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STUDY OF THE ^{40}Ca(n, α)^{37}Ar REACTION INDUCED BY FAST NEUTRONS

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1. Introduction

Investigation of the fast neutron-induced (n,α) reaction is of importance in the design of reactor shielding, in particular for estimation of nuclear transmutation rates, nuclear heating, radiation damage and other related safety aspects. Calcium is an element of shielding material. Natural calcium contains 96.94% ^{40}Ca. Energy spectra and angular distribution of α-particles and cross section of the ^{40}Ca(n,α)^{37}Ar reaction in the energy range of a few MeV are specifically required to determine the secondary gamma radiation field in concrete shielding /1/. On the other hand the fast neutron-induced (n,α) reaction is of interest from the stand-point of basic nuclear physics, in the study of reaction mechanisms, for example.

The ^{40}Ca(n,α)^{37}Ar reaction in the neutron energy range of 3 to 14 MeV was experimentally studied over a long period of time by various authors /2–14/. Theoretical calculations based on the Hauser-Feshbach method were performed by Fu /15/ for the (n,α) and (n,p) cross sections of ^{40}Ca. However, there are considerable discrepancies between the results of these studies. Therefore, we recently measured the angular distribution of α-particle emission at neutron energies of 4 and 5 MeV, and the cross section for the ^{40}Ca(n,α_0)^{37}Ar reaction at 5 MeV.

2. Experiment

Nearly monoenergetic neutrons of 3.94$\pm$ 0.20 MeV and 4.98$\pm$ 0.26 MeV were produced via the D(d,n)^{3}He reaction using the Van de Graaff accelerator at the Institute of Heavy Ion Physics (Peking University, Beijing). A surface barrier detector was used to detect protons from the accompanying D(d,p)^{3}H reaction as the neutron monitor. Determination of the absolute neutron flux for 5 MeV was perfected with the help of the previously calibrated BF_3 long counter. α-particles from the ^{40}Ca(n,α)^{37}Ar reaction were detected using a double-grid, parallel-plate, twin ionization chamber with a common cathode /16/, which made a good showing in our measurements with slow neutrons /17/. The first section of the twin ionization chamber contained the CaF_2 target with a density of 0.86± 0.03 mg/cm^2. The second section was empty and was used for background measurements. Natural CaF_2 of 99.9 % purity was evaporated in vacuum on 0.3 mm thick tungsten foil that was used as the cathode. The anode plates were 0.2 mm thick aluminium foils. The grids consisted of parallel gold-coated tungsten wires 0.1 mm in diameter spaced 2 mm apart. Argon mixed with 5% carbon-dioxide was utilized to fill the chamber. The ionization chamber has a large solid angle for detection and the capabilities of energy-angle determination and charged particle identification.

Two dimensional energy spectra of signals from the anode and cathode were obtained with the help of a measuring system designed at the Institute of Heavy Ion Physics /18/ and based on the IBM PC AT-386 computer. The anode signal of the ionization chamber gave the energy spectrum of charged particles emitted from the cathode at that time the cathode signal gave the information of their angular distribution /16,19/.

3. Results and Discussion

1. Angular distribution

Only α-transition to the ^{37}Ar ground-state (α_0) will be considered because in our measurements there were not enough intensity of the other transitions to stand out against the background. Our results of the measurements for angular distribution of α- particles emitted in the ^{40}Ca(n,α_0)^{37}Ar reaction, together with data taken from refs. /3,8/ at 4 and 5 MeV, are shown in the centre- of-mass system in Fig.1 and 2, respectively. The angular distributions that we measured at 4 and 5 MeV, are nearly symmetrical with respect to $\vartheta=90^o$ though some small asymmetry in the forward direction at E_n=5MeV can be seen. But such results disagree with the only other available data, reported by Calvi et al. at 4 MeV /8/ and Abaschi et al./3/ at 5.13 MeV. In connection with this fact it is advisable to consider the dependence of angular

distribution on neutron energy over a wider energy range. Fig.3 shows the angular distribution of α- particles emitted in the ^{40}Ca(n,α_0)^{37}Ar reaction between 3.6 and 13.9 MeV as reported in refs./4-7/.

