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AVERAGE NEUTRON PARAMETERS FROM DIFFERENTIAL ELASTIC SCATTERING CROSS SECTIONS OF NEUTRONS WITH ENERGIES BELOW 450 KEV.

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Abstract: The paper describes a recently developed method of extracting s- and p-wave neutron strength functions and scattering radii from average differential cross sections measured at the pulsed reactor IBR-30. The results for nuclei in the region 48<A<238 are compared with other experimental data and theoretical calculations.

(Neutrons, differential cross sections, strength functions, scattering lengths)

Introduction

The possibility of extracting neutron strength functions S^l_j (l is the orbital momentum, j- the total angular momentum of the neutron) and R^∞_l parameters for l=0,1 from average differetial elastic scattering cross sections of keV-neutrons was first demonstrated in/1/. This method exploits the fact that a cross section averaged over resonances in a given energy range is described within a good accuracy by

$$\langle\sigma(\theta)\rangle=\frac{\sigma_s}{4\pi}\left[1+\omega_1P_1(\cos\theta)+\omega_2P_2(\cos\theta)\right],$$

with coefficients $\sigma_s(E)$, $\omega_1(E)$ and $\omega_2(E)$ for even-even target nuclei being easily expressed through the parameters S^0, $S^1_{1/2}$, $S^1_{3/2}$, R^∞_0 and R^∞_1 by averaging one-level resonant expressions. Here ω_2 accounts also for the contribution from interference between s- and d-wave potential scattering, provided $R^\infty_2=R^\infty_0$. In /2/ the above parameterization was generalized to A-odd nucei, for which in the expressions for σ_s and ω_2 there appear terms dependent on a common distribution function of partial neutron widths Γ_{nj} for two-channel p-wave resonances. This allowed obtaining of more correct values of parameters for odd nuclei together with some information about correlation between j-channels. In /3/ the inclusion in analysis of earlier data on polarizing power of scattering at E=400 keV allowed qualitative observation of spin-orbit splitting of potential scattering phase shift δ_1, i.e. observation of $R^\infty_{11/2}$ and $R^\infty_{13/2}$ instead of mean R^∞_1.

Method

Measurements by the time-of-flight method were carried out at the IBR-30 reactor in Dubna under a resolution of ≃25 ns/m. Neutrons scattered from a sample plate 0.002-0.025 barn^{-1} thick were detected at angles 45°, 90° and 135° by a battery of ^{3}He-counters. Data analysis gave $\langle\sigma(\theta)\rangle$ in the form of σ_s, ω_1, ω_2 parameters related to ≃ 20 energy intervals with mean energy from 1.5 to 442 keV. In additon, densities of neutron widths over 2-8 intervals were calculated from data /4/ and expressed as

$$\sum g\Gamma_n/\Delta E=\sqrt{E}\left[S^0+V_1(S^1_{1/2}+2S^1_{3/2}\right],$$

where $V_1=(kR)^2[1+(kR)^2]^{-1}$, $R=1.35A^{1/3}$ fm and E is in eV. In the analysis of $\langle\sigma(\theta)\rangle$ for heavy nuclei (starting from Gd) the influence of isotropic inelastic scattering was accounted for with its cross section being parametrized through the sought-for strength functions S^l_j within the Hauser-Feshbach formalism taking into account the Moldauer fluctuation corrections. The scattering radius in the general case can be defined similar to $R'_0=R(1-R^\infty_0)$ for s-wave:

$$\frac{R'_l}{R}=\frac{\delta_l}{\phi_l},$$

where ϕ_l is the phase shift on a hard sphere. Then at E ⇒ 0 it is

$$R'_l=R\left[1-\frac{(2l+1)R^\infty_l}{1+(l+b_l)R^\infty_l}\right].$$

We work under boundary conditions b_l /5/, which are close to traditional $b_l=s_l$ (s_l is the shift factor) or $b_l=-l$. They all are the same at $E \Rightarrow 0$ and give $R'_1=R(1-3R^{\infty}_1)$.

Results

Up to the present 42 samples have been investigated. The results are partly reported in /5/ and the table lists the remaining ones (including the parameters for ^{103}Rh,Ag, ^{117}Sn and ^{119}Sn corrected in accordance with /2/).

