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ON DISCREPANCY BETWEEN THE GARCHING AND DUBNA RESULTS OF DETERMINATION OF THE (*ne*)-SCATTERING LENGTH ON BISMUTH

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1.Introduction

In the last time widely discussed [1-8] is the question of what the mean square radius of the neutron related to the electric charge distribution inside the neutron

$$< r_{in}^2 >_N = 6(dF_1/dq^2)_{q^2=0} = \frac{3\hbar^2}{Me^2}(a_{ne} - a_F), \quad (1)$$

is actually equal to. In eq.(1) a_{ne} is the measurable scattering length of a slow neutron on an electron (ne-interaction), $a_F = \mu_n \frac{e^2}{2Mc^2} = -1.468 \times 10^{-3}$ fm the Foldy scattering length related to a free neutron satisfying the Dirac equation and exhibiting an anomalous moment μ_n, F_1 is the Dirac form factor.

From the Table of experimental data given in [4] it follows that most accurate experiments can be divided into two groups: the measurements [9,10] resulting in $< a_{ne} > = (-1.309 \pm 0.024) \times 10^{-3}$ fm , which leads to $< r_{in}^2 >_N > 0$ in contradiction with modern theoretical representations of the neutron, and the measurements [11-13] giving $< a_{ne} > = (-1.577 \pm 0.034) \times 10^{-3}$ fm) to lead to $< r_{in}^2 >_N < 0$ in confirmation of modern ideas of the neutron.

Earlier in [5,6] the possibility was noted of errors now present in [9]. The reasons for them to arise are mainly the following: 1) very weak asymmetry of neutron scattering on noble gases in comparison with strong symmetry of neutron-nuclear interaction (so in [9] a half per cent asymmetry effect of (ne)-interaction is measured with an error $\pm 2.5\%$); 2) because the effect under measurement is so weak, experimentalists must be absolutely sure that no side effects affect it (e.g., the ones due to weak p-resonances, admixtures of light gases, etc.); 3) large values of corrections introduced in the experiment. So the neutron energy-dependent correction for scattering asymmetry caused by gas thermal motion exceeds the measured effect for xenon by a factor of 4, for crypton — of 10, etc.

A more promising methodical direction in (ne)-interaction study is the applied in Dubna method of thermal neutron diffraction on tungsten-186 crystals [12]. In this case the sought-for effect reaches the value of 20% and as a result we obtain $a_{ne} = (-1.60 \pm 0.05) \times 10^{-3}$ fm. Note that this value is in agreement with the result reported in an earlier work [11] and has not been an object of criticism as yet.

2. Comparative Description of Experiments Carried out at Garching and Dubna

The main discussion centers around the results of the Garching experiment [10] and the Dubna one [13]. The data obtained in them for the energy

dependence (from 1 to 100 eV) of the total cross section σ_{tot} of bismuth practically coincide. However, different data treatment gave a difference of not more than 1.5 uncertainty in values for $a_{ne} = (-1.32 \pm 0{,}04) \times 10^{-3}$ fm [10] and $a_{ne} = (-1.55 \pm 0.11) \times 10^{-3}$ fm [13]. Therefore, strictly speaking one should look for contradictions between the works [10] and [11,12] and not between [10] and [13]. Nevertheless, strangely enough the discussion mainly goes around the latter two works.

First note that some discrepancy between the result of [10] and [13] comes from different methods of data treatment. With formulas (1), (2) and (5) in [10] one can obtain for the s-wave nuclear interaction (at $e(k) = 1$, $\Delta E >> \Gamma/2$ and $R = (sin\delta_o)/k$) :

$$\frac{\sigma_{tot}}{4\pi} =$$

$$= \frac{\sigma_{coh} + \sigma_i + \sigma_{n\gamma}}{4\pi} = \frac{\sin^2\delta_o}{k^2} - \frac{\sin\delta_o}{k^2}\left[\sum_+ \frac{g_+\Gamma_n\Delta E}{\Delta E^2 + \Gamma^2/4} + \sum_- \frac{g_-\Gamma_n\Delta E}{\Delta E^2 + \Gamma^2/4}\right] +$$