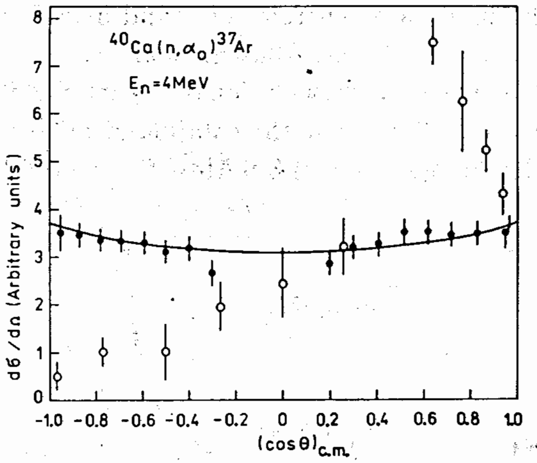

Figure 1. Angular distribution of α-particles emitted in the ^{40}Ca (n,α_0)^{37}Ar reaction at 4 MeV. Experimental points: o-ref./8/, •-present work. The solid curve is the least-squares fit of our data by the expression $P(cos\vartheta)=a+bcos^2\vartheta$

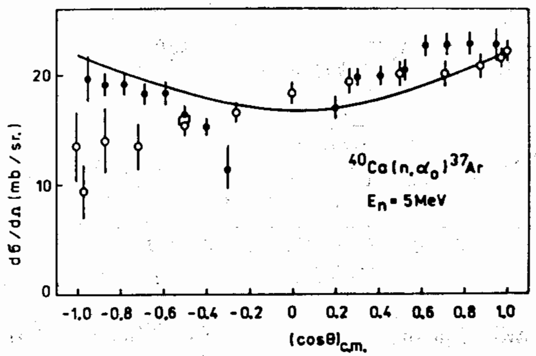

Figure 2. The same as in Fig.1 at E_n=5MeV. Experimental points: o-ref./3/, •-present work.

From here, with due regard for the results of Abaschi et al./2/ around 3 MeV, it can be concluded that the angular distributions of α-particle emissions from the $^{40}Ca(n,\alpha_0)^{37}Ar$ reaction are nearly symmetrical with respect to $\vartheta=90^o$ in the energy range of 3 to 6 MeV. These results are in agreement with our data at energies of 4 and 5 MeV and disagree with reports by Calvi et al./8/ and Abaschi et al./3/.

Nearly symmetrical angular distribution of α-particles emitted in the $^{40}Ca(n,\alpha_0)^{37}Ar$ reaction shows that the compound nucleus mechanism predominates in the energy range of 3-6 MeV for the double

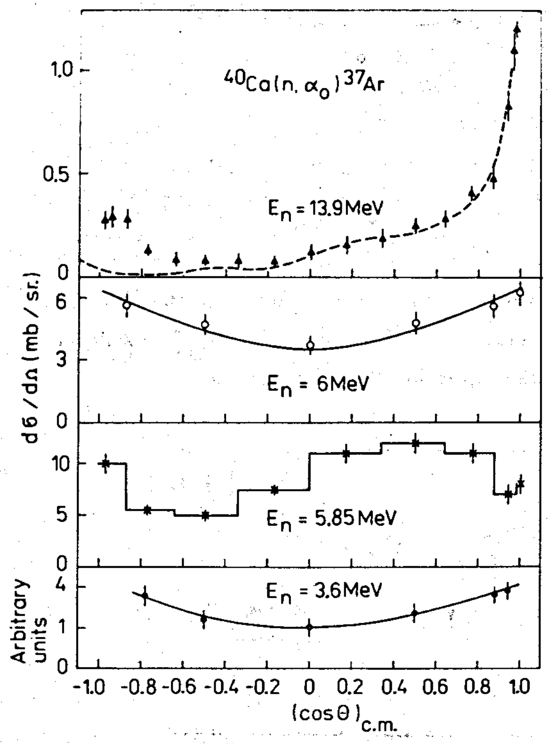

Figure 3. Angular distribution of α-particles from the $^{40}Ca(n,\alpha_0)^{37}Ar$ reaction in the energy range of 3.6 to 13.9 MeV. Experimental points: ▲-ref./5/, o-ref./7/, x-ref./6/, •-ref./4/. The dashed curve is the DWBA calculation/5/. The solid curves are the least-squares fit of experimental data by the expression $P(\cos\vartheta)=a+b\cos^2\vartheta$. The histogram represents experimental points only.

magic target nucleus ^{40}Ca. Regarding the energy region of 14 MeV the angular distribution is strongly asymmetrical in the forward direction which may describe the direct reaction mechanism/5/.