T a b l e

Target	$S^1_{1/2}$	$S^1_{3/2}$	R^{∞}_0	R^{∞}_1
Cu	3.0±1.8	1.1±0.6	-0.25±.06	0.32±.06
Y	1.2±1.2	5.5±0.5	-0.20±.03	0.52±.04
Nb	9.8±1.5	4.4±0.5	-0.23±.03	0.26±.03
^{92}Mo	2.1±2.4	4.0±0.5	-0.16±.06	0.21±.05
^{94}Mo	3.2±1.8	4.8±0.4	-0.17±.04	0.16±.03
Rh	8.3±1.1	3.1±0.4	0.07±.03	-0.01±.03
Ag	5.8±1.0	3.8±0.4	0.02±.03	-0.05±.02
In	7.4±0.9	2.5±0.3	0.04±.02	-0.19±.01
^{117}Sn	4.7±0.9	2.3±0.3	0.11±.02	-0.22±.02
^{119}Sn	3.8±0.9	1.3±0.2	0.05±.02	-0.22±.02
Sb	5.1±1.0	2.2±0.3	0.17±.03	-0.24±.03
Nd	3.3±1.4	1.5±0.3	0.13±.07	-0.11±.05
Gd	2.6±0.9	2.2±0.3	0.10±.04	-0.13±.03
Dy	0.2±0.8	2.2±0.5	-0.09±.04	-0.11±.02
Er	2.0±0.9	1.8±0.4	-0.02±.03	-0.02±.02
Ta	3.5±0.9	1.7±0.3	0.06±.03	0.16±.02
W	3.4±1.0	2.4±0.4	0.09±.05	0.21±.03
Re	5.4±1.4	3.0±0.7	0.22±.05	0.03±.07
Pt	0.0±0.4	0.7±0.2	-0.20±.02	0.15±.02
^{238}U	2.0±1.0	1.8±0.5	-0.11±.03	0.14±.03

Comparison

It is interesting to compare the extracted from $\langle\sigma(\theta)\rangle$ valuesof S^0, R'_0 and $S^1=\frac{1}{3}S^1_{1/2}+\frac{2}{3}S^1_{3/2}$ with the compilation data from /4/. Figures 1 and 2 demonstrate a good agreement of our values for S^0 and R'_0 with those recommended in /4/. Only for nuclei with A<90 our S^0 values are systematically lower than those in /4/ due to a significant self-shielding effect for strong s-wave resonances.

Since in our case the R'_0 values were determined by using wide energy intervals, they must less experience fluctuations due to resonance statistics, than local R'_0 values extracted from thermal cross sections or from resonance shapes. Fig.2 shows that both kinds of R'_0 values coincide within error limits and the discrepancy is not bigger than 15%. This fact disagrees with the conclusion of Nikolenko [6] that fluctuations of local R'_0 can reach 100%. Independence of R'_0 of the method of its extraction appears essential for the estimation of recommended values. One may judge agreement of our p-wave strength functions

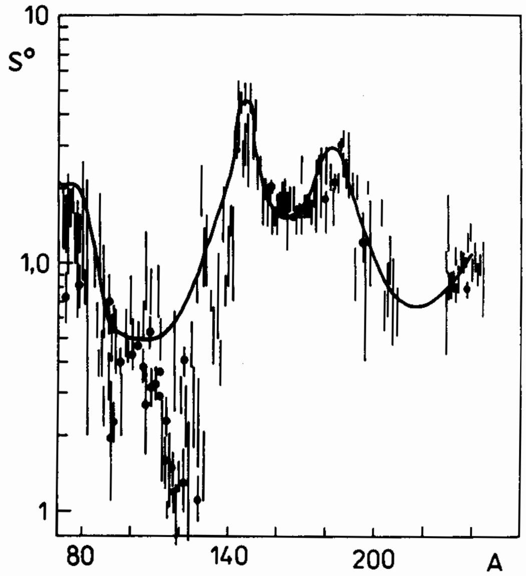

Fig.1. S^0 data. Vertical lines-experimental values from /4/, points-this work data. The curve-calculated behaviour for $S^0(A)$ also from /4/.

