CALCULATION OF CORRECTIONS FOR PRECISE OBTAINING THE n,e-SCATTERING LENGTH FROM THE ANGULAR ANISOTROPY OF SLOW NEUTRONS SCATTERED BY NOBLE GASES

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For the precise measuring the angular anisotropy of neutrons scattered by noble gases in energy region from a few meV up to 1 eV with use of time-of-flight method it is necessary to know all corrections with the accuracy not worse than of 10^{-4}. Only in this case one can assure obtaining the n,e-scattering length $b_{\rm ne}$ with the accuracy 2 − 3 %. The corrections for efficiency difference of detectors, which register slow neutrons scattered forward or backward, with taking into account the thermal motion of Ar is calculating by Monte Carlo method in real geometry.

1. Introduction

As we noted more than once (see, for example [1]), a necessity of measuring the n,e-scattering length is still kept, as a dispersal of a number of obtained by this time b_{ne} values is several times more than their uncertainties. Thus, an accuracy of corrections in precision experiments is open to question. From the point of view of corrections clarity the experiment with measuring the angular anisotropy of slow neutrons scattered by noble gases is the most easily understood. The b_{ne} value extraction from a neutron scattering anisotropy, when neutrons elastically scattered by noble gases forward and backward, was done by Krohn and Ringo a long time ago [2]. But as these experiments were carried out at the reactor using thermal neutron beam, the authors had to average all energy dependent corrections and atom form-factor over whole neutron spectrum. Application of the time-of-flight method [3] allows exact corrections introducing at certain neutron energies.

The success of b_{ne} value extraction is determined by the accuracy of obtained intensities ratio at neutrons scattering forward ($\theta_1 \sim 45^0$) and backward ($\theta_2 \sim 135^0$). Of course, the correction for the thermal motion of gas atoms is the largest one in this experiment, but it must be calculated in case of noble gas sample absolutely correctly for each certain neutron energy [4]. Seemingly, the main difficulty in this experiment is the correct calculation of the energy loss at scattering of a neutron: it is necessary to know the counters efficiencies ratio with the accuracy $\sim 10^{-4}$ in order to obtain b_{ne} value with systematic uncertainty notably less than statistical one.

2. Setting of experiment and geometry for calculations

The experimental installation represents the turn-table and fixed on it the chamber with gas Ar and four ^{3}He-counters (with gas pressure 8 at and sizes Ø3×18 cm). Neutron counters are placed at the angles 45^0 and 135^0 relative to the beam axis at the distance 30 cm from the center of working volume, where neutrons are scattered. The scattering volume is confined by cadmium (or boron polyethylene) collimators, which also restrict the scattering angles range. Using the Monte Carlo method the calculations of the neutron scattering anisotropy were carried out taking into account thermal motion of gas atoms for argon in geometry, which is shown in Fig.1.

The chamber, in which neutrons are scattered, is a double cross of collimators. They form neutron beam and windows in the directions of detectors. Four collimators with detectors at the ends (in the boron polyethylene shielding), where neutrons come after scattering, and collimators for neutron beam passing before scattering are disposed cross-wise. Turning at 45^0 the turn-table allows to use for measurements all possible positions of each detector with respect to neutron beam.

