E3-98-375

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CROSS SECTION AND ANGULAR DISTRIBUTION MEASUREMENTS OF THE FAST NEUTRON INDUCED (n,α) REACTION FOR MEDIUM-MASS NUCLEI

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1998

1. INTRODUCTION

Investigation of the fast neutron induced (n,α) reaction is of interest to studies of reaction mechanisms and nuclear structure. In addition, the study of the (n,α) reaction is important for estimation of nuclear heating, radiation damage and induced activity in structural materials of nuclear reactors. However, in the energy region of 1 to 10 MeV, where the thresholds of many (n,α) reactions lie, the experimental data base is rather scarce and there are significant discrepancies between the available results of various authors. Therefore, in 1990 we started the study of the (n,α) reaction induced by neutrons with the energy of several MeV using gridded ionization chamber [1-3].

In this paper, our results of cross section and angular distribution measurements of the (n,α) reaction in the energy range from 4 to 7 MeV for isotopes of ^{40}Ca, ^{54}Fe, ^{58}Ni and ^{64}Zn important for nuclear power engineering, are discussed.

2. EXPERIMENT

Nearly monoenergetic neutrons were obtained from the $D(d,n)^3He$ reaction at the Van de Graaff accelerator in the Institute of Heavy Ion Physics, Peking University, Beijing, P.R.China. A water-cooled TiD solid target was used. Neutron yield for beam current $I_d \approx 10$ μA was $\sim 2\times10^8$ n/s.

Alpha particles from the (n,α) reactions were detected using a parallel plate, gridded twin ionization chamber with a common cathode [4] which was made in the Frank Laboratory of Neutron Physics, JINR, Dubna, Russia. The first section of the twin ionization chamber contained the target isotope. The second section of the chamber was empty and was used for background measurements. The anode plates were 0.2 mm thick aluminium foils. The grids consisted of parallel gold-coated tungsten wires 0.1 mm in diameter arranged with a 2 mm spacing. Argon mixed with 3-5% CO_2 or krypton mixed with 1.7-3.0% CO_2 was utilized to fill the chamber.

Three-dimensional spectra were obtained by measuring coinciding signals of the anode and the cathode with a multiparameter system [5]. The energy spectra and angular distributions of alpha-particles emitted in the (n,α) reaction were extracted from the anode and cathode signals, respectively [4, 5]. The absolute neutron flux was determined using previously calibrated BF_3 long counter and ^{238}U (99.997%) fission chamber. The basic characteristics of the targets are given in Table 1.

Table 1. The target characteristics

Nuclei	Sample	Abundance of isotope (%)	Thickness (mg/cm^2)
^{40}Ca	CaF_2	Natural	0.86±0.03
^{54}Fe	metal	99.87	0.96±0.03
^{58}Ni	metal	99.95	1.05±0.02
	metal	99.8	0.50±0.01
^{64}Zn	metal	99.4	0.72±0.03
	metal	99.4	0.250±0.013

3. RESULTS AND DISCUSSION

3.1. Angular distribution

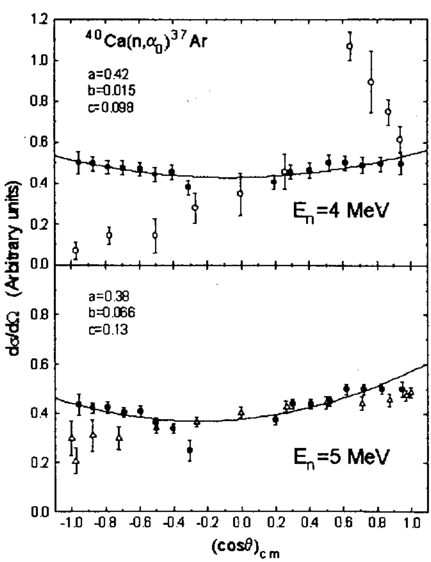

Fig. 1. The angular distribution of α-particles emitted in the $^{40}Ca(n,\alpha_0)^{37}Ar$ reaction at 4 MeV.