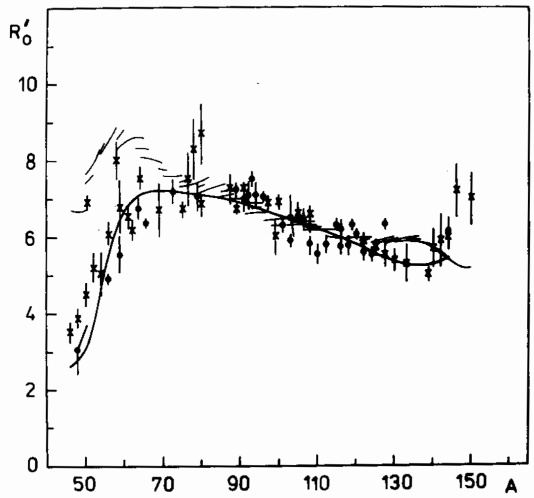

Fig.2. R'_0 in the 3p-resonance region. Crosses-values from /4/, points-our data, solid curve-OM calculation for Moldauer potential, sections of curves-calculation with the "regional" potential.

with literary data by looking at fig.3. It shows that the obtained from $<\sigma(\theta)>$ S^1 values agree with a full set of data satisfactorily described by various optical model (OM) calculations.

New information

Experimental $S^1_{1/2}$, $S^1_{3/2}$ and R'_1 values are the new ones. For the first time noncoinciding $S^1_{1/2}$ and $S^1_{3/2}$ peaks with the distance between maxima $\Delta A=13\pm4$ were observed as a function of A . (This is a first direct observation of spin-orbit splitting of an unbound single particle state.) Besides of that, there is observed a specific behaviour for $R'_1(A)$ which is an evidence for the extremely weak nonresonant p-wave scattering on nuclei with A=60-90 (see fig.4).

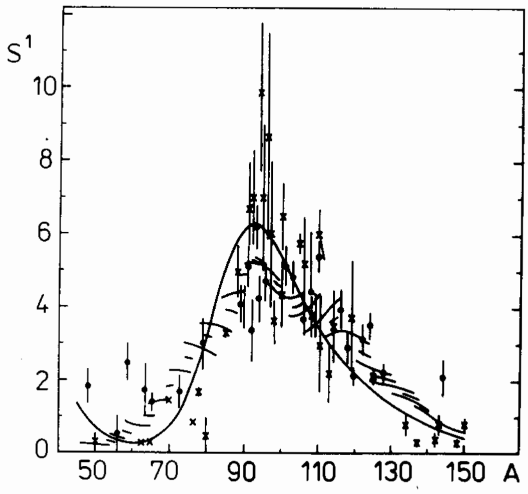

Fig.3. S^1 strength functions.Crosses-from /4/, points-this work,solid curve-OM calculation with the Camarda potential, solid-line sections- for the "regional" potential.

OM calculation

The agreement of the above mentioned facts with the OM calculations was checked by using the SCAT-program /7/. We obtained a satisfactory agreement of experimental data with the R'_0, R'_1 and S^1 values calculated by using the Moldauer potential /8/ for the s-wave neutron data and its modified by Camarda /9/ version with a larger real term for the p-wave data (with a depth of 1 MeV and a diffuseness of 0.1 fm). Figures 2,3,4 illustrate the results (solid curves). As for the description of the $S^1_{1/2}$ and $S^1_{3/2}$ experimental values the

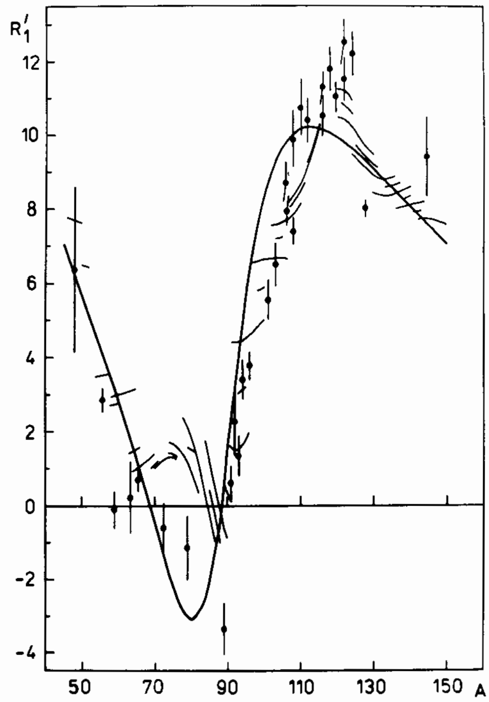

Fig.4. P-wave scattering radii.Solid curve-calculation with the Camarda potential, solid-line sections- with the "regional" potential.