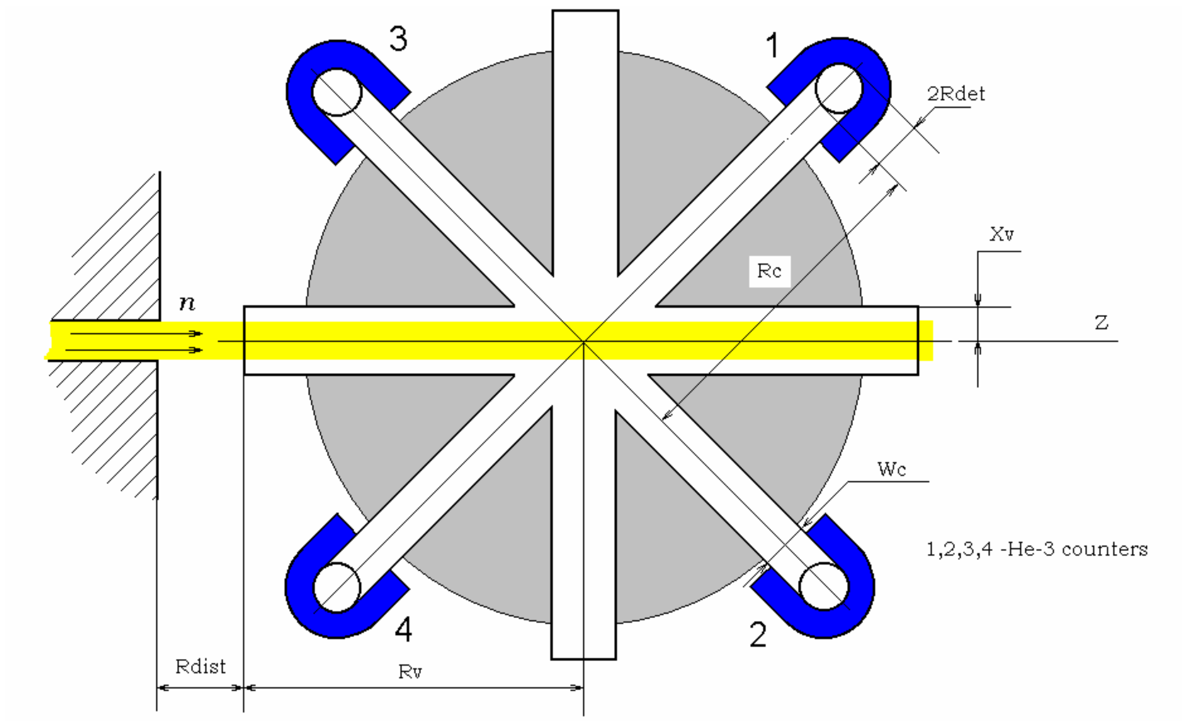

Fig.1. Scheme of the installation for calculating the neutron scattering (view from above).
1, 2, 3, 4 – detectors in shielding at the ends of collimators on the tern-table.

Width of collimators slit before detector Wc and diameter of the detector $2R_{det}$ are equal to 3 cm, height of counters inlets is 18 cm, and the height of collimators slits and neutron beam is the same. Width of collimators for neutron beam is 2Xv=3 cm, their length is Rv=30 cm, length of collimators from the centre of installation to the slit is Rc=30 cm.

For each of four counters a measuring anisotropy of neutrons scattered at angles θ_1 and θ_2 is determined as a ratio of scattering intensities $I(E,\theta)$:

$$R(E) = \frac{\sigma(E,\theta_1)}{\sigma(E,\theta_2)} = \frac{I(E,\theta_1)}{I(E,\theta_2)} C(E),$$

where $I(E,\theta)$ are the scattering intensities of neutrons. The correction coefficient $C(E) = \varepsilon(\theta_2)/\varepsilon(\theta_1)$ for efficiency variation of neutron registration at different angles is indispensable to extract the b_{ne} value. The motion of turn-table changes positions of detectors, and intensities ratio is obtained from the ratio of counts of neutrons scattered forward ($\theta_1 \sim 45^0$)

and backward (θ_2~ 135^0), which are measured alternately at turning the installation relative to the beam axis. This ratio is calculated by the formula of the geometrical mean

$$R = \left(\frac{N_{1f} N_{2f} N_{3f} N_{4f}}{N_{3b} N_{4b} N_{1b} N_{2b}} \right)^{1/4},$$

where N are corrected counts, numbers determine counters, and counters positions (at forward or backward scattering) are indicated by letters f and b.

