

The unknown resonance parameters were determined using the method of least squares, fitting the transmission values calculated using expression (1) and the cross-section σ_γ^{th} to the experimental values. The variable parameters were the potential scattering radius R', the energy values E_λ, and the reduced neutron widths $\Gamma_{\lambda n}^0$ of the s-resonances which contribute significantly to the total cross-section in the 0-10 keV region.

Owing to the resolution, the relatively weak p-resonances were practically undetectable in the experimental dependence T(E). Their parameters and the parameters of the s-resonances which did not fall within the range under consideration did not vary and were taken from Ref. [1].

The radiation widths $\Gamma_{\lambda\gamma}$ of intermediate atomic weight nuclei fluctuate slightly from resonance to resonance, and the transmission function T(E) is not sufficiently sensitive to such fluctuations. Consequently, for all resonances it was assumed that the value of $\Gamma_{\lambda\gamma}$ was equal to the mean value $\Gamma_\gamma = 0.23$ eV, except for the second and fifth resonances where the $\Gamma_{\lambda\gamma}$ values were 0.25 eV and 0.21 eV [1] respectively.

The resonance parameters obtained in the analysis are given in the table. Data from Ref. [1] are included in the two right-hand columns for the purposes of comparison. The E_λ and $\Gamma^1_{\lambda n}$ values for the invariable resonances are given in the lower part of the table. The transmission values calculated from the resonance parameters obtained and the total neutron cross-sections $\sigma_t(E)$ generated using those parameters are shown in Fig. 1. As can be seen from the figure, the calculated curve T(E) describes the experimental points fairly well. Their standard deviation is $\chi = 1.69$, whereas that for the transmission values calculated using the parameters in Ref. [1] is $\chi = 6.36$.

To parameterize the cross-sections, a set of equidistant negative resonances with identical reduced neutron widths was introduced (in the table these resonances are given negative numbers). The only variables among these were the parameters of the first closest resonance E_{-1} and Γ^0_{-1n}; the rest were assigned the mean inter-level distance values $\bar{D}_0 = 3500$ eV and $\Gamma^0_n = 0.564$ eV [1]. This approach does not require a large number of variable parameters by comparison with the traditional approaches, which use one (sometimes two-three) effective negative resonance, however it is more rigorous [9, 10].

The value we obtained for the potential scattering radius $R' = 8.00 \pm 0.15$ fm is somewhat lower than the estimated value of $R' = 8.7 \pm 0.8$ fm given in Ref. [1]. This difference may be due to the narrower energy range used in this experiment. Since the corresponding fluctuation error level for R′ in this experiment is $\Delta R'_f = 0.29$ fm Ref. [11], the value obtained for R′ does not contradict Ref. [1] within the margins of error.

Both values of R′ for ^{80}Se are shown in Fig. 2, together with the systematics of the data on neighbouring isotopes from Ref. [1]. From the figure it can be seen that the value of R′ obtained in this experiment agrees slightly better with the overall systematics.

In conclusion, the authors would like to thank P.N. Vorona for assistance in preparing the sample. The experiment was performed with partial financial support from the Consolidated Fund of the Government of Ukraine and the International Science Foundation (Grant No. K4S100).

