The Angular Anisotropy of Slow Neutrons Scattering Measured at IREN Facility with Vanadium as a Sample

Enik T.L., Mitsyna L.V., Popov A.B., Salamatin I.M.

Frank Laboratory of Neutron Physics (FLNP) of Joint Institute for Nuclear Research (JINR), Joliot Currie 6, 141980 Dubna, Moscow region, Russia

For testing the AURA setup operation the angular anisotropy dependence on energy in the neutron elastic scattering by vanadium was measured using the time-of-flight method in the energy interval 0.005 – 10 eV at the neutron source IREN. The results obtained are compared with ones available in literature.

Introduction

The problem of n,e-scattering length b_{ne} precision and coupled with it the mean square charge radius of neutron continues to attract an attention of both experimentalists and theorists [1,2]. The idea to repeat the Krohn and Ringo experiment [3] using the time-of-flight method led to construction of the AURA setup [4]. In the present work the measurements of angular anisotropy of slow neutrons scattering for samples of metallic vanadium at the AURA setup were carried out.

Experiment

The AURA experimental installation (fig.1 and 2) represents the turn-table and fixed on it four ^{3}He-counters situated at the angles 45^0 and 135^0 relative to the neutron beam and turn-table axes.

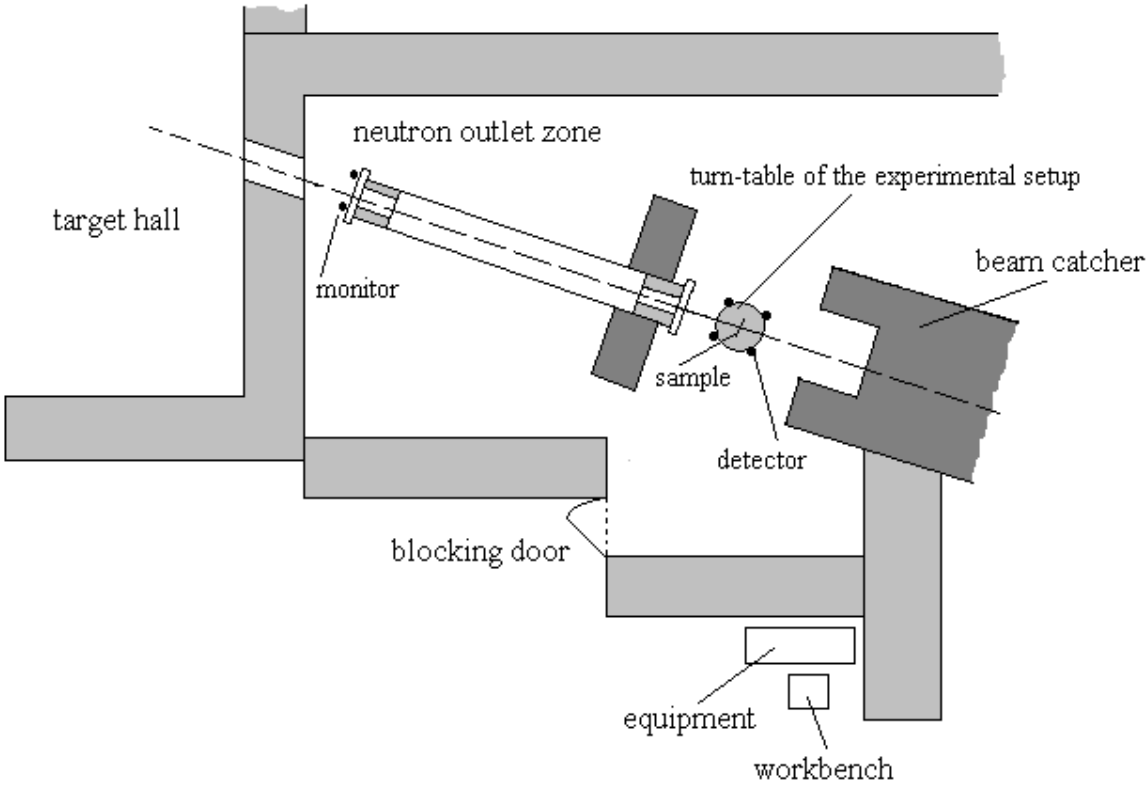

Fig.1. Scheme of the AURA setup location in the experimental hall of the IREN facility.