3. Results of calculations

The ratio of counter efficiencies for neutrons scattered backward and forward is dependent on energy of incident neutron and real scattering angular distributions, which are complicated by thermal motion of gas atoms. It must be calculated carefully to have a possibility to correct experimental results at each point of investigated energy range. For that the Monte Carlo calculations were carried out at initial energy of neutrons from 0.001 eV to 1 eV for argon pressure 10 at. The capture cross section was presumed to be zero to reduce a counting time. Addition individual calculations showed that influence of capture can be neglected for argon. These calculations in above-mentioned geometry allowed to obtain the angular distributions of neutrons scattered into forward and backward detectors and efficiencies of their registration with taking into account thermal motion of gas atoms.

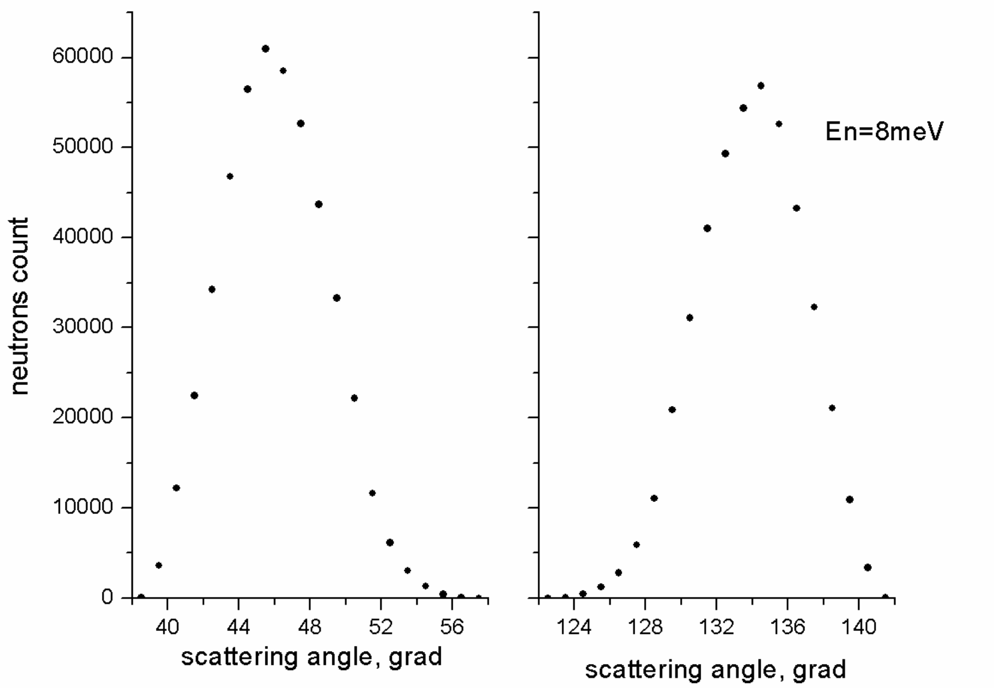

Fig.2. The calculated angular distributions of neutrons with initial energy 8 meV scattered by argon forward (left picture) and backward (right picture) taking into account registration efficiency of counters (one run for ~10^{11} neutrons falling into the target)

With the purpose to determine the correction coefficient $C(E)$ with the adequate accuracy it is necessary to carried out a multiple calculations for each energy point (the higher neutron energy the more statistics of events is required). Gradual "rise of statistics" is realized by averaging-out of independent calculations, which imitate separate measurements, with computation of random uncertainty of their arithmetic mean. Bit by bit this uncertainty is made more exact.

The angular distributions of neutrons with initial energy 8 meV for one of the calculations are shown in Fig.2. The statistics was 6×10^{10} of incident neutrons into scattered volume. As Fig.2 illustrated the limited by detectors slits dispersions of angles in given geometry after forward and backward scattering are $38^0\div 58^0$ and $122^0\div142^0$, correspondingly.

The scattering anisotropy dependence on neutron energy $R(E)$ for argon is shown in Fig.3. Here the results of calculating the $R(E)$ without taking into account of the efficiencies of neutrons registration and after introducing of these corrections are shown by the black and open points, correspondingly. In all calculations the effect of n,e- scattering was taken into account, and it was of opinion that $b_{ne}= -1.32\cdot10^{-3}$ fm. Effect induced by n,e-scattering is apparent in the Fig.3 as a evident depression of revised (open) points relative to $R(E)$=1.07 what must be at b_{ne}= 0 in the concerned neutron energy region.