Experimental points:

O - ref. [6], Δ - ref.[7], ● - our data. The solid curve is the least-squares fit of our data by the expression

$$P(\cos\theta) = a + b\cos\theta + c\cos^2\theta .$$

Our results of the measurements for angular distribution of α-particles emitted in the $^{40}Ca(n,\alpha_0)^{37}Ar$ reaction, together with the data from refs. [6,7] at 4 and 5 MeV, are shown in the centre-of-mass system in Fig. 1. Our results are nearly symmetrical with respect to θ=90°, and they disagree with the only other available data obtained by Calvi et al. at 4 MeV [6] and Abashi et al. at 5.15 MeV [7].

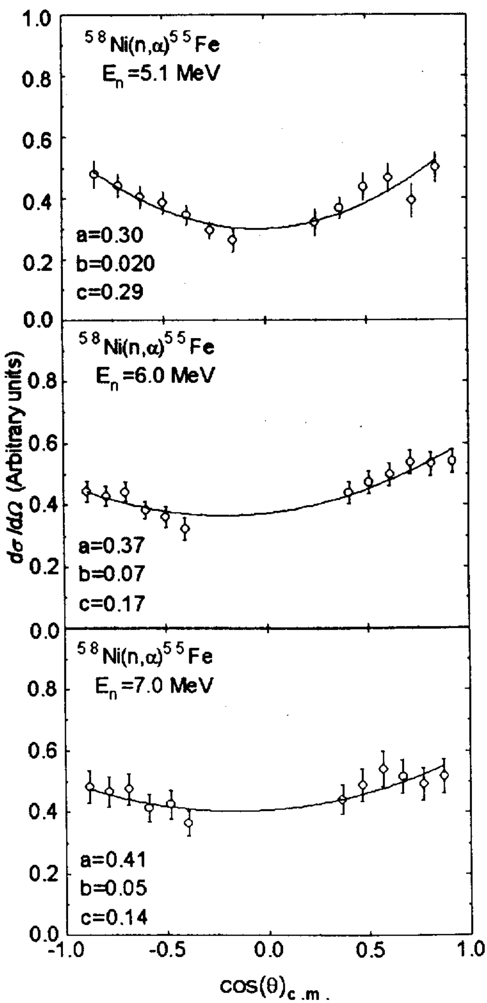

Fig. 2. The angular distribution of the $^{58}Ni(n,\alpha)^{55}Fe$ at E_n=5.1, 6.0, 7.0 MeV.

The curves are the Legendre polynomial fit

$$P(\cos\theta) = a + b\cos\theta + c\cos^2\theta \ .$$

Our results on the angular distributions of the ^{58}Ni(n,α)^{55}Fe reaction at E_n=5.1, 6.0 and 7.0 MeV are shown in Fig. 2. The angular distributions nearly symmetrical around θ=90° are in better qualitive agreement with the results of Goverdovski et al. obtained at E_n=5.05 MeV [8]. Analogous results were obtained by Wattecamps [9] and Baba et al. [10].

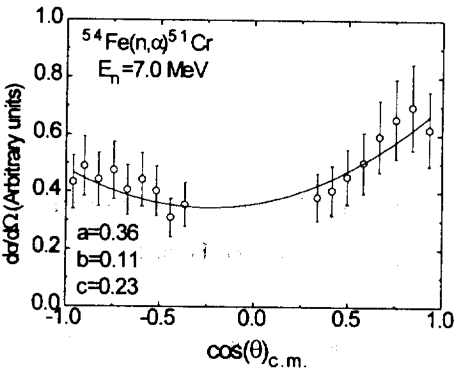

Fig. 3. The angular distribution of the ^{54}Fe(n,α)^{51}Cr reaction at E_n=7 MeV.
The curve is the Legendre polynomial fit $P(\cos\theta) = a + b\cos\theta + c\cos^2\theta$.