$$+ \frac{1}{4k^2}\left[\sum_+ \frac{g_+\Gamma_n\Delta E}{\Delta E^2 + \Gamma^2/4} + \sum_- \frac{g_-\Gamma_n\Delta E}{\Delta E^2 + \Gamma^2/4}\right]^2 + \frac{\sigma_i}{4\pi} + \frac{\sigma_{n\gamma}}{4\pi}, \quad (2)$$

where σ_i is the nuclear incoherent cross section, $g_{+-} = \frac{2J+1}{2(2I+1)}$ (in [10] they do not write g_{+-}in their formulas), $J = I \pm 1/2$, $I = 9/2$ (for Bi), $\Delta E = E - E_{oj}$.

From [13] it follows that

$$\frac{\sigma_{tot}}{4\pi} =$$

$$= \frac{\sin^2\delta_o}{k^2} - \frac{\sin\delta_o}{k^2}\left[\sum_+ \frac{g_+\Gamma_n\Delta E}{\Delta E^2 + \Gamma^2/4} + \sum_- \frac{g_-\Gamma_n\Delta E}{\Delta E^2 + \Gamma^2/4}\right] +$$

$$+ \frac{1}{4k^2}\left[\sum_+ \frac{g_+\Gamma_n^2}{\Delta E^2 + \Gamma^2/4} + \sum_- \frac{g_-\Gamma_n^2}{\Delta E^2 + \Gamma^2/4}\right] + \frac{\sigma_{n\gamma}}{4\pi} . \quad (3)$$

The first two and the last term in eqs.(2) and (3) coincide, while the others are different. The first reason for this difference is the fact that eq.(3) was derived on the basis of a generally accepted S-matrix of scattering

$$S_{nn} = (1 - i\sum \frac{\Gamma_n}{\Delta E + i\Gamma/2})exp(2i\delta_{pot}) \quad (4)$$

which does not take into account small inter-resonance interference. However, as it will be shown below the taking into account of this phenomenon cannot influence the result of a_{ne} determination in [13]. An attempt of taking into account the inter-resonance interference has been undertaken in [1]. As shown in [2] that cannot be considered correct. Meanwhile there are the long known S-matrices accounting for this phenomenon of inter-resonance interference (e.g., see refs.[14-16]). Based on them calculations of $\frac{\sigma_{tot}}{4\pi}$ were performed in [5]. The calculations have shown that with the known resonances $0 < E_{oj} < 265 keV$ being taken into account [17], the additional inter-resonance interference term in eq.(3) for bismuth at the energy about 10 eV makes $\frac{\Delta\sigma_{int}}{4\pi} = 0.0086 \times 10^{-24} cm^2/ster$ (the total cross section of bismuth at this energy is $\frac{\sigma_{tot}}{4\pi} = 0.74 \times 10^{-24} cm^2/ster$, i.e., nearly 90 times larger). It is very important, however, that at energies below 50 eV the value of $\frac{\Delta\sigma_{int}}{4\pi}$ does not practically depend on energy.

For example, so does the calculated with S-matrix [15] inter-resonance interference term

$$\frac{\Delta\sigma_{int}}{4\pi} \simeq \frac{g}{4k^2} \times \frac{\Gamma_{1n}(\Gamma_2\frac{\Delta E_1}{\Delta E_2} + \Gamma_3\frac{\Delta E_1}{\Delta E_3} + ...)}{\Delta E_1^2 + \frac{1}{4}(\Gamma_1 + \Gamma_2\frac{\Delta E_1}{\Delta E_2} + \Gamma_3\frac{\Delta E_1}{\Delta E_3} + ...)^2} +$$

$$+\frac{g}{4k^2} \times \frac{\Gamma_{n2}(\Gamma_1\frac{\Delta E_2}{\Delta E_1} + \Gamma_3\frac{\Delta E_2}{\Delta E_3} + ...)}{\Delta E_2^2 + \frac{1}{4}(\Gamma_2 + \Gamma_1\frac{\Delta E_2}{\Delta E_1} + \Gamma_3\frac{\Delta E_2}{\Delta E_3} + ...)^2} +$$

$$+\frac{g}{4k^2} \times \frac{\Gamma_{3n}(\Gamma_1\frac{\Delta E_3}{\Delta E_1} + \Gamma_2\frac{\Delta E_3}{\Delta E_2} + ...)}{\Delta E_3^2 + \frac{1}{4}(\Gamma_3 + \Gamma_1\frac{\Delta E_3}{\Delta E_1} + \Gamma_2\frac{\Delta E_3}{\Delta E_2} + ...)^2} + ... \qquad (5)$$