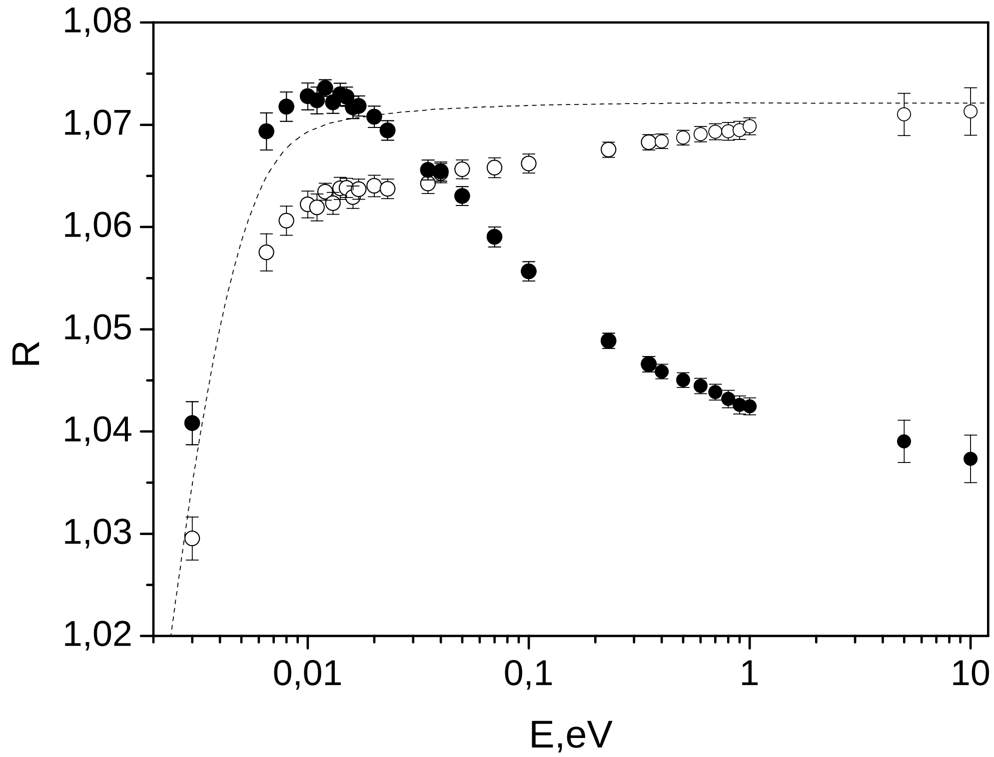

Fig.3. The neutron scattering anisotropy dependence on their incident energy with taking into account thermal motion of argon atoms (scattering length of n,e- interaction is $b_{ne}= -1{,}32\cdot10^{-3}$ fm): open circles are calculations with correction for efficiency, black circles are the calculations without these correction. Dashed curve is anisotropy calculation without taking into account n,e-scattering.

At last, the calculations of the energy dependence for correction coefficient $C(E)$ is shown in Fig.4. For comparison a rough count of $C(E)$ without taking into account thermal motion of argon atoms is illustrated by a dashed curve. In this case a counter efficiency was calculated as multiple integral by working scattering volume and by volume of counter, and the energy losses for neutrons scattered forward and backward were determined exactly at the angles 45^0 and 135^0 (without angular dispersal), i.e. the neutron energy E_{ns} after scattering was found from a simple expression $E_{ns} = E_n(40+\cos\theta)^2/(40+1)^2$, where θ is a scattering angle, and E_n is the initial neutron energy. Taking into account the thermal motion the energy distributions of neutrons scattered backward shifts towards smaller energies at $E_n>0.025$ eV and towards bigger energies at $E_n<0.025$ eV. The efficiency of ^{3}He-counter with gas pressure 8 at slumps with neutron energy increasing (from almost 100% at the neutron energies ~ meV up to somewhat more 15% at 10 eV), and hence at $E_n>0.025$ eV the counter efficiency of registration for neutrons scattered backward become higher. And vice versa, the counter efficiency for these neutrons become smaller at $E_n<0.025$ eV. This explain trend of curve $C(E)$ at these neutron energies below 1. The energy distributions of neutrons scattered forward shifts incidentally, and the efficiency of registration for neutrons scattered backward becomes slightly higher than for neutrons scattered forward at the energies more than 0.05 eV. As it is shown in our papers, to ensure an accuracy of the b_{ne} value 2 – 3% the energy region more than 0.1 eV is very important.