^{3}He-counters (with gas pressure 8 atm.) are surrounded by shields of borated polyethylene and covered by cadmium. The turn-table, which rotates at $\pm 180^0$ by a stepper motor, is situated at 15 m flight path from the neutron reproducing target of IREN. The 8 cm diameter of the neutron beam is formed by two collimators installed in the neutron guide of 7 m length and vacuum inside. The distance from the center of the turn-table to the detectors is 30 cm.

The electron accelerator during present measuring cycle worked with a tungsten target under such parameters: electron energy of 35 MeV, pulse duration of 200 ns, current in the pulse of 2.5 A and frequency of 25 Hz.

The AURA electronic module operates on a stepper motor, which rotates the turn-table with a given time exposition, and stores time-of-flight spectra received from eight-channel time-coder [5] through an USB-2 port. The time-coder records signals from 4 detectors and 2 monitor counters placed before a neutron guide. Fig.3 shows the program menu for experiment control and spectra accumulation.

As samples we used two plates of metallic vanadium with thicknesses ~0.45 and 2.5 mm ($3.3 \cdot 10^{21}$ cm^{-2} and $1.8 \cdot 10^{22}$ cm^{-2}). The vanadium plates were placed perpendicular to the neutron beam at the center of the turn-table.

Four runs of measurements were carried out: one run – with the thin sample and three others – with the thick sample of vanadium. Between the runs with samples three runs without vanadium in the beam were performed. Each of the runs continued for 20 – 40 expositions (time of one exposition was an hour) in each position of the turn-table.

Fig.2. The AURA setup view.

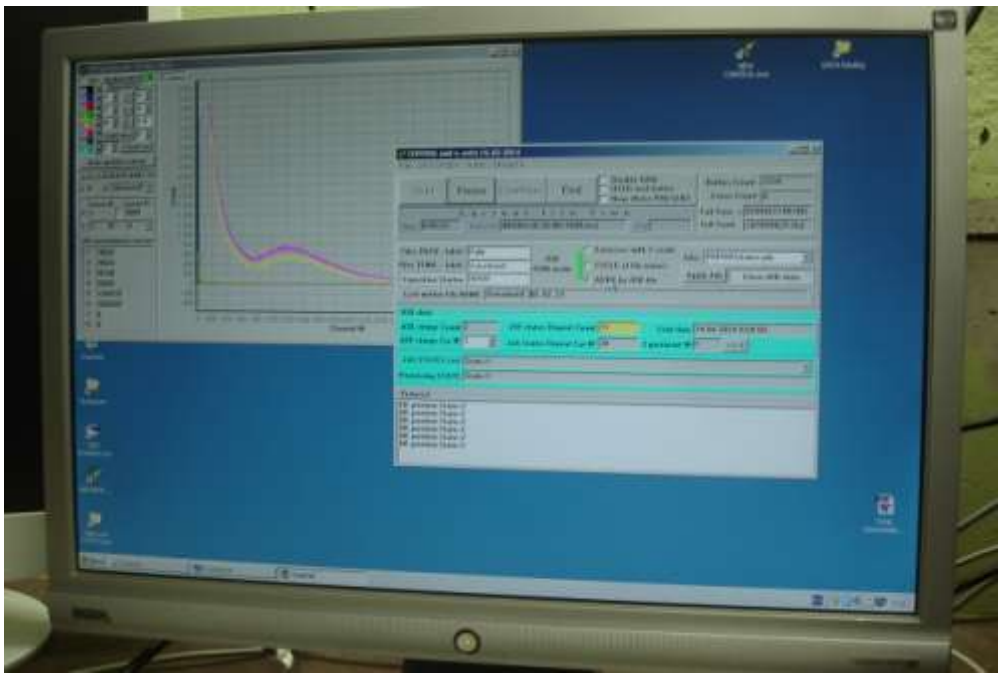

Fig.3. The display view with the control program menu.