Far from the resonance exp.(5) does not practically change with energy.

In the Dubna work [13] to find the value of a_{ne} we analysed the value of $Y = \frac{\sigma_{tot}(E)}{4\pi} - a_{coh}^2$, where a_{coh} is the coherent scattering length. The expression for Y has an energy-independent term p_2, that can be varied to achieve the best of experimental data description. Since p_2 does not depend on energy, by introducing a constant term $\Delta\sigma_{int}$ one cannot affect the result of a_{ne} determination in [13] as well, though will somewhat change the analytical expression for p_2.

So, $a_{ne} = (-1.55 \pm 0.11) \times 10^{-3}\ fm$ and $< r_{in}^2 >_N < 0$. What kind of error does come into [10]?

Let us compare the formulas (2) and (3) taking into account the resonances with the energy $E_{oj} > 0$ and the additional inter-resonance interference term (5):

$$\frac{1}{4k^2}[\sum_{+} \frac{g_+\Gamma_n\Delta E}{\Delta E^2 + \Gamma^2/4} + \sum_{-} \frac{g_-\Gamma_n\Delta E}{\Delta E^2 + \Gamma^2/4}]^2 + \frac{\sigma_i}{4\pi} =$$

$$= (0.0113 + 0.0006)10^{-24}\ cm^2/ster = 0.0119 \times 10^{-24}\ cm^2/ster. \qquad (6)$$

$$\frac{1}{4k^2}[\sum_{+} \frac{g_+\Gamma_n^2}{\Delta E^2 + \Gamma^2/4} + \sum_{-} \frac{g_-\Gamma_n^2}{\Delta E^2 + \Gamma^2/4}] + \frac{\Delta\sigma_{int}}{4\pi} =$$

$$= (0.0029 + 0.0086)10^{-24}\ cm^2/ster = 0.0115 \times 10^{-24}\ cm^2/ster. \qquad (7)$$

Thus, if the contribution of the term $\frac{\Delta\sigma_{int}}{4\pi}$ is taken into account (formula (5)), expressions (2) and (3) give practically like results (at $E_{oj} > 0$).

Still there is some difference between works [10] and [13] in approach to calculation of the contribution of negative energy resonances ($E_{oj} < 0$) into the total cross section. In [10] this contribution of one bound and of missed levels has been calculated using the average parameters of s-wave scattering: the strength function, S_o=0.65±0.15, and the mean level distance $<D_o>$= 4.5± ±0.6 keV [17]. In this situation I think an error may easily crawl into, since a resonance at $E_{o1} < 0$, for example, may be at a distance $| E_{o1} | << D_o >$ from the point $E = 0$ and it will hardly be possible to estimate its influence on the term b_R with good accuracy, because uncertainty in determination of S_o is large (of the order of ±23%).

In [13] we have used a more realistic method consisting in variation of the parameter p_2, in particular. This is the main reason for discrepancy between the results of Garching and Dubna. Treatment of the experimental data of [10] taking into account the parameter $p_2 = -0.0023 \times 10^{-24}\ cm^2/ster$ found in [13] by the least square method will lead to a 1.2 times increase of the absolute value of a_{ne}, i.e. to $a_{ne} = -1.58 \times 10^{-3}\ fm$.

3. Conclusions

Thus to my thinking the values of a_{ne} obtained in [9, 10] are not grounded enough and consequently the actual $< r_{in}^2 > < 0$. This conclusion is in agreement with measurements [11, 12, 13] and with the modern ideas of the inner structure of the neutron [6, 18, 19, 20].

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