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SYSTEMATICS OF THE (*n*, *p*) REACTION CROSS SECTIONS AVERAGED OVER ^{235}U THERMAL FISSION NEUTRON SPECTRUM

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Introduction

The (n,p) reaction cross sections averaged over the fission neutron spectrum are important in reactor design, particularly for calculations of the nuclear transmutation rate, nuclear heating, radiation damage and related safety problems. On the other hand, these reactions are also of interest from the stand-point of basic nuclear physics, for example, in the study of nuclear reaction mechanisms.

It is useful to derive some empirical law for governing neutron cross section variation, because in practice it is often necessary to evaluate the cross sections of the nuclides, for which no experimental data are available. Several formulae have been suggested to describe the isotopic dependence of the (n,p) reaction cross section around the neutron energy 14 MeV [1-4]. In the case of fission neutron spectrum averaged cross sections of (n,p) reactions an empirical rule of Horibe [5] describes the dependence of the cross section on the effective threshold energy.

In this paper we report another attempt at systematics of the known (n,p) cross sections in the thermal fission neutron spectrum of ^{235}U.

Systematics Formulae and Data Analysis

It is well known that at the neutron energy around 14 MeV to describe the systematics of (n,p) reaction cross sections one can use the formula referred in literature as the isotopic effect:

$$\sigma_{np}=C\pi r_0^2(1+A^{1/3})^2\exp[-K(N-Z)/A], \quad (1)$$

where $r_0=1.4\times10^{-13}$cm; A,N and Z are the mass number, the number of neutrons and the charge of the target nucleus, respectively; C and K are the fitting parameters. In the case of the 14 MeV neutrons it was found that C=0.73 and K=33 [1]. Besides, the parameter C=0.73 can be approximately considered as a ratio of the (n,p) cross section to the sum of the (n,p) and (n,α) ones.

Now, we use this expression to describe the (n,p) cross section in the fission neutron spectrum. In the energy range of thermal fission neutrons the experimental (n,α) cross section data base is very scarce and their available values are , as a rule, small. Therefore, we can neglect a contribution of the (n,α) cross section and assume C=1, as a first approximation. The parameter K can be determined from experimental data fitting.

The values of measured [6] and estimated [7,8] (n,p) cross sections in the ^{235}U thermal fission neutron spectrum are listed in Table 1.

Since the fission neutron spectrum shape depends on the facility it has been measured at, to minimize systematic error in arranging the (n,p) cross sections we consider only the experimental values of Horibe et al. [6], the more so as their measured values are in agreement with the estimated ones, with the exception of those for ^{84}Sr and ^{86}Sr. Systematics of the experimental results of Horibe et al. for the (n,p) cross sections averaged over the ^{235}U thermal fission neutron spectrum are shown in Fig.1. Plus and minus symbols denote the positive and negative Q-values, respectively. The solid line is the straight-line fit to the experimental data points. $\langle E_n \rangle \approx 2$ MeV means the average neutron energy of the ^{235}U thermal fission neutron spectrum [9].

The fitted coefficient, K, for the exponent in (1) has been found to be 80.6. Thus, finally we have for the ^{235}U thermal fission neutron spectrum the following formula

$$\sigma_{np} = \pi r_0^2 (1+A^{1/3})^2 \exp[-80.6(N-Z)/A] \qquad (2)$$

Figure 1 also shows that in this case the Q-values of the (n,p) reaction are apparently of greater importance for such systematic in comparison with the 14 MeV neutrons. In conclusion it should be noted that the experimental cross

sections of ^{84}Sr and ^{86}Sr show deviation from this systematics.

Table 1

Target nuclei	(N-Z)/A	Q_{np} (MeV)	σ_{np} (mb)		
			[7]	[8]	[6]
^{27}Al	0.0370	-1.828	4.0±0.45	3.86±0.25	4.09±0.26
^{42}Ca	0.0476	-2.734	——	3.44	2.92±0.22
^{43}Ca	0.0698	-1.035	0.3±0.15	2.3	2.58±0.19
^{46}Ti	0.0435	-1.585	12.5±0.9	12.5±0.9	11.6±0.8
^{47}Ti	0.0638	0.182	20±2.3	19±1.4	20.2±1.4
^{48}Ti	0.0833	-3.208	0.315±0.027	0.300±0.018	0.305±0.020
^{54}Fe	0.0370	0.088	82.5±5	79.7±4.9	81.7±5.2
^{56}Fe	0.0714	-2.918	1.07±0.08	1.03±0.075	1.13±0.07
^{59}Co	0.0847	-0.783	1.42±0.14	1.42±0.14	1.39±0.10
^{58}Ni	0.0345	0.395	113±7	108.5±5.4	106±7
^{60}Ni	0.0666	-2.041	2.3±0.4	2.3±0.4	2.19±0.17
^{61}Ni	0.0820	-0.525	1.4±0.2	1.4±0.2	1.33±0.10
^{64}Zn	0.0625	0.208	31±2.3	29.9±1.6	29.4±7.5
^{67}Zn	0.1045	0.208	1.07±0.04	1.07±0.04	1.01±0.09
^{84}Sr	0.0952	-0.104	——	0.7	5.36±0.45
^{86}Sr	0.1163	-0.980	——	0.11	0.664±0.067
^{92}Mo	0.0870	0.427	7.0±0.6	9.1	6.78±0.42
^{95}Mo	0.1158	-0.142	0.14±0.01	0.14±0.01	0.142±0.011
^{96}Mo	0.1250	-2.405	0.058±0.008	0.058±0.008	0.0256±0.0025
^{103}Rh	0.1262	0.0198	0.107±0.006	0.107±0.006	0.119±0.013
^{115}In	0.1478	0.668	——	0.041	0.00938± 0.00104
^{140}Ce	0.1714	-2.984	4.3±1.6	0.005	0.00415± 0.00029

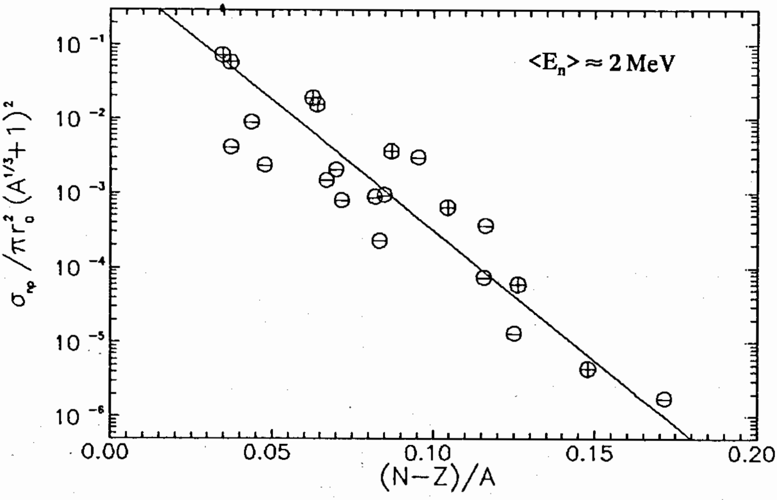

Fig.1. The dependence of reduced (n,p) cross sections on the asymmetry parameter (N-Z)/A of the target nucleus

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