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STUDY OF STRUCTURE IN THE $^{27}Al(n,\alpha)$ REACTION CROSS-SECTION

N.V. Kornilov, A.B. Kagalenko, V.Ya. Baryba
Power Physics Institute, Obninsk

S. Daroczy, D. Csikai, Z. Papp, Zs. Schram
Power Physics Institute, Hungary

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The $^{27}Al(n,\alpha)$ reaction is widely used in reactor dosimetry and as a standard to determine the flux of monoenergetic neutrons. However, as Ref. [1] reveals, the accuracy of existing experimental data and evaluations is not high enough to meet the stringent requirements laid down for a standard of this kind.

At the IAEA meeting which took place in Gil in 1984, it was recommended that experiments with an accuracy level of 1-2% and a high energy resolution ~ 50 keV be carried out to assist in making a selection among existing cross-section evaluations, and to confirm the presence of the resonances in the 6-7 MeV energy region. This work was undertaken with a view to meeting those demands.

The cross-section of the $^{27}Al(n,\alpha)$ reaction was measured using the activation method in relation to the fission cross-section of ^{238}U. In order to meet the above requirements, it was necessary to do the following:

1. Detailed study of the neutron source to ensure a high level of accuracy for calculation of the neutron flux density distribution on the sample; in this way an energy resolution in the order of 50 keV can be achieved and a high level of accuracy for determining the mean neutron energy;

2. Measurement of the activity level of the irradiated samples to an accuracy of 1-2%;

3. Measurements of the speed of the fission reaction to an accuracy of 1-2%.

1. Description of experiment

The samples studied (aluminium discs 0.5 mm thick and 10 or 19 mm in diameter, chemical purity 99.99%) were mounted in a fission ionization chamber against a uranium tetrafluoride layer. The UF_4 layers used in the experiment were manufactured by the vacuum volatilization method in the V.G. Khlopin Radium Institute. Their major parameters are as follows:

- Accuracy for determination of the number of nuclei in the layer - 1%;
- Content of ^{238}U in relation to other isotopes - 99.999%;
- Homogeneity of the active layer - 2%;
- Thickness of the layer - 0.133 mg/cm^2;
- Diameter of the active layer - (18.95 + 0.01) mm.

The distance between the irradiated sample and the ^{238}U layer was determined to an accuracy of $\pm$ 0.1 mm.

A gaseous deuterium target in an EhGP-10M accelerator was used to obtain monoenergetic neutrons with an energy level of 7-9 MeV. The irradiated samples were mounted at an angle of 0° to the axis of the beam at a distance of (7.0 $\pm$ 0.1) cm from the butt end of the target. The maximum target-sample angle was 8.7°. The gas pressure in the target was 200 mm Hg. The diameter of the deuton beam was no more than 5 mm. The target entry window was made of molybdenum foil.

Two series of measurements were performed. In the first series, samples of diameter 19 mm were irradiated in twos, the thickness of the molybdenum foil was 6.45 mg/cm^2. In the second series, pairs of samples 10 and 19 mm in diameter were irradiated and, thanks to the use of homogenous molybdenum foil, a better energy distribution was achieved.

The cross-section of the $^{27}Al(n,\alpha)^{24}Na$ reaction was determined from the activity level of the ^{24}Na accumulated in the samples (T = 1/2 = 14.96 h, E_β = 1392 keV, E_{γ_1} = 1369 keV, E_{γ_2} = 2754 keV).

The task in hand - a detailed study of the structure in the $^{27}Al(n,\alpha)$ reaction cross-section - necessitates a very accurate knowledge of neutron source characteristics such as the energy distribution of the neutron flux and mean neutron energy at the point where the sample is located.

For the real beam-target-sample geometry, calculations taking into account the influence of the following factors were performed:

- Diameter of the charged particle beam;
- Energy losses in the entry window and deuton energy straggling after the window;
- Deuton angle straggling after the window;
- Deuton energy spread owing to inhomogeneity of the molybdenum foil in the entry window;
- Losses in incident deuton energy in the target gas;
- Reaction kinematics - dependence of neutron energy on the angle of emission.