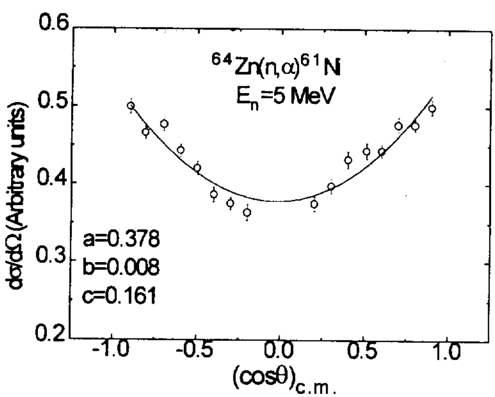

Fig. 4. The angular distribution of the ^{64}Zn(n,α)^{61}Ni reaction at E_n=5 MeV for the excitation energy E^*<2 MeV of the residual nucleus.
The curve is the Legendre polynomial fit $P(\cos\theta) = a + b\cos\theta + c\cos^2\theta$.

The Angular distributions for the ^{54}Fe(n,α)^{51}Cr reaction at 7 MeV and the ^{64}Zn(n,α)^{61}Ni reaction at 5 MeV are displayed in Figs. 3 and 4, respectively. For the ^{54}Fe(n,α)^{51}Cr reaction there exist no other experimental data on the angular distribution in that energy interval. As to the ^{64}Zn(n,α)^{61}Ni reaction our symmetrical result is in disagreement with the only other available forward peaked distributions reported by Calvi et al. at E_n=4.5 MeV and 5 MeV [6]. Nearly symmetrical angular distributions with respect to θ=90° measured by us show that the compound mechanism predominates in the (n,α) reaction on medium-mass nuclei in the energy range of several MeV.

3.2. Cross section

Our values of the angle integrated cross sections for the $^{40}Ca(n,\alpha_0)^{37}Ar$, $^{54}Fe(n,\alpha)^{51}Cr$, $^{58}Ni(n,\alpha)^{55}Fe$ and $^{64}Zn(n,\alpha)^{61}Ni$ (for E^*<2 MeV) reactions around E_n=5-7 MeV, are given in Table 2.

Table 2. The experimental (n,α) cross sections

Target Nuclei	E_n (MeV)	σ(n,α) (mbarn)
^{40}Ca	5	234±23
^{54}Fe	7	8.8±2.6
^{58}Ni	5.1	47.4±5.0
^{58}Ni	6	75±7.5
^{58}Ni	7	71±14
^{64}Zn	5	34±3

Our results on the (n,α) cross sections in comparison with other experimental and theoretical data of various authors are illustrated in Figs. 5, 6 and 7 for ^{40}Ca, ^{54}Fe and ^{58}Ni, respectively.

Figure 5 shows that our value of the (n,α) cross section for ^{40}Ca is slightly larger than other results. Our value of the (n,α) cross section for ^{54}Fe at 7 MeV (Fig. 6) is lower than the experimental data by Meadows et al. [19], the results of the pre-equilibrium model calculation by Avrigeanu et al. [21] and the ENDF/B-VI evaluation [19]. However, our result is considerably larger than the result of statistical model calculations [18].

Our results for ^{58}Ni in the energy range E_n=6-7 MeV (Fig. 7) are lower than the data of Qaim et al. [22], but in the energy region E_n=5-6 MeV they are larger than the values of Goverdovski et al. [8].

As to the ^{64}Zn isotope our result on the (n,α) cross section at 5 MeV is in disagreement with only other available value $\sigma_{n\alpha} \approx 42$ mbarn obtained by Calvi et al. [6].

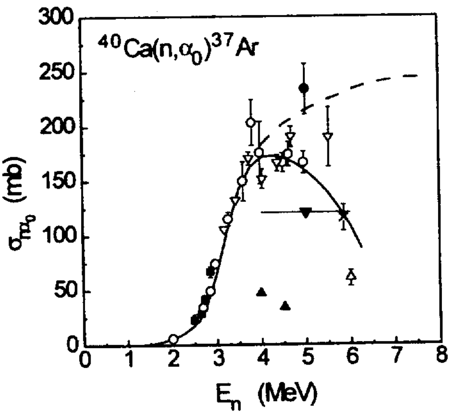

Fig. 5. The excitation function for the ^{40}Ca(n,α_0)^{37}Ar reaction.

