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SYSTEMATICS OF THE FAST NEUTRON INDUCED (n, α) REACTION CROSS SECTIONS

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INTRODUCTION

Investigation of charged particle emission reactions induced by fast neutrons is of interest for both nuclear energy applications and the understanding of basic nuclear physics problems. In particular the study of (n,α) cross sections is important for estimating radiation damage due to helium production in the structural materials of fission and fusion reactors, as well as for research of nuclear reaction mechanisms and α-cluster structure. Because of this, it would be very useful to derive some empirical law governing the variation of charged particle emission reaction cross sections induced by fast neutrons. Several formulae have been suggested to describe the isotopic dependence of the (n,p) cross section around the neutron energy of 14.5 MeV [1-4]. Recently, we observed a similar dependence for the (n,p) cross section, averaged over the thermal neutron induced fission spectrum of ^{235}U [5], and in the energy range of 6-16 MeV [6].

As for the (n,α) cross section for fast neutrons there is an empirical law of Levkovsky [1] around neutron energy of 14 MeV, only.

In this paper we report on the attempt to make a systematic analysis of the known (n,α) cross sections in a wide energy range, namely, at energies of 8, 10, 14.5 and 16 MeV.

FORMULAE AND DATA ANALYSIS

The (n,α) cross section at a neutron energy around 14 MeV is satisfactorily described by the formula [1]

$$\sigma_{n\alpha} = C\pi r_0^2\left(1 + A^{1/3}\right)^2 \exp\left[-\frac{K(N-Z)}{A}\right], \qquad (1)$$

where $r_0 = 1.4\cdot10^{-13}$ cm; A, N, and Z are the mass number, number of neutrons and charge of the target nucleus, respectively; and C and K are the fitting parameters. Formula (1) can be partly interpreted, as in the case of the (n,p) cross section [7], within the framework of the statistical model for nuclear reactions [8]. The pre-exponential term, in fact, is the cross section for formation of a compound nucleus by neutrons, whereas the exponential term represents the escape of the alpha-particle from the compound nucleus. Since we are considering the wide energy range of 8-16 MeV, it is necessary to take energy dependence into account in the compound nucleus formation cross section. Then the compound nucleus formation cross section can be written as [8]

$$\sigma_C = \sum_{l=0}^{R/\lambda} \pi\lambda^2(2l+1)T_l. \qquad (2)$$

Here $\lambda = 4.55\cdot10^{-13}$ cm$/\sqrt{E(\mathrm{MeV})}$ is the wavelength of the incident neutrons divided by 2π; l is the orbital angular momentum of the neutrons; $R = r_0A^{1/3}$ is the radius of the target nucleus; T_l is the transmission coefficient; and E is the energy of the neutrons.

For a black target nucleus $T_l = 1$ and formula (1) can be rewritten in the following form:

$$\sigma_{n\alpha} = C\pi(R+\lambda)^2 \exp\left[-\frac{K(N-Z)}{A}\right]. \qquad (3)$$

Then, using formula (3) we can obtain the fitting parameters K and C for different energies of neutrons.

Figs.1-4 show the known experimental values of reduced (n,α) cross sections taken from [9-16], depending on the (N-Z)/A parameter and the line fitted by expression (3) at energies 8, 10, 14.5 and 16 MeV, respectively. Plus and minus symbols denote the positive and negative Q-values of reactions, respectively. Corresponding values of the fitting parameters C and K are given in these figures. Figures 1-4 demonstrate that formulae of type (3) satisfactorily describe the dependence of known experimental (n,α) cross sections on the asymmetry parameter (N-Z)/A of the neutron and proton numbers in the target nuclei for the wide energy range of 8 to 16 MeV. In the case of 8 MeV considerable deviation from the fitted line was observed for the experimental point of ^{19}F. Such behaviour of ^{19}F is apparently explained by the strong resonance of its (n,α) cross section around 6 MeV. Unfortunately it is not possible at present to do any systematic analysis below 8 MeV because in this energy range the experimental data of (n,α) cross sections is very scarce. Besides it should be noted that in most cases of (n,α) reactions, the target nuclei have a threshold energy below 8 MeV and perhaps the correlation between the (n,α) cross section and parameter (N-Z)/A is not valid for energies close to that threshold. Figs.1-4 also show that for the (n,α) cross section systematic analysis, Q-values are apparently not important as distinct from the (n,p) reaction [6,7].