OM calculations with Camarda potential using a conventional spin-orbit term $V_{so}=7$ MeV give for the $S^1_{1/2}$ and $S^1_{3/2}$ peaks a spacing of $\Delta A=6$ only. Calculations were also made with a potential from /10/ named by the authors a "regional" potential (for $85<A<125$). This potential is more complicate than the Moldauer-Camarda one since the r_0 parameter $(R=r_0A^{1/3})$ and parameter of diffuseness entering the Saxon-Woods form factor are taken different for the real and the imaginary part and are the linear functions of A. Moreover, potential depths contain isospin terms proportional to $\frac{N-Z}{A}$, therefore, the calculated R'_l and S^l_j are represented in figs. 2, 3, 4, 5 by sections of curves, each corresponding to a given element. Both tested potentials, though providing a satisfactory description for the experimental scattering radii R'_0 and R'_1 and S^1 strength functions, were unable to give explanation for the observed splitting of S^1_j. The experimental data require $V_{so}=10$ MeV. This value is by a

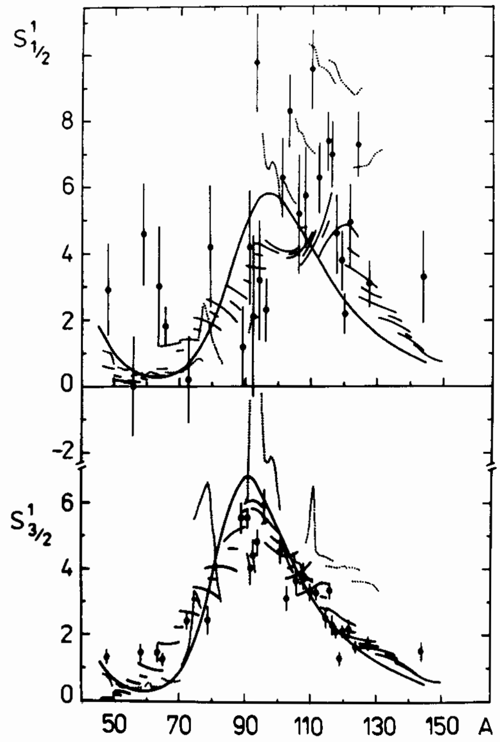

Fig.5. $S^1_{1/2}$ and $S^1_{3/2}$ strength functions. Solid curve- Camarda potential, solid-line sections- "regional" potential with V=10 MeV, dotted curve- calculated in /11/.

factor of 1.5-2 larger than that used in most of potentials for the description of bound as well as unbound nuclear states. Just with the fitted value of V_{so}=10 MeV we have obtained for the "regional" potential the solid-line sections shown in the figures. Calculations have demonstrated also that the conventional spherical OM did not give an explanation for a higher experimental maximum of $S^1_{1/2}$ with respect to the $S^1_{3/2}$ peak. Recently the $S^1_{1/2}$ and $S^1_{3/2}$ were calculated /11/ in the 3p-single particle resonance region in the frame of the OM which takes into account coupling with many phonon excitations and uses the generally accepted value for the spin-orbit term. The results are presented in fig.5 by dotted curves. Although it is difficult to draw a definite conclusion about agreement of the newly calculated S^1_j values with experimental data, they look like being in better correspondence with the observed splitting of the $S^1_{1/2}$ and $S^1_{3/2}$ peaks and correlation of their maxima. In this model variations in phonon coupling strength from nucleus to nucleus result in a different from the conventional OM behaviour for the $S^1_j(A)$. An idea to calculate R'_1 within this approach looks attractive.

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