сообщения
объединенного
института
ядерных
исследований
дубна

E4-91-106

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ON DIFFERENT VALUES OF THE NEUTRON-ELECTRON SCATTERING AMPLITUDE AND NEUTRON MEAN SQUARE CHARGE RADIUS OBTAINED FROM THE LOW-ENERGY DEPENDENCE OF THE SCATTERING AMPLITUDE

1991

The neutron-electron scattering amplitude a_{ne} is the fundamental physical quantity closely (within recent ideas) connected with the neutron mean square charge radius. That is why the a_{ne} values were frequently measured.

Recently two very precise though essentially different values ($-1.32(4)\ 10^{-3}$ fm [1] and $-1.59(4)\ 10^{-3}$ fm [2]) were obtained from the analysis of energy dependences of the amplitude for Bi [1,2] and Pb [1] nuclei. Their precision is only comparable with the value $a_{ne} = -1.30(3)\ 10^{-3}$ fm obtained by measuring angular scattering anisotropy of thermal neutrons from noble gases [4].

The results of refs. [1] and [2] differ by more than 20% within the accuracy of 3% and lead to the values with opposite signs for the neutron mean square charge radius: +0.12(2) fm and -0.11(2) fm, respectively. To explain such discrepancy we shall analyze the results of refs. [1,2].

In refs. [1,2] the (n,e)-amplitude is obtained thanks to much stronger dependence on energy E (in the range from E=0 to E=5-10 eV) of the electron shell atomic form-factor F (varying from Z to about zero) which leads to the variation of the interference term $\pi F a_{ne} a_N$ in σ_t from -260 to -23 mb (a_N is the nuclear scattering amplitude).

In both works [1,2] the same value of the coherent amplitude $a_{coh}(E_o)$ (scattering lengh at E_0=0) measured in [1] was used while at E > 1eV each team used their own data on the total cross section $\sigma_t(E)$ which are different. In ref. [1] absolute values for σ_t have been measured near E = 1 , 5, 18, 130 eV with an accuracy of about 4 mb. In ref. [2] just a relative behaviour of the energy dependence of $n\sigma_t(E)$ was measured with an accuracy of 10 mb, at 20 points in the interval from 1 eV to 30 eV (n - the number of nuclei in the sample). To obtain $\sigma_t(E)$ the authors of ref. [2] have normalized σ value to its value from ref. [1] at E=5 eV. This normalization to the value at 5 eV and the use of the $a_{coh}(0)$ value together with the fact that F varies essentially with energy from E=0 to E=5 eV only means that the authors of ref. [2] obtained, in fact, a_{ne} from the experimental data of ref. [1].

Thus it can be concluded that the a_{ne} values from [1] and [2] are different by 20% just because of different theoretical approaches used in [1] and [2].

It is the aim of this paper to call attention to the principal error made in ref. [2] when discribing the difference $Y=\sigma_t(E)/4\pi - a^2_{coh}(E_0)$, which led to the increased value of a_{ne} in [2]. Just a single glance at the relationship (1) in ref. [2] for the difference Y (fitted in ref. [2]) allows one to see the error in it. Indeed, if the incoherent scattering cross section value and the capture cross section value are assumed to be negligible, then the considered difference should tend to zero when E tends to E_0 , because in such conditions: $\sigma_t = \sigma_{coh}$. In contradiction to this according to equation (1) in ref. [2] the difference $\sigma_t(E)/4\pi - a^2_{coh}(E_0)$ is equal to the sum of resonance corrections

$$P_2 = R^2\{ [\sum_i \gamma_i^2 /(E_0-E_i)]^2 - 2 \sum_i \sum_j \gamma_j^2\gamma_i^2 /(E_0-E_j)(E-E_i) + \sum_i [\gamma_i^2 /(E-E_i)]^2 \} , \qquad \gamma^2=\Gamma_n/2kR \qquad (1)$$

(R is a channel radius) which is estimated in ref. [2] to be equal to -29 mb. Thus the energy differential of the interference term $8\pi a_{ne}a_N$ [F(E) - F(E_0)] being before this correction equal to -230 mb between the points E=0 eV and 5 eV, is increased by -29 mb and, consequently, the a_{ne} value is increased by 13% because

$$a_N [F(E) - F(E_0)] \Delta(a_{ne}) = \Delta(p_2) .$$

Below we shall discuss the resonance correction more carefully and on better justified grounds.