Experimental data and analysis

Thus we had eight summarized spectra for each run – two for each detector (in two positions, when the neutron scattered forward and backward to this detector). For 10000 channels of time-coder scale we chose a channel width of 2 mcs. We supposed that the location of sample in the beam does not produce an additional background due to re-scattered neutrons and that background is created by neutrons, which are scattered by air before the sample and behind it only. So we took as background the spectra without the samples in the neutron beam. We obtained the desired scattering anisotropy of neutron scattering as an average geometrical value of the ratios of detectors counts "forward/backward":

$$R = \sqrt[4]{\frac{(N_s - N_{bg})_{2f}(N_s - N_{bg})_{3f}(N_s - N_{bg})_{1f}(N_s - N_{bg})_{4f}}{(N_s - N_{bg})_{1b}(N_s - N_{bg})_{4b}(N_s - N_{bg})_{2b}(N_s - N_{bg})_{3b}}}\ , \qquad (1)$$

where under root in the numerator are detectors counts (after background subtraction) in position of neutron scattering forward and in denominator are detectors counts in position "backward". Relative uncertainties were calculated as

$$\delta R = \sqrt{\sum_{1}^{8} \delta^2 (N_s - N_{bg})}\ . \qquad (2)$$

Naturally, during calculations of R and δR the normalization of all spectra were made for monitor counts in the interval from 700 to 2000 channel. So $\delta(N_s - N_{bg})$ was determined as

$$\delta(N_s - N_{bg}) = \frac{\sqrt{(N_s + c^2 N_{bg})}}{N_s - cN_{bg}},\ \text{where}\ c = \frac{M_s}{M_{bg}}.$$

Here M_s and M_{bg} are monitor counts in runs with the sample and without it (background), correspondingly.

The energies of neutrons after elastic scattering forward and backward are different, so it is necessary to correct the calculated ratios for the difference of efficiencies

$$R_{true} = R\frac{\varepsilon_b}{\varepsilon_f}.$$

The fig.4 shows that the efficiencies calculated by multiple integration for our ^{3}He-counters at a few energy points can be interpolated well enough by the indicated formula, that is more convenient for calculating, and we used this formula to correct the obtained results.

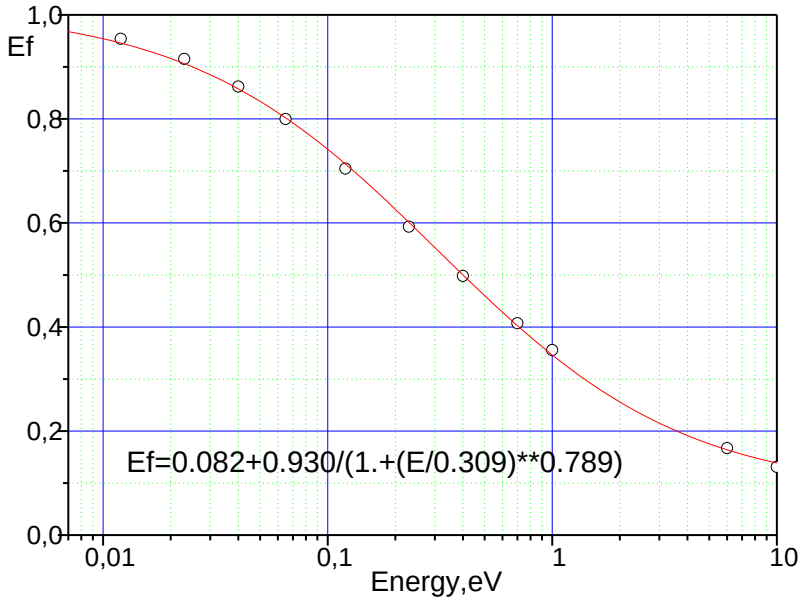

Fig.4. The calculated efficiencies (open points) and their extrapolation (line and formula) for our ^{3}He-counters.