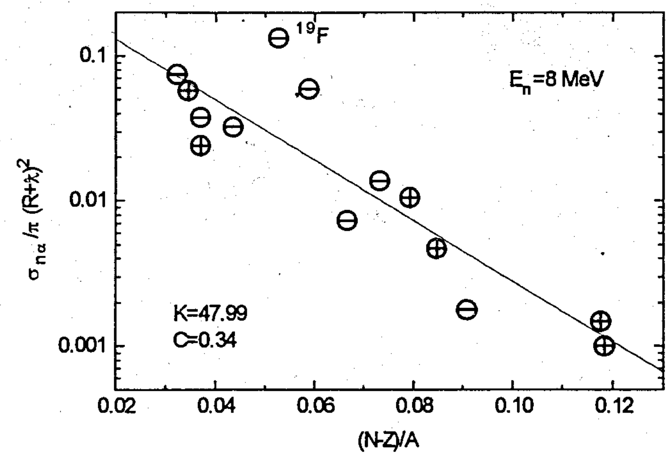

Figure 1. The dependence of reduced (n,α) cross sections on the asymmetry parameter (N-Z)/A of neutron and proton numbers in the target nucleus at E_n=8 MeV

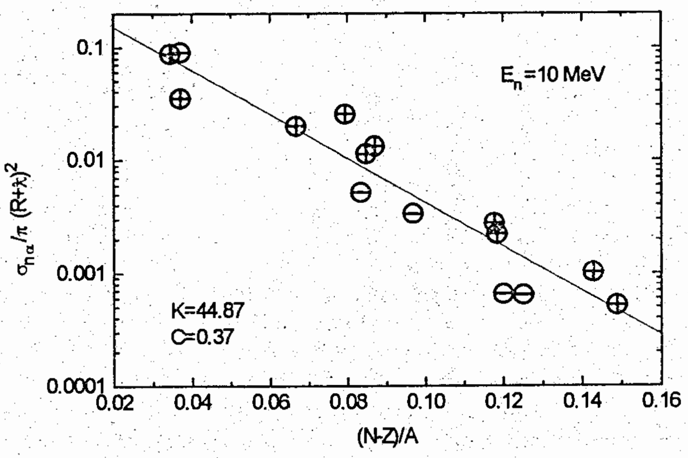

Figure 2. The same as in Fig.1 at 10 MeV

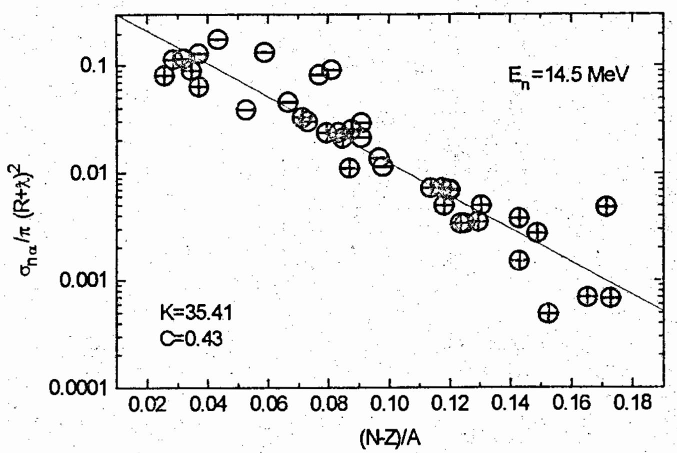

Figure 3. The same as in Fig.1 at 14.5 MeV

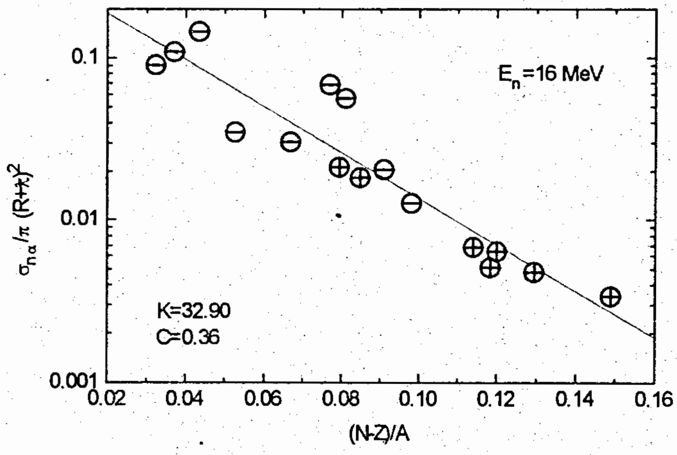

Figure 4. The same as in Fig.1 at 16 MeV

CONCLUSION

1. Figs.1-4 demonstrate that formula (3) satisfactorily describes the dependence of known experimental (n,α) cross sections on the asymmetry parameter (N-Z)/A of the proton and neutron numbers in the target nucleus for the wide energy range of 8 to 16 MeV.

2. The dependence of the (n,α) cross sections on the parameter (N-Z)/A in the wide energy interval and for the wide range of mass numbers A=19-140 indicates that this systematics is apparently independent of nuclear reaction mechanisms.

3. For such a systematic analysis, it would be very useful to make an exact experimental study of (n,α) cross sections especially below 10 MeV [17] where experimental data is very scant.

4. Further, it is necessary to study such behaviour of the (n,α) and (n,p) cross sections [6,7] from the united view-point of nuclear reaction and nuclear structure theories.

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