It should be noted that the works discussed here had one more aim , i.e. to extract the scattering amplitude arising due to the electric polarizability of the neutron in the Culomb field of the nucleus. In our analysis for the sake of simplicity we take it equal to the polarizability of the proton in order to estimate its contribution to σ_t which is smaller than 1 mb at E < 100 eV and, thus, its effect on a_{ne} is small (in comparison with 260 mb) Terefore, in the analysis to follow we neglect this contribution.

In ref. [3], where the formulas used in ref. [2] were derived, to describe nuclear interaction, S-matrix was taken in the form (single resonance approach):

$$S = [1 - \sum i\Gamma_n/(E-E_j + i\,\Gamma_j/2) \exp(2i\delta_{pot}) . \qquad (2)$$

It means that the nuclear amplitude is

$$f_N = f_{pot} + \sum f_j^{res} + 2ikf_{pot} \sum f_j^{res} , \qquad (3)$$

where f_j is the amplitude of some neutron compound resonance.

The application of the optic theorem to so incorrectly constructed amplitude (by summation of the amplitudes of single resonances) in order to derive an expression for σ_t (as it was just done in ref. [2]) leads obviously to the loss of inter-resonance interference terms.

Generally speaking, in order to take into account the interference between two processes with amplitudes f_1 and f_2 , one should use the sum amplitude of the form

$$f = f_1 + f_2 + 2ikf_1 f_2 , \qquad (4)$$

which is obtained not by taking summation over single amplitudes, but by taking the product of the coresponding S_1- and S_2-matrices, i.e. by taking summation over phases δ_1 and δ_2 in the case of pure scattering. The application of the optic theorem to the so constructed (4) amplitude in order to derive an expression for σ_t leads to the interference term $8\pi f_1 f_2$.

On the contrary, in ref. [1] (where, though the amplitudes of "single processes" were summed up, but the optical theorem was not used), σ_t is presented as the sum of the coherent cross section and the incoherent one: $4\pi a^2_{coh} + \sigma_{in}$, with $a_{coh}(E)$ taking into account the resonance contribution $\sum_j \Gamma_{nj} /k (E-E_j)$] as the addition to the sum of the nuclear potential and n-e amplitudes and, consequently, the expression for a^2_{coh} contains inter-resonance interference terms.

To estimate in a more consequent manner (than it was done by us before, i.e when we ?omitted the P_2 term) the error in the a_{ne} value determination due to omitting interference terms in refs. [2,5] , let us add to the amplitude f_N (2) the terms :

$$2ik \sum f_i^{res} \sum_j^{res} ,$$

necessary for the application of the optical theorem, like those in (4). Then in the expression for $\sigma_t/4\pi = \mathrm{Im} f_N /k$ the inter-resonance interference term appears:

$$d = R^2 \sum_i \sum_j \gamma_j^2 \gamma_i^2 /(E-E_j)(E-E_i), \quad i \neq j \qquad (5)$$

(here and further the values of d and P_2 are estimated under assumption that $\Delta E >> \Gamma = \Gamma_\gamma + \Gamma_n$).

Now in the expression $\sigma_t/4\pi - a^2_{coh}$ (fitted in ref. [2]) the resonance correction term P_2 must be added with the d term. This causes convolution of P_2 +d into the simple expression:

$$a^2 [R^{\infty}(E\ ) - R^{\infty}(E)]^2 = P + d , \qquad (6)$$

where $R^{\infty}(E) = \sum \gamma_i^2 /(E-E_i)$ is the background R-matrix which takes into account the contribution from far (from point E) resonances.

A numerical estimate of P_2 +d for a nucleus with the atomic number about that of Pb gives a value 30-50 times smaller than P_2=-29 mb used in ref. [2] . By taking into account this fact (by using P_2 +d instead of P_2 in relationship (1) from ref. [2]) we obtain with $a_{coh}(E_0)$ and σ_t at 5 eV from ref. [1] the corrected for resonance interference value of $a_{ne} = -1.36(6)\ 10^{-3}$ fm.

Thus, the account for resonance interference made here leads to the value of a_{ne} that does not contradict with its value from refs.[1] and [4]. In other words, from the viewpoint of the present work the values for $a_{ne} = -1.59(4)\ 10^{-3}$ fm and neutron mean square charge radius -0.11(2) 10^{-3} fm reported in ref. [2], are erroneous.

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Received by Publishing Department
on February 26, 1991.