Also it is necessary to take into account correction for neuron capture in the sample and secondary scattering, i.e. for difference of scattering probabilities forward and backward. This correction was introduced by formula from [6] for neutrons incident at right angle to the planar sample (β is an outgoing angle of neutron from the sample):

$$W_{backward} = \frac{\sigma_s}{\sigma_t}\frac{1-\exp[-n\sigma(1+1/\cos\beta)]}{1+1/\cos\beta},$$

$$W_{forward} = \frac{\sigma_s}{\sigma_t}\frac{\exp(-n\sigma_t/\cos\beta)-\exp(-n\sigma_t)}{1-1/\cos\beta}.$$

These formulae were verified by Monte-Carlo calculations. For thin vanadium sample this correction is negligible. The size of introduced corrections is indicated in the fig.5.

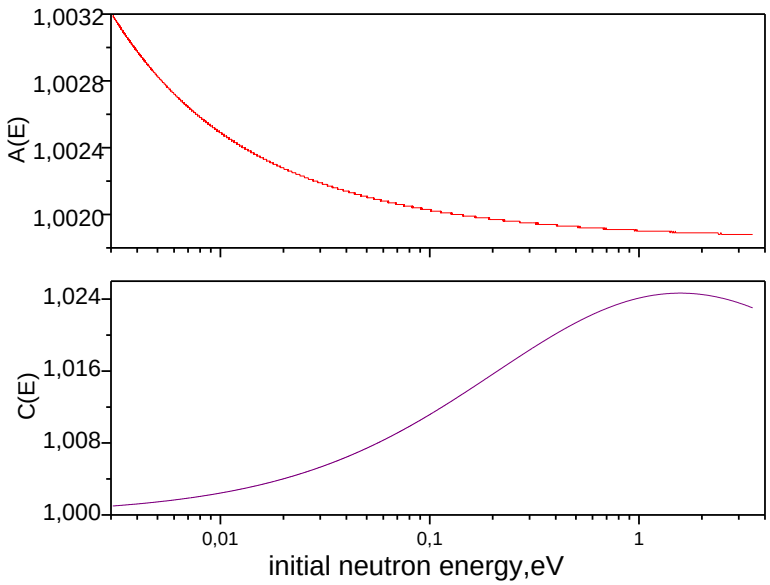

Fig.5. Corrections for energy loss of neutrons scattered by vanadium $A(E)=\varepsilon_b/\varepsilon_f$ (upper line) and for vanadium thickness $C(E)=W_{backward}/W_{forward}$ (bottom line).

