ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

ДУБНА

E3-82-849

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SLOW NEUTRON SCATTERING ON BISMUTH AND LEAD AND ELECTRIC POLARIZABILITY OF THE NEUTRON

Submitted to "Ядерная физика, письма"

1982

As reported in ref.[1] the possibility exists to obtain information about electrical polarizability of the neutron while making more precise the experimental total neutron cross sections σ_{tot} of Bismuth and Lead and their amplitudes of coherent scattering b_{coh} in the low neutron energy range. The present paper reviews the results of processing of experimental data reported in literature on neutron interaction with nuclei of Bismuth and Lead in the energy range up to 200 keV.

1. Using expression (2) from ref. [1] for the scattering amplitudes of neutrons on atoms, which accounts for the potential and resonance nuclear scattering, the neutron-electron interactions and the polarizability of the neutron within the Coulomb field of the nucleus are as follows:

$$y=\frac{\sigma_{tot}(E')}{4\pi}-b^2_{coh}(E)\left(\frac{A}{A+1}\right)^2=a^2(Z^2-2ZF)-2ab_{coh}(Z-F)-f^2-2aFf-$$

$$-\frac{2}{3}\pi k'Rb_{coh}f+\left(\sum_i\frac{\Gamma_{ni}\Delta E_i}{k(\Delta E_i^2+\frac{\Gamma_i^2}{4})}-\sum_i\frac{\Gamma_{ni}\Delta E_i'}{k'(\Delta E_i'^2+\frac{\Gamma_i^2}{4})}\right)\times[b_{coh}-a(Z-F)-$$

$$-\frac{\pi}{3}k'Rf]+\frac{1}{4}\left(\sum_i\frac{\Gamma_{ni}\Delta E_i}{k(\Delta E_i^2+\frac{\Gamma_i^2}{4})}\right)^2-\frac{1}{2}\sum_i\frac{\Gamma_{ni}\Delta E_i}{k(\Delta E_i^2+\frac{\Gamma_i^2}{4})}\sum_i\frac{\Gamma_{ni}\Delta E_i'}{k(\Delta E_i'^2+\frac{\Gamma_i^2}{4})}+$$

$$+\frac{1}{4}\sum_i\frac{\Gamma_{ni}^2}{k'^2(\Delta E_i'^2+\frac{\Gamma_i^2}{4})}+\frac{\Gamma_\gamma}{4k'}\sum_i\frac{\Gamma_{ni}}{k'(\Delta E_i'^2+\frac{\Gamma_i^2}{4})}, \qquad (1)$$

where $f=\frac{M\alpha}{R}\left(\frac{Ze}{h}\right)^2$, M - is the neutron mass, R is the radius of the nucleus, F is the atomic form-factor, α is the coefficient of electrical polarizability of the neutron, E and E' are the neutron energies at which b_{coh} and σ_{tot} are measured, a is the amplitude of neutron-electron interaction, $\Delta E_i=E-E_i$, $\Gamma_i=\Gamma_{ni}+\Gamma_\gamma$, E_i, Γ_{ni}, Γ_γ are the energy, neutron and γ-widths of i-th resonance.

The experimental values of b_{coh} and σ_{tot} reported in refs.[2,3,4] (see table 1) were used here to obtain a- and α-values with expression (1).

Table 1

Energy E′ in eV		1.26	5.19	10,1 (averaged over spectrum),
σ_{tot} in barns	Bi	9.2566 (42)	9.2830 (40)	9.2900 (76)
	Pb	11.2357 (45)	11.2554 (44)	—
		$\lambda \simeq 15$ Å	$\lambda \simeq 1,79$ Å	
b_{coh} in Fm	Bi	8.5256 (15)	8.5030 (120)	
	Pb	9.4003 (14)	—	

The value of σ_{tot} was corrected for the solid-state effects and the Doppler correction (ref. /5/) as well as for the Schwinger and incoherent scattering. Thus corrected values of σ_{tot} are summarized in Table 2.

Table 2

Energy in eV		1,26	5,19	10,1
σ_{tot} in barns	Bi	9,2525	9,2728	9,2782
	Pb	11,2371	11,2507	—

The effect of neutron scattering due to magnetical dipole moment and quadrupole electrical moment of Bismuth nucleus was also estimated. It appeared to be negligibly small.

The total contribution of the resonance scattering (including the effect of the resonances at negative energies) and of the capture was calculated using the known parameters of Bismuth and Lead resonances and their strength functions /6/. For the Bismuth it appears to be 10-15 per cent of y.

Least-square analysis of all data /2,3,4/ yields next results:

$$\alpha = (13 \pm 8)\ 10^{-42}\ cm^3 \quad (2)$$

$$a = (1.38 \pm 0.16)\ 10^{-16}\ cm^3. \quad (3)$$

The further measurements of the Bismuth total cross section in the eV range neutron energies would define the α-meaning more accurately.