The thickness of the molybdenum foil was determined experimentally: by weighing a square of given area and from α-particle transmission. The results tallied to an accuracy of ~ 1%. In the experiments with α-particles the inhomogeneity of the foils was also determined, and it was 0.45 mg/cm^2 for the first series and 0.1 mg/cm^2 for the second series of $\sigma_{n\alpha}$ measurements.

Deuton energy was measured from the flight time across the fixed portion of the ion guide. For these measurements the accelerator was working in a pulsed regime.

Measurement of the mean neutron energy and the distribution function in the experiments was based on transmission in the vicinity of the (6.293 $\pm$ 0.005) MeV resonance in the total carbon cross-section. The experimental transmission function was compared with the Monte Carlo calculation which incorporated all the above factors. The single variable parameter was deuton energy which coincided to an accuracy of 0.2% with the results of measurements based on time of flight. The calculated and experimental transmission functions showed a high level of agreement (Fig. 1), which confirms that the neutron flux distribution was calculated correctly. The details of the calculation and the methods for determining energies are

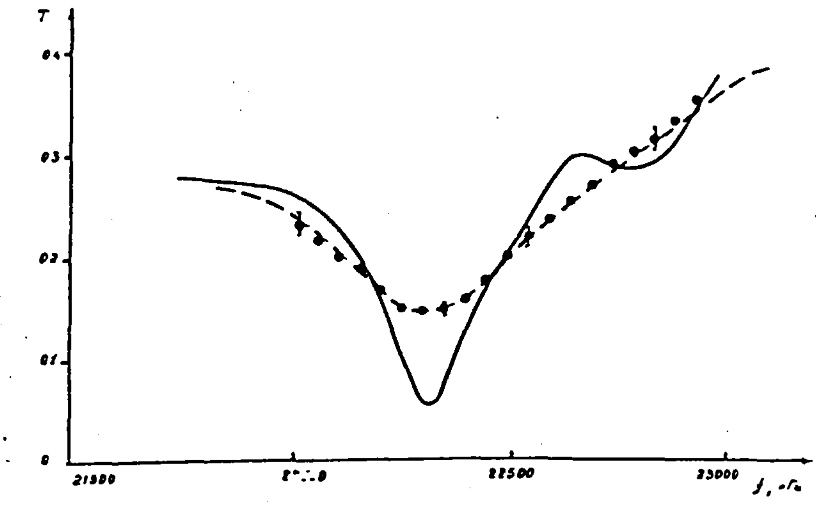

Fig. 1. Experimental (•) and theoretical (– – –) transmission function. The continuous line shows transmission for an ideal monoenergetic source. The total carbon cross-section is taken from ENDF/B-V.

analysed in greater depth in Ref. [3]. We shall simply give the general patterns essential for an analysis of the experiment.

The function for distribution of the neutron flux by energy is close to normal in our case, with a dispersion which is slightly dependent on energy:

S1 = $81.48 - 3.68 \cdot E_n$, first series Ø = 19 mm;

S2 = $37.44 + 0.085 \cdot E_n$, second series Ø = 19 mm;

S3 = $40.59 - 1.11 \cdot E_n$, second series Ø = 10 mm;

where [S] = keV, [E_n] = MeV.

The level of resolution achieved is determined in the main by the interaction of charged particles with target materials, and it is close to the limit for experiments of this type. The experimentally measured neutron flux is 30-40% lower than the calculated value; this is significantly greater than the calculation error level. This may be due to local heating of the target gas and a reduction in the number of nuclei along the trajectory of the incident particles. There may also be a concomitant reduction in energy losses in the gas and an increase in the mean neutron energy by ~ 10 keV by comparison with the calculated value.

Thus, the mean neutron energy in this experiment is determined to an accuracy of 15-20 keV.

Fission fragments were registered using a flow fission ionization chamber in 2π-geometry. Fragment losses below the discrimination threshold did not exceed 0.5%, self-absorption in the layer was (0.02-0.38)% for the various neutron energies. A correction was introduced into the chamber counts for electromagnetic interference which, in 87% of cases, did not exceed 1%, and in 10% of cases was (1-2)%. The contribution of background neutrons from the target body was measured to an accuracy of 20% in experiments with an evacuated target, and it varied from 3.5% (E_n = 7 MeV) to 12% (E_n = 9 MeV). Where neutron energy > 8.5 MeV, the contribution of neutrons from the disintegration reaction d(d,np) was also taken into account and it comprised 0.5% (E = 8.7 MeV) and 3.1% (E = 9.1 MeV). The data in Ref. [4] give the cross-section of this reaction to an accuracy of ~ 8%, which results in an inaccuracy of ~ 0.3% in the determination of the flux.

