(n,α) REACTION CROSS SECTION AND ALPHA DECAY PROBABILITY OF NUCLEUS

[1]G.Khuukhenkhuu, [2]Yu.M.Gledenov, [2]M.V.Sedysheva and [1]M.Odsuren

[1]Nuclear Research Center, National University of Mongolia, Ulaanbaatar, Mongolia
[2]Frank Laboratory of Neutron Physics, JINR, Dubna, Russia

Introduction

According to Bohr assumption of compound mechanism for nuclear reactions the (n,α) cross section can be supposed as two steps process: formation of the compound nucleus by neutron incident upon the target nucleus and α-decay of the compound nucleus. The two stages of formation and decay of the compound system can be treated as independent process. So, the α-decay of the compound nucleus can be compared with radioactive α-decay.

In this work, fast neutron induced (n,α) reaction cross section and probability of radioactive α-decay are compared.

The (n,α) Reaction Cross Section

In the framework of the compound mechanism, using the statistical model nuclear reactions was deduced following formula for fast neutron induced (n,α) reaction cross section [1]:

$$\sigma_{n,\alpha}^{com} = C\pi(R+\lambda\!\!\!^{-})^2 e^{-K\frac{N-Z+0.5}{A}} . \qquad (1)$$

Here: A, N, Z and R are the mass number, neutron and proton numbers and radius of the target nucleus, respectively; $\lambda\!\!\!^{-}$ is the wavelength of incident neutrons divided by 2π; C and K are the parameters which can be fitted for experimental cross sections or are immediately determined by formulas [2]:

$$K = 2\xi\sqrt{\frac{A}{13.5(E_n + Q_{n\alpha})}} \qquad (2)$$

and

$$C = 2\exp\sqrt{\frac{A}{13.5(E_n + Q_{n\alpha})}}\left\{-3\alpha + \gamma\left(\frac{4Z}{A}\right) + \varepsilon_\alpha - 2.058\frac{Z}{A^{1/3}}\right\}. \qquad (3)$$

Here: ξ, α and γ are the Weizsacker's formula constants for binding energy; E_n is the incident neutron energy; $Q_{n\alpha}$ is the (n,α) reaction energy; ε_α is the internal binding energy of α-particle.

The compound nucleus formation cross section is determined as following

$$\sigma_n(C) = \pi(R+\lambda\!\!\!^{-})^2 \qquad (4)$$

Then, the α-decay probability of the compound nucleus is expressed by formula

$$W_\alpha = Ce^{-K\frac{N-Z+0.5}{A}} . \qquad (5)$$

Alpha Decay Probability of Nucleus

The probability for radioactive α-decay of nucleus is determined as following

$$W_\alpha = \lambda_\alpha = f_\alpha P_\alpha , \tag{6}$$

where: λ_α is the disintegration constant for α-decay; f_α is the α-cluster formation factor; P_α is the barrier penetration factor.

In the framework of the so-called one-body theory, in which an α-particle already formed in the nucleus, for even-even nuclei we can determine the α-particle formation factor as a collision frequency in the potential barrier of the daughter nucleus [3]

$$f_\alpha = \frac{\upsilon_\alpha}{R_0} = \frac{\sqrt{\ell(\ell+1)}\hbar}{m_\alpha R_0^2} . \tag{7}$$

Here: ℓ, m_α and υ_α are the orbital momentum, mass and velocity of the α-particle; R_0 is the radius of the daughter nucleus.

If we neglect a centrifugal barrier and consider nuclear potential as simple square well the barrier penetration factor can be written as [4]:

$$P_\alpha = \exp\left\{ -\frac{2}{\hbar} \int_{R_0}^{R} \sqrt{2m_\alpha \left[V_C(r) - E_\alpha \right]} dr \right\} . \tag{8}$$

Here $V_C(r)$ is the Coulomb potential; E_α is the kinetic energy of the α-particles; R is the turning point which can be found from the condition

$$E_\alpha = \frac{2Ze^2}{R} . \tag{9}$$

Probability of α-Decay and Analysis of (n,α) Cross Sections

From (5) and (6) can be obtained following expression:

$$Ce^{-K\frac{N-Z+0.5}{A}} = f_\alpha P_\alpha . \tag{10}$$

Taking into account formulas (7) and (8) from (10) can be write

$$f_\alpha \sim C$$
$$P_\alpha \sim e^{-K\frac{N-Z+0.5}{A}} \tag{11}$$

On the other hand, using the formula (1), from analysis of known experimental (n,α) cross sections for fast neutrons the fitting parameter K can be determined [2] which is given in Table 1 and is shown in Fig.1.

Table 1.

E_n (MeV)	6	8	10	13	14.5	16	18	20
K	62.1	59.0	53.4	48.3	38.2	34.3	32.5	25.3

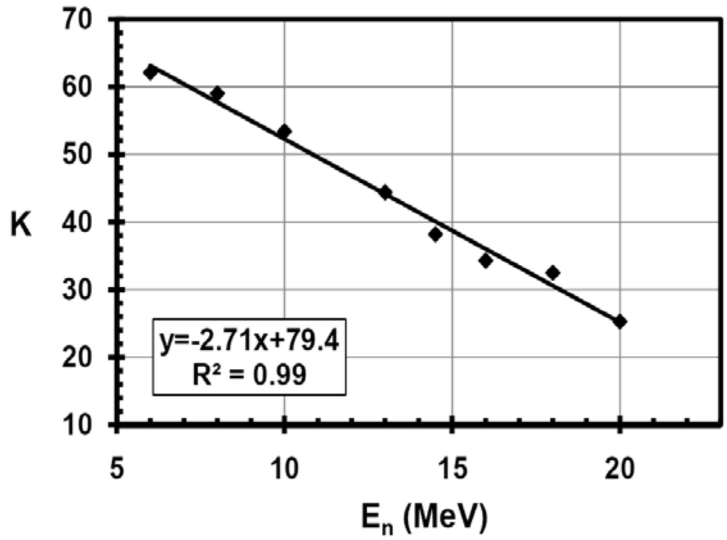

Fig.1. Energy dependence of parameter K.

From Fig.1 it can be obtained K=0 at neutron energy $E_n \approx 29.5$ MeV. This fact means that in this energy range penetration factor $P_\alpha = 1$.

So, exponential term in the formula (1) is perhaps represented by the penetration factor of the potential barrier. In future, immediate mathematical demonstration for this assumption is needed.

References

1. G.Khuukhenkhuu, M.Odsuren, J.Badamsambuu, Yu.M.Gledenov, M.V.Sedysheva. In book: Proceedings of the XV International Seminar on Interaction of Neutrons with Nuclei, ISINN-15, Dubna, Russia (16-19 May 2007), 2008, p.157.
2. M. Odsuren. Ph.D. Thesis, Nuclear Research Center, National University of Mongolia, Ulaanbaatar, 2010.
3. Л.Ландау, Я.Смородинский.
   Лекции по теории атомного ядра.
   изд. ТТЛ, Москва, 1955.
4. J.O.Rasmussen.
   Phys. Rev., v.113, N6, 1959, p.1593.