2. Differential neutron scattering of the keV range neutrons on nuclei may be expressed as follows:

$$\sigma(\theta) = \frac{\sigma_s}{4\pi}\left[1 + \sum_{\ell=1}^{\infty} \omega_\ell P_\ell(\cos\theta)\right]. \quad (4)$$

Let's suppose that in the neutron energy region up to 200 keV only s - and p-scattering is essential. Using the expression (2) from the work /1/ , generalizing it for the p-wave scattering and averaging over the resonances we obtain the following*

* The effect of the neutron-electron interaction is negligibly small at energies above several hundred eV.

$$\omega_1 = \frac{6(\overline{ReS\,ReP + ImS\,ImP}) + 6\,Sin\,\xi_1\,\overline{ReS} + 6\,Sin\,\xi_0\,\overline{ReP}}{\overline{(ReS)^2 + (JmS)^2}}, \quad (5)$$

$$\omega_2 = \frac{6\,Sin^2\delta_1 + \pi\sqrt{E}\,S^1 V}{\overline{(ReS)^2 + (ImS)^2}}, \quad (6)$$

where E is the neutron energy in eV, ReS, ReP, ImS, ImP are real and imaginary amplitude parts of the s- and p-scattering, ξ_0 and ξ_1 are zero and first phase shifts of scattering caused by the electric neutron polarizability, S^0 and S^1 are s- and p- strength functions. $V = \frac{(kR)^2}{1 + (kR)^2}$, $R = 1.4\ A^{1/3}$ Fm

$$\overline{ReS\,ReP + ImS\,ImP} = Sin\,\delta_0\,Sin\,\delta_1\,Cos[\delta_0 - \delta_1 + 2\xi_0 - 2\xi_1] - \\ - \pi\sqrt{E}[S^0 Sin\,\delta_1 Sin(2\delta_0 - \delta_1 + 2\xi_0 - 2\xi_1) - S^1 V\,Sin\,\delta_0\,Sin(2\delta_1 - \delta_0 - 2\xi_0 - 2\xi_1), \quad (7)$$

$$\overline{ReS} = (1 - \pi\sqrt{E}\,S^0)\,Sin\,\delta_0\,Cos(\delta_0 + 2\xi_0) - \frac{\pi}{2}\sqrt{E}\,S^0\,Sin\,2\xi_0, \quad (8)$$

$$\overline{ReP} = (1 - \pi\sqrt{E}\,S^1 V)\,Sin\,\delta_1\,Cos(\delta_0 + 2\xi_1) - \frac{\pi}{2}\sqrt{E}\,S^1 V\,Sin\,2\xi_1. \quad (9)$$

For nuclear scattering phase shifts δ_0 and δ_1 we take the following expressions:

$$\delta_0 = -kR + arctg(kR\,R_0^\infty) \quad (10)$$

$$\delta_1 = -kR + arctg(kR) + arctg\left[\frac{(kR)^3 R_1^\infty}{1 + (kR)^2 + R_1^\infty}\right] \quad (11)$$

and phase shifts ξ_0 and ξ_1 were calculated in the first Born approximation:

$$\xi_0 = \frac{M\alpha}{R}\left(\frac{Ze}{\hbar}\right)^2 k\left\{\frac{Cos(2kR)}{3} + \frac{Sin(2kR)}{6kR} + \frac{1}{6(kR)^2}[1 - Cos(2kR)] - \frac{\pi}{3}kR\right\}, \quad (12)$$

$$\xi_1 = M\alpha\left(\frac{Ze}{\hbar}\right)^2 k^2\left\{\frac{\pi}{15} - \frac{Cos(2kR)}{15kR} - \frac{Sin(2kR)}{30(kR)^2} + \frac{1}{6(kR)^3}\left[1 + \frac{Cos(2kR)}{5}\right] - \frac{Sin(2kR)}{5(kR)^4} + \frac{1 - Cos(2kR)}{10(kR)^5}\right\}. \quad (13)$$

For the least-square analysis with the help of formulas (5) and (6) the experimental data ω_1 and ω_2 for lead obtained in /7,8/ in the energy range 500 eV-200 kV were used. R_1^∞, S^1 and α parameters were variated. The value of S^0 was taken from (6) and it influenced the fitting parameters weakly. Least-square analysis yields next results:

$R_1^{\infty} = 0.24 \pm 0.04,$
$S^1 = (0.3 \mp 0.2)\ 10^{-4},$
$\alpha = (6 \pm 3)\ 10^{-42}\ cm^3$.

To define α-meaning more accurately we have to make more precise ω_1 and ω_2. It should be noticed that investigation with low energy neutrons (eV range) is preferable because the uncertainty connected with the cutoff of the divergent integrals at calculating ξ phase shifts increases with neutron energy.

The author is grateful to V.G.Nikolenko, A.B.Popov and G.S.Samosvat for useful discussions.

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Received by Publishing Department
on December 13,1982.

Александров Ю.А. E3-82-849

Рассеяние медленных нейтронов на висмуте и свинце и электрическая поляризуемость нейтрона

В результате обработки опубликованных в литературе экспериментальных данных получены значения коэффициента электрической поляризуемости нейтрона: $/13 \pm 8/ \cdot 10^{-42}$ см^3 /электронвольтная область энергий нейтронов/ и $/6 \pm 3/ \cdot 10^{-42}$см^3 /килоэлектронвольтная область энергий нейтронов/.

Работа выполнена в Лаборатории нейтронной физики ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1982

Alexandrov Yu.A. E3-82-849

Slow Neutron Scattering on Bismuth and Lead and Electric Polarizability of the Neutron

Least-square analysis data published in literature yields the coefficient of electric polarizability of the neutron: $(13 \pm 8) \cdot 10^{-42}$ cm^3 (eV range of the neutron energies) and $(6 \pm 3) \cdot 10^{-42}$ cm^3 (kV range of the neutron energies).

The investigation has been performed at the Laboratory of Neutron Physics, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1982