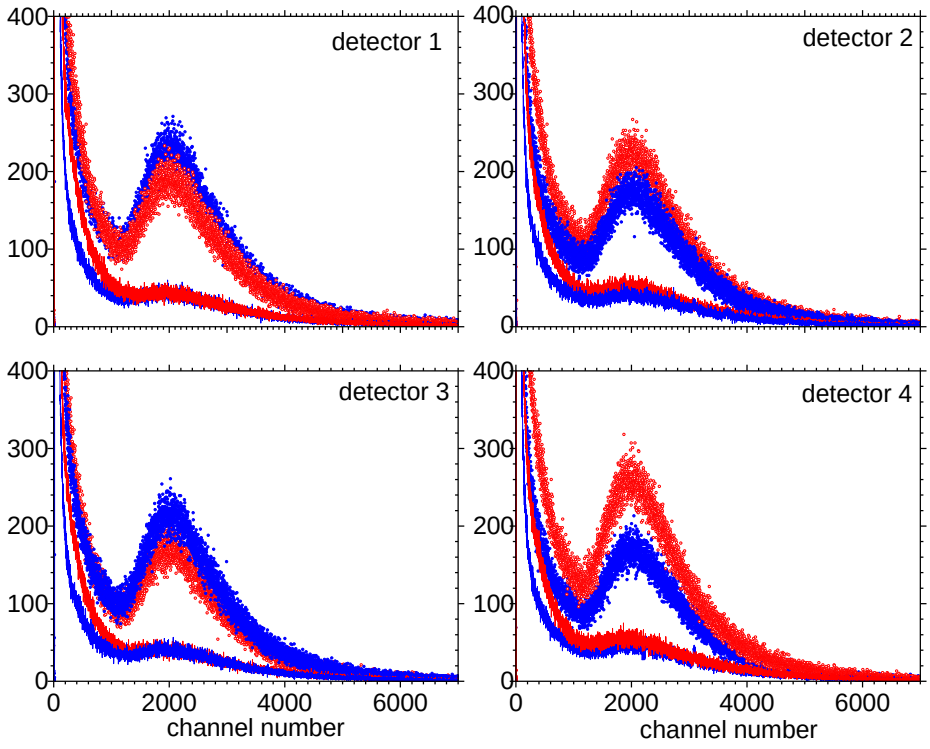

Fig.6. Time-of-flight spectra of neutrons scattered by thick vanadium forward (open points) and backward (solid points) recorded by all detectors. Exposure time is 46 hours. Spectra without the sample normalized by monitors are shown below.

At fig.6 spectra of neutrons recorded by each of four detectors at positions “forward” and “backward” are presented for one of runs with thick sample. The background spectra are also shown with normalization for monitors in the same figure. There was no perfect alignment of the turn-table performed relative to the neutron beam. All the samples were significantly bigger than the beam diameter for both turn-table positions. It is obvious that there is asymmetry of intensities of scattered neutron in spectra of all detectors and for each detector in different positions. We would like to make sure that the alignment inaccuracy allowed nevertheless the extraction of the right value of *R* using (1).

Results

Fig.7 shows *R*(*E*) values obtained for four runs (total exposure time was ~300 hours) after all necessary corrections. Calculations were carried out for 28 energy intervals in available range, and for each obtained value of R the mean energy of the corresponding interval was attributed.

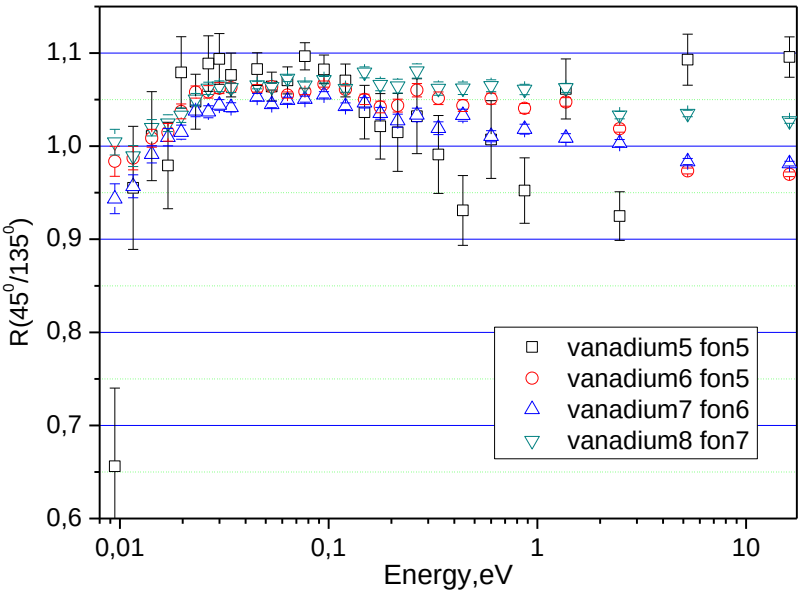

Fig.7. R(E) values obtained in 4 different runs: one run for thin sample (vanadium5) and three runs for thick sample (vanadium6, vanadium7 and vanadium8).

The weighed mean results of all 4 runs in each energy point are shown in fig.8. The results from [6] for middle scattering angles $R(30^0/150^0)$ are presented as well.

