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

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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.

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 $\simeq$20 energy intervals with mean energy

T a b l e

Target	$S^1_{1/2}\cdot10^4$	$S^1_{3/2}\cdot10^4$	$S^1\cdot10^4$	R^∞_0	R^∞_1
Cu	3.0(1.8)	1.1(0.6)	1.7(0.7)	-0.25(0.06)	0.32(0.06)
^{89}Y	1.2(1.2)	5.5(0.5)	4.1(0.5)	-0.20(0.03)	0.52(0.04)
^{93}Nb	9.8(1.5)	4.4(0.5)	6.2(0.6)	-0.23(0.03)	0.26(0.03)
^{92}Mo	2.1(2.4)	4.0(0.5)	3.4(0.9)	-0.16(0.06)	0.21(0.05)
^{94}Mo	3.2(1.8)	4.8(0.4)	4.3(0.7)	-0.17(0.04)	0.16(0.03)
^{103}Rh	8.3(1.1)	3.1(0.4)	4.8(0.5)	0.07(0.03)	-0.01(0.03)
Ag	5.8(1.0)	3.8(0.4)	4.5(0.4)	0.02(0.03)	-0.05(0.02)
In	7.4(0.9)	2.5(0.3)	4.1(0.4)	0.04(0.02)	-0.19(0.01)
^{117}Sn	4.7(0.9)	2.3(0.3)	3.1(0.4)	0.11(0.02)	-0.22(0.02)
^{119}Sn	3.8(0.9)	1.3(0.2)	2.1(0.3)	0.05(0.02)	-0.22(0.02)
Sb	5.1(1.0)	2.2(0.3)	3.2(0.4)	0.17(0.03)	-0.24(0.03)
Nd	3.3(1.4)	1.5(0.3)	2.1(0.5)	0.13(0.07)	-0.11(0.05)
Gd	2.6(0.9)	2.2(0.3)	2.3(0.4)	0.10(0.04)	-0.13(0.03)
Dy	0.2(0.8)	2.2(0.5)	1.5(0.4)	-0.09(0.04)	-0.11(0.02)
Er	2.0(0.9)	1.8(0.4)	1.9(0.4)	-0.02(0.03)	-0.02(0.02)
Ta	3.5(0.9)	1.7(0.3)	2.3(0.4)	0.06(0.03)	0.16(0.02)
W	3.4(1.0)	2.4(0.4)	2.7(0.4)	0.09(0.05)	0.21(0.03)
Re	5.4(1.4)	3.0(0.7)	3.8(0.7)	0.22(0.05)	0.03(0.07)
Pt	0.0(0.4)	0.7(0.2)	0.5(0.2)	-0.20(0.02)	0.15(0.02)
^{238}U	2.0(1.0)	1.8(0.5)	1.9(0.5)	-0.11(0.03)	0.14(0.03)

from 1.5 to 442 keV. In additon, densities of neutron widths over 2-8 intervals were calculated from data [4] and expressed as

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

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 $E \to 0$ 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 is the shift factor) or $b_l=-l$. They all are the same at $E \to 0$ and give $R'_1=R(1-3R^\infty_1)$.

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]).

It is interesting to compare the extracted from $\langle\sigma(\theta)\rangle$ values of 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.

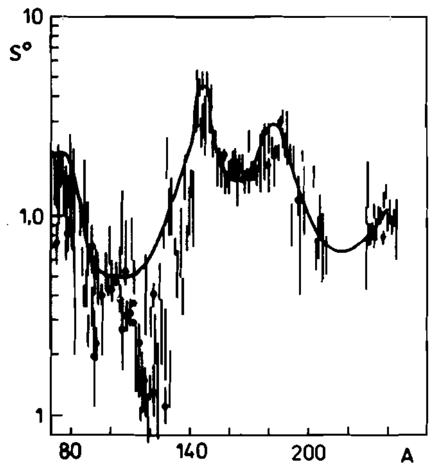

Fig.1. S^0 data. Vertical lines-experimental values from [4], points-this work data. The curve-calculated behaviour for $S^0(A)$ also from [4].

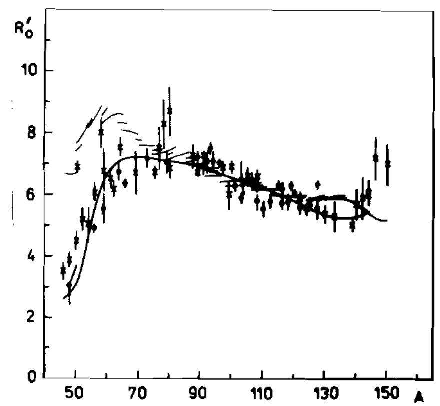

Fig.2. R'_0 in the 3p-resonance region. Crosses-values from [4], points-our data, solid curve-OM calculation for Moldauer potential, sections of curves-calculation with the "regional" potential.

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 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.

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). 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

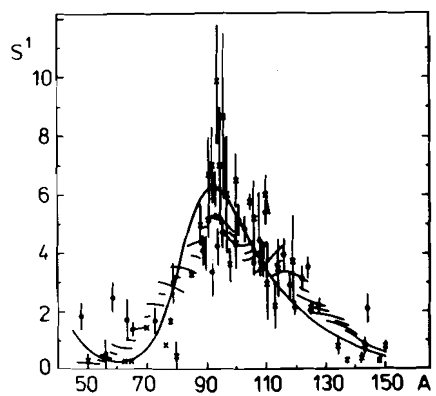

Fig.3. S^1 strength functions. Crosses-from [4], points-this work, solid curve-OM calculation with the Camarda potential, solid-line sections-for the "regional" potential.

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 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 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

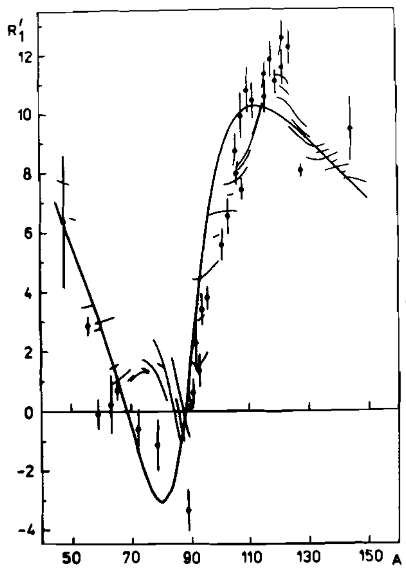

Fig.4. P-wave scattering radii. Solid curve-calculation with the Camarda potential, solid-line sections-with the "regional" potential.

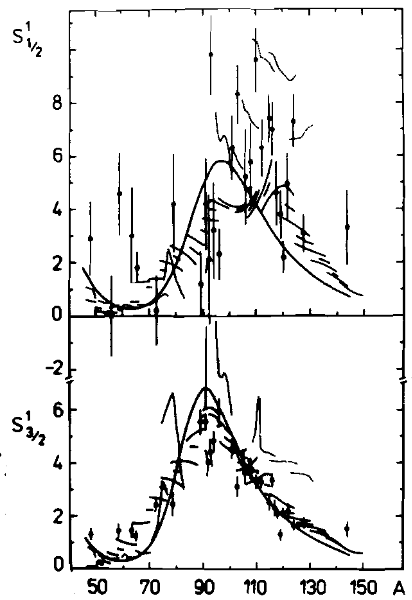

Fig.5. $S^1_{1/2}$ and $S^1_{3/2}$ strength functions. Solid curve-Camarda potential, solid-line sections-"regional" potential with V_{so}= =10 MeV, dotted curve-calculated in [11].

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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