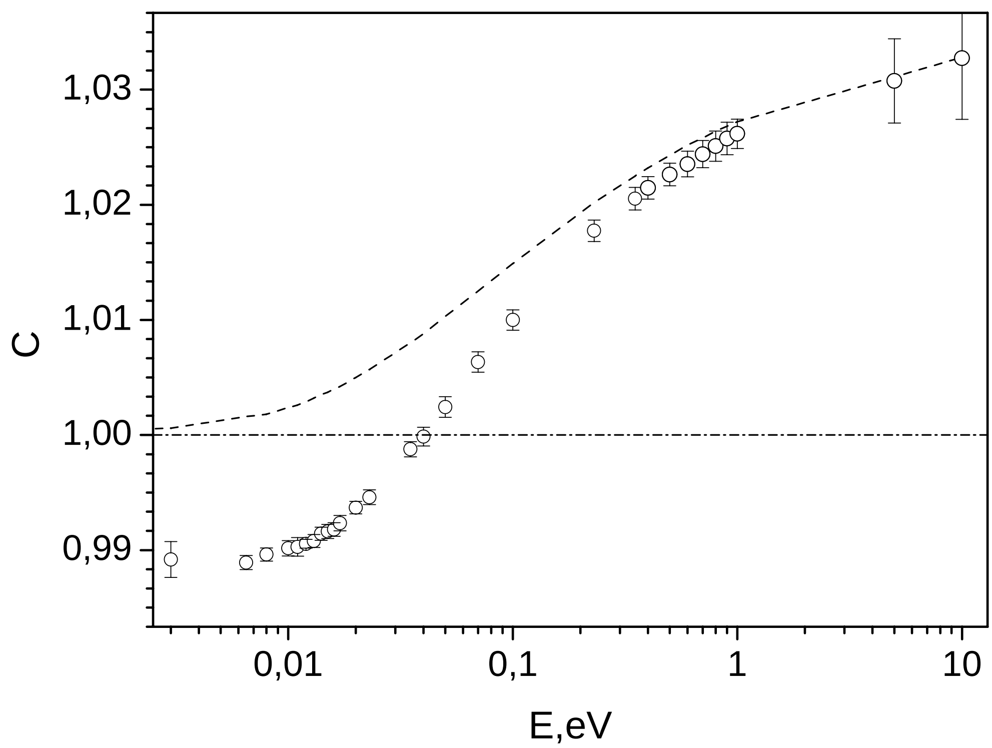

Fig.4. The corrections $C(E)=\varepsilon(135^0)/\varepsilon(45^0)$ obtained from Monte Carlo calculations for intensities of neutrons scattered forward and backward by argon. Dashed curve is raw count of *C(E)* without taking into account thermal motion of gas atoms.

Calculations showed that the introducing of corrections for efficiency variation is necessary in principle, if we use ^{3}He-counter with gas pressure 8 at as a detector. Parameterization of $C(E)$ values calculated in certain energy points by curve with adequate accuracy will allow correcting the desired quantity of $R(E)$ at any neutron energy. In order to improve an accuracy of these corrections calculations are still continued.

Conclusion

The bulky calculations in real geometry with taking into account the thermal motion of gas is urgent to reduce the uncertainty of correction coefficient $C(E)$ to required magnitude. Just accurate taking into account of these corrections allows obtaining the $R(E)$ values in the neutron energy region more than 0.1 eV.

References

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