Conclusions

Theoretically calculated anisotropy of neutron elastic scattering at free nucleus ^{51}V: $R(30^0/150^0)$ =1.070 and $R(45^0/135^0)$ =1.057. Our data agree with them and do not contradict the result of [6] for energies below 0.2 eV. The drop in *R*(*E*) below 0.03 eV is a consequence of solid state effects and, as it is shown in [6], is in a good agreement with theoretical calculations in the framework of Gaussian approximation for multi-phonon cross-section description [7]. The *R*(*E*) reduction at energies higher than 0.2 eV is probably connected with

systematic errors of background evaluation at large neutron energies. These systematic effects are probably because of backgrounds which become different from spectra without the sample due to contribution of neutrons scattered from the sample after disseminating them by surround materials. Clearly, this problem requires some additional investigations and improvements of the detectors shieldings.

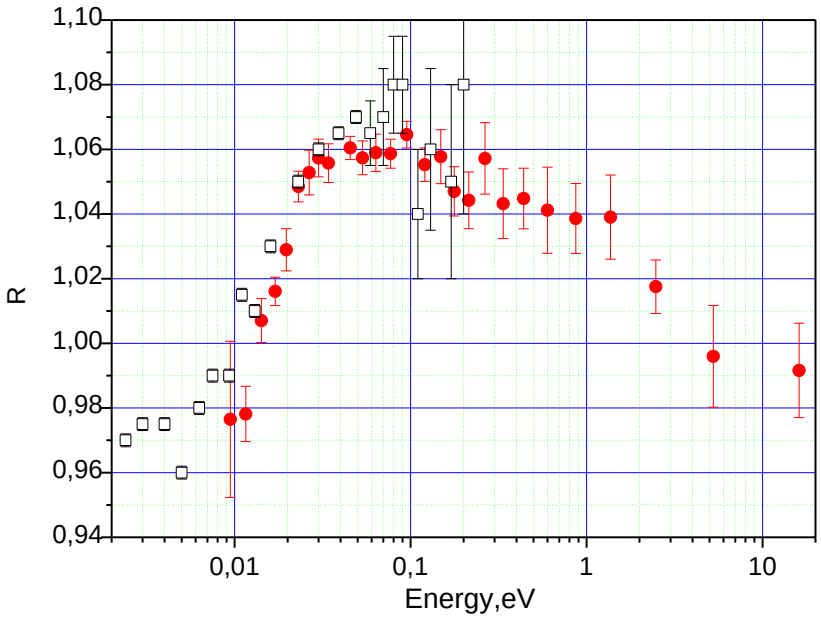

Fig.8. The weighed mean results $R(E)$ of present work (points) and data from [6] (open squares).

References

1. Popov A.B., Tretyakova T.Yu. In: Neutron spectroscopy, nuclear structure, related topics. XV Int. Seminar on Interaction of neutron with nuclei. Dubna, May 16 – 19, 2007, JINR E3-2008-26, p. 66; arXiv:0812.5019
2. Mitsyna L.V., Nikolenko V.G., Parzhitski S.S., Popov A.B., Samosvat G.S. Nucl. Phys., **A819**(2009)1.
3. V.Krohn, J.Ringo, Phys.Rev.,**D8**(1973)1305.
4. Enik T.E., Likhachev A.N., Mitsyna L.V., Popov A.B., Salamatin I.M., Sirotin A.P. In: Neutron spectroscopy, nuclear structure, related topics.XXI Int. Seminar on Interaction of neutron with nuclei. Alushta, Ukraine, May 20 – 25, 2013, JINR E3-2014-13, 2014, p. 227.
5. В.Н.Швецов, С.В.Алпатов, Н.В.Астахова et al., ПТЭ, №5, с.54(2012); Instruments and Experimental Techniques, **55,** No 5(2012)56.
6. Enik T.L., Jurin A.A., Kharjuzov R.V., Mitsyna L.V., Parzhitski S.S., Samosvat G.S. In: Neutron spectroscopy, nuclear structure, related topics. XI. Int. Seminar on Interaction of neutron with nuclei. Dubna, May 28 – 31, 2003, JINR E3-2004-9, 2004, p.20.