Experimental points: O - ref. [11], ■ - ref. [12], ∇ - ref. [13], ▲ - ref. [6], ▼ - ref. [14], × - ref. [15], Δ - ref. [16], and ● - our data.

The solid curve is the statistical model calculation for $\sigma(n,\alpha_0)$ [13].

The dashed curve is the statistical model calculation for $\sigma(n,\alpha)$ [17].

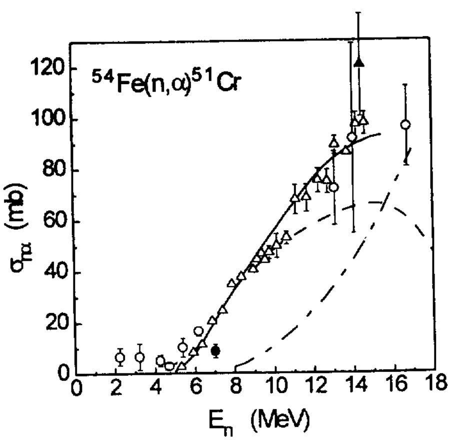

Fig. 6. The excitation function for the ^{54}Fe(n,α)^{51}Cr reaction.

Experimental points: O - ref. [18], Δ - ref. [19], ▲ - ref. [20], and ● - our data.

The solid curve is the ENDF/B-VI evaluation [19]; the dashed curve is the pre-equilibrium model calculation [21]; the dot-dashed curve is the statistical model calculation [18].

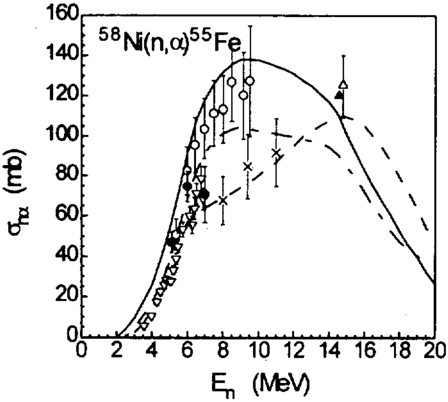

Fig. 7. The excitation function for the ^{58}Ni(n,α)^{55}Fe reaction. Experimental points: O - ref. [22], × - ref. [23], ▲ - ref. [20], Δ - ref. [24], ∇ - ref. [8], and ● - our data. The solid curve is the evaluated ENDF/B-VI file; the dashed curve is the JEF-2/EFF-2 code; the dot-dashed curve is the JENDL-3 (ref. [25]).

This work was supported by Russian Foundation for Basic Research and National Natural Science Foundation of China, grant 96-02-10031.

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Received by Publishing Department
on December 24, 1998.

Гледенов Ю.М. и др. E3-98-375

Измерения сечений и угловых распределений (n,α)-реакции, вызванной быстрыми нейтронами, для ядер средних масс

Измерены сечения и получены угловые распределения для (n,α)-реакции на изотопах ^{40}Ca, ^{54}Fe, ^{58}Ni и ^{64}Zn в диапазоне энергий нейтронов от 4 до 7 МэВ. Проведено сравнение этих результатов с экспериментальными и теоретическими данными, полученными другими авторами.

Работа выполнена в Лаборатории нейтронной физики им. И.М.Франка ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна, 1998

Gledenov Yu.M. et al. E3-98-375

Cross Section and Angular Distribution Measurements of the Fast Neutron Induced (n,α) Reaction for Medium-Mass Nuclei

Angular distributions and cross sections of the (n,α) reaction for the ^{40}Ca, ^{54}Fe, ^{58}Ni and ^{64}Zn were measured in the neutron energy range of 4 to 7 MeV. These results were compared with other experimental and theoretical data of various authors.

The investigation has been performed at the Frank Laboratory of Neutron Physics, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna, 1998

Макет Т.Е.Попеко

Подписано в печать 09.02.99
Формат 60 × 90/16. Офсетная печать. Уч.-изд. листов 0,99
Тираж 335. Заказ 51161. Цена 1 р. 20 к.

Издательский отдел Объединенного института ядерных исследований
Дубна Московской области