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Table

Resonance parameters of ^{80}Se

№	l	J	This experiment		[1]	
			E_{λ}, eV	$\Gamma^{l}_{\lambda n}$, eV	E_{λ}, eV	$\Gamma^{l}_{\lambda n}$, eV
-10	0	0.5	-33030	0.564		
-9	0	0.5	-29530	0.564		
-8	0	0.5	-26030	0.564		
-7	0	0.5	-22530	0.564		
-6	0	0.5	-19030	0.564		
-5	0	0.5	-15530	0.564		
-4	0	0.5	-12030	0.564		
-3	0	0.5	-8530	0.564		
-2	0	0.5	-5030	0.564		
-1	0	0.5	-1600(450)	0.93(30)	-3690	3.331
1	0	0.5	1982(3)	1.13(2)	1970	1.13
2	0	0.5	4348(12)	1.08(3)	4270(32)	0.80(20)
3	0	0.5	4690(100)	0.10(2)	4720(36)	0.07(4)
4	0	0.5	5210(25)	0.65(3)	5100(10)	1.00(30)
5	0	0.5	5566(160)	0.06(2)	5660(46)	0.09(3)
6	0	0.5	12632	0.230	12632(156)	0.23(7)
7	0	0.5	18300	0.812	18300	0.812
8	0	0.5	20300	0.496	20300(320)	0.496
9	0	0.5	23122	0.300	23122(390)	0.30(10)
10	0	0.5	29600	0.211	29600	0.21
11	0	0.5	39900	0.936	39900	0.936
12	1	0.5	1470	0.540	1470(10)	0.54(14)
13	1	1.5	5240	0.500	5240	0.50
14	1	1.5	6120	0.450	6120(52)	0.45
15	1	0.5	8150	0.800	8150(80)	0.80
			R'=8.00(15) fm		R'=8.7(8) fm	
			χ=1.69		χ=6.36	

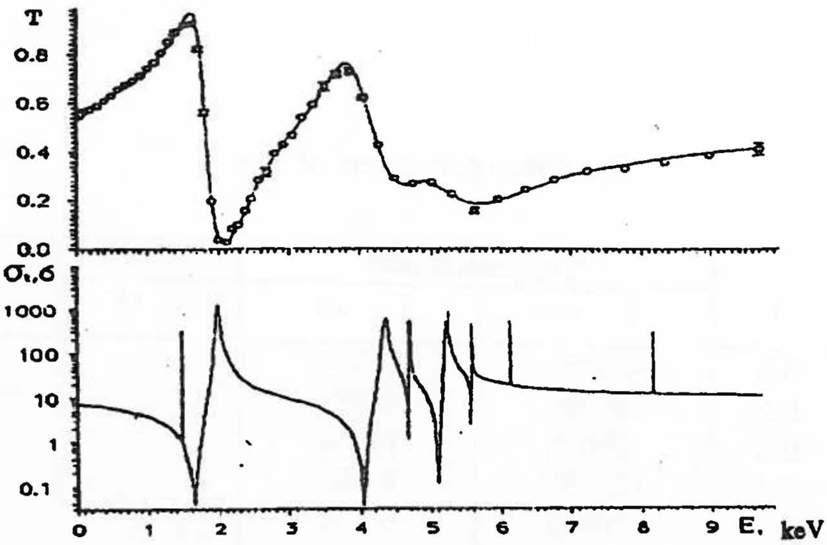

Fig. 1. Experimental transmission values for ^{80}Se (points on the upper graph) relative to neutron energy. The continuous curves show the transmission values (upper graph) and the total neutron cross-sections (lower graph) calculated using the resonance parameters obtained.

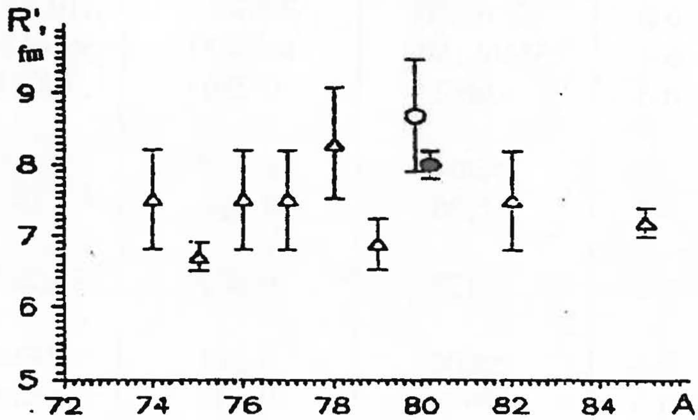

Fig. 2. Potential scattering radius R′ relative to mass number in the vicinity of A ≈ 80 [1]. For the sake of clarity, the data for A = 80 are placed side by side along the vertical axis: ● is the value obtained in this experiment; O are the values from Ref. [1].

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