2. *Cross section*

Angle integrated cross section of the $^{40}Ca(n,\alpha_0)^{37}Ar$ reaction at a neutron energy of 5 MeV was found to be $\sigma(n,\alpha_0)=234\pm23$ mb. This value , in comparison with the experimental data reported in /6–12/ and the statistical model calculation result /15/, is illustrated in Fig.4.

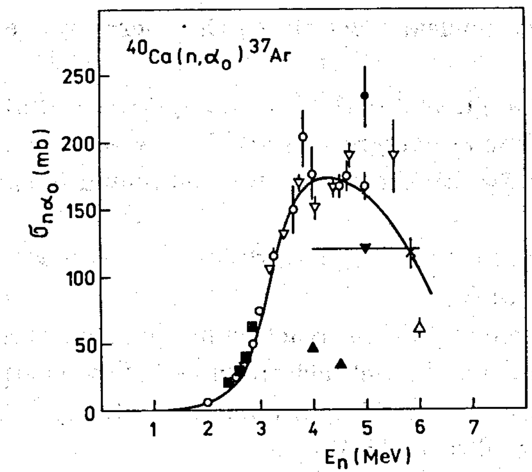

Figure 4. Excitation function of the $^{40}Ca(n,\alpha_0)$ ^{37}Ar reaction. Experimental points: o-ref./9/, ■- ref./11/, ∇-ref./12/, ▲-ref./8/, ▼-ref./10/, x-ref./6/, △- ref./7/, •-present work. The solid line is the statistical model calculation /12,15/.

Fig.4 shows that our value is slightly above the other results but it should be noted that the spread of experimental data of the various authors is great. Fig.4 does not show the $\sigma(n,\alpha)=430\pm100$ mb value at E_n=6MeV obtained by Urech et al./13/ and the data reported by Barnes et al./14/ in the energy range of 3 to 14.7 MeV which have values of 180-

200 mb in the energy range of 4.5 to 9 MeV. These results were not included because they are total (n, α) cross section values. Since is not known the exact value of the intensity of α-transitions to the different final states of ^{37}Ar, it is difficult, at present, to obtain (n,α_0) cross section from these results.

4. Conclusions

1. The results of our measurements have shown that the double-grid twin ionization chamber can be used for charged particle spectrometry from neutron induced nuclear reactions in the energy range of several MeV.

2. The fact that angular distribution of α-particles emitted in the ^{40}Ca(n,α_0)^{37}Ar reaction at energies of 4 and 5 MeV are nearly symmetrical with respect to $\vartheta = 90^o$ shows that the compound nucleus mechanism predominates.

3. The cross section of the ^{40}Ca(n,α_0)^{37}Ar reaction was found to be 234±23 mb at E_n=5 MeV.

4. To clarify the role of different reaction mechanisms it is necessary to perfect more detailed and exact measurements of the energy spectra, angular distribution and cross section for the ^{40}Ca(n,α_0)^{37}Ar reaction in the energy range of 6 to 10 MeV.

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Исследование реакции $^{40}Ca(n, \alpha)^{37}Ar$ на быстрых нейтронах

Угловые распределения α-частиц, вылетающих из реакции $^{40}Ca(n, \alpha_0)^{37}Ar$, были измерены при энергиях нейтронов 4 и 5 МэВ с помощью плоско-параллельной двойной ионизационной камеры с двумя сетками. Почти моноэнергетические нейтроны были получены на ускорителе Ван де Граафа с помощью реакции $D(d, n)^3He$. При энергии нейтронов 5 МэВ было измерено сечение реакции (n, α_0) и получено значение 234 ± 23 мб. Полученные результаты сравниваются с другими экспериментальными данными и предсказаниями статистической модели.

Работа выполнена в Лаборатории нейтронной физики им. И.М.Франка и Институте физики тяжелых ионов Пекинского университета, КНР.

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Study of the $^{40}Ca(n, \alpha)^{37}Ar$ Reaction Induced by Fast Neutrons

The angular distributions of α-particles emitted in the $^{40}Ca(n, \alpha_0)^{37}Ar$ reaction have been measured at neutron energies of 4 and 5 MeV with a double-grid, parallel-plate, twin ionization chamber. Nearly monoenergetic neutrons were produced via the $D(d, n)^3He$ reaction using the Van de Graaff accelerator. For 5 MeV neutrons the (n, α_0) cross section has been found to be 234 ± 23 mb. These results were compared with other experimental data and the predictions of the statistical model.

The investigation has been performed at the Frank Laboratory of Neutron Physics, JINR and the Institute of Heavy Ion Physics, Peking University, Beijing, P.R.China.

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