The activity level of the aluminium samples was determined on a 2πβ-γ-coincidence device (accuracy ~ 1.1%) using a calibrated Ge(Li) detector (accuracy ~ 2%). The results tally within the limits of measurement error. Thus, the mean ratio of the activity levels determined using the different methods is 1.016 ± 0.023.

The total measurement accuracy of the cross-section ratio for the majority of points is (2-3)%.

2. Discussion of results

To obtain the cross-section of the ^{237}Al(n,α) reaction from the measured ratios, the evaluation of the ^{238}U(n,f) reaction cross-section given in ENDF/B-V was used. The results of the present work confirm the presence of the resonance structure discovered in Ref. [2] over the whole energy range studied. Six well-resolved peaks are clearly visible, and measurements with a better energy resolution show the resonance structure even more clearly (see Fig. 2). The shape of the cross-section tallies well with the results given in Ref. [2], however the data in Ref. [2] are systematically shifted 50-70 keV towards the higher energies; this is 2-3 times greater than the error level for determining the energy in this paper.

The procedure for unfolding the "true" cross-section involved finding the solution of the integral equation whose kernel is the neutron energy distribution in the sample calculated using the Monte Carlo method. For this

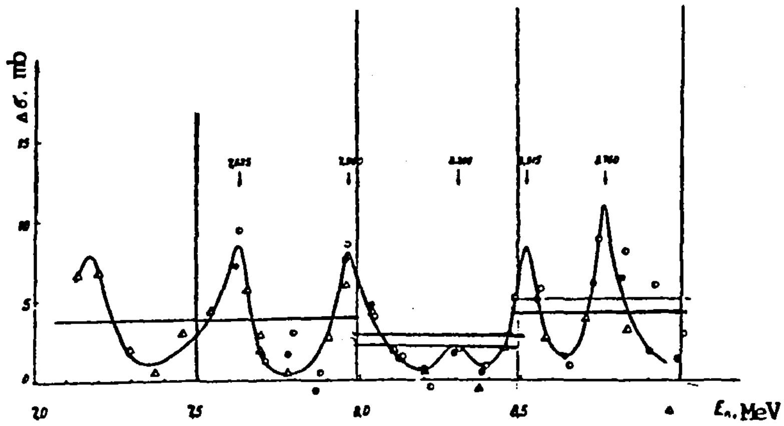

Fig. 2. Fluctuation portion of the cross-section after elimination of the linear dependence of $\sigma(E) = 25\text{–}28.7\ (E_n - 7.51)$, where $[\sigma]$ = mb, $[E]$ = MeV. The symbols indicate experimental points obtained with varying energy resolution: Δ – S1; $\bullet$ – S2; $\circ$ – S3.
The smooth dependence has been drawn in by eye.

purpose, the fluctuating portion of the cross-section was described using the sum of the Lorentz terms, the parameters of which were selected on the basis of the best description of all three groups of experimental points. We evaluate the accuracy level for determinination of the resonance widths Γ_i at $\pm$ 50%. All values of Γ_i lie in the range 40–90 keV, which corresponds to a lifetime of $(4\text{–}9)\cdot 10^{-21}$ s.

The mean distance between peaks is ~ 300 keV and they therefore cannot be linked to the levels of the compound nucleus, the mean distance between the latter being ~ 1 keV for an excitation energy of 14 MeV.

The authors of Ref. [2] associate these levels with the formation of quasi-molecular states. If, when a neutron interacts with a nucleus of ^{27}Al, a stable system is established in the form of a ^{24}Na core and an α-particle cluster, then resonances should be observed in the reaction cross-section under investigation which corresponds to the characteristic states of this system. For the ^{24}Na + α-particle system, the evaluation yields a distance between levels of ~ 400 keV.

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