Nuclear Data for Science and Technology (1988 MITO), 513- 516, Copyright © 1988 JAERI.

SYSTEMATICS OF AVERAGE NEUTRON CAPTURE CROSS SECTIONS AROUND 25 keV

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Abstract: The systematic behavior of average neutron capture cross sections around 25 keV has been studied. These cross sections demonstrate the shell effect clearly. A simplified and parameterized formula of

$$\sigma_{n\gamma} = C1A^{C2}U^{C3}a^{C4}\exp\,(C5\sqrt{aU}\,)$$

was used to fit the measured data by the least squares method and the five parameters were obtained.

(systematics, neutron capture cross sections, shell effect)

Introduction

The neutron capture cross sections around 25 keV are of importance for nuclear science and technology as well as astrophysics. As usual, results of systematics study can be used to predict the cross sections of those nuclides for which no measured data are available. One such study was presented in 1982 by Nedvejuk et al[1]..

Formulae

Based on the Breit-Wigner resonance theory, average cross sections can be given by the following formula

$$\sigma_{n\gamma}=\frac{\pi 2.6\times10^6}{2E_n}\sum_{L=0}^{L_m}(2L+1)\frac{\overline{\Gamma}_{\gamma L}}{\overline{D}_L}\int_0^\infty\frac{2}{\sqrt{\pi}}\frac{t^2}{(t^2+b_L)}dt \qquad (1)$$

where

$$b_L = \overline{\Gamma}_{\gamma L}/(2V_L\sqrt{E_n}\overline{\Gamma}^L_n)\ . \qquad (2)$$

The E_n denotes the incident neutron energy and $\overline{\Gamma}_{\gamma L}$, $\overline{\Gamma}^L_n$, $\overline{D}_L$ and V_L are the average capture width, average reduced neutron width, average level spacing and penetrability factor for L-wave respectively.

In eq. (1), the integral term is close to unit if b_L is not too large. As an approximation, we suppose that at E_n= 25 keV the capture cross sections are dominated by S-wave neutron, then the cross section is directly proportional to gamma strength function of S-wave,

$$S_{\gamma o} = \overline{\Gamma}_{\gamma o}/\overline{D}_o\ . \qquad (3)$$

Taking the inverse of level spacing $\overline{D}$ as

$$1/\overline{D} = \rho \propto \frac{a}{(aU)^{5/4}}\exp(2\sqrt{aU}) \qquad (4)$$

and average capture width of S-wave, $\overline{\Gamma}_{\gamma o}$, as the result of Malecky's systematics[2]

$$\overline{\Gamma}_{\gamma o} \propto U^{0.9}A^{-0.9}a^{-0.57}\ , \qquad (5)$$

we can get

$$\sigma_{n\gamma} \propto A^{-0.9}U^{-0.35}a^{-0.82}\exp(2\sqrt{aU}) \qquad (6)$$

where A, a and U denote the mass number, the level density parameter and the effective excitation energy for the compound nucleus respectively. For 25 keV neutron, we took

$$U = S_n - \delta\ ,\ \text{MeV} \qquad (7)$$

and

$$\delta=\begin{cases} 22/A & \text{for e-e compound nucleus} \\ 11/A & \text{for odd-A compound nucleus} \\ 0 & \text{for o-o compound nucleus} \end{cases} \quad (8)$$

where S_n is the neutron separation energy of the compound nucleus.

From eq. (6), it can be found that the average neutron capture cross sections at 25 keV are determined by the value of aU mainly.

We took the systematics formula as a form similar to eq. (6)

$$\sigma_{n\gamma} = C1A^{C2}U^{C3}a^{C4}\exp(C5\sqrt{aU}) \quad . \qquad (9)$$

The parameters C1, C2, C3, C4 and C5 can be obtained from the least squares fit with eq. (9) to a body of measured data.

Systematics

The measured data in the energy region of E_n = 20-30 keV have been collected in the light of refs. 3, 4. The 10% errors are given to those data for which experimental errors have not given by the authors and 20% to the data quoted from graphs. The dispersions of measured data are often large as compared with their errors for given nuclide. In this case, we always adopted the data which are close to our systematics. Fig. 1 shows the cross sections adopted by this work versus target neutron number N. From fig. 1, one can find that the shell effect exists at N = 28, 50, 82 and 126.

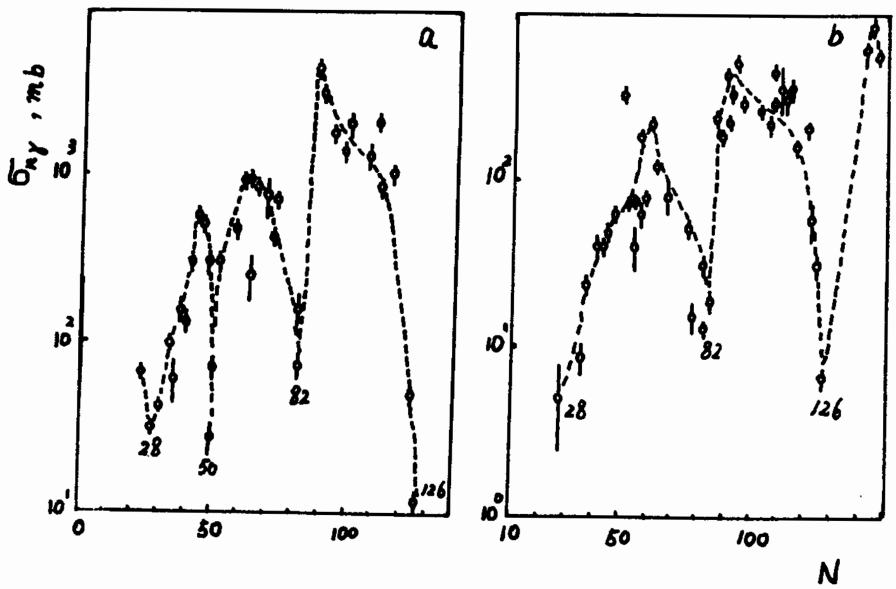

Fig. 1 Neutron Capture Cross Section Adopted by This Work Versus Target Neutron Number N
a, for odd-Z targets
b, for even-Z targets

To calculate the level density parameter a in eq. (9), a formula considering the shell effect was used

$$a = a_0 g_1 g_2 \qquad (10)$$

where

$$\begin{cases} a_0 = 0.128A-4.94\times10^{-5}A^2 \text{ , MeV}^{-1} \\ g_1 = 1+\dfrac{1-\exp(-0.054S_n)}{S_n}S \\ g_2 = 1+\dfrac{1-\exp(-0.23S_n)}{S_n}P \end{cases} \qquad (11)$$

In these eqs., P is pairing energy correction factor

$$P = \begin{cases} 11/A & \text{for o-o compound nucleus} \\ 0 & \text{for odd-A compound nucleus} \\ -11/A & \text{for e-e compound nucleus} \end{cases} \qquad (12)$$

and S, shell correction factor, was equal to the difference between the mass excesses Δ_{exp} and Δ_0

$$S = \Delta_{exp} - \Delta_0 \qquad (13)$$

where Δ_{exp} is the experimental value taken from ref. 5 and Δ_0 is the semi-empirical value[6,7]:

$$\begin{cases} \Delta_0 = M_n N + M_z Z - a_1 A + a_2 A^{2/3} + a_3 Z^2/A^{1/3} - a_4 Z^2/A + P \\ M_n = 8.07144 \text{ MeV} \quad M_z = 7.28879 \text{ MeV} \\ a_1 = 15.4941(1-1.7826(\frac{N-Z}{A})^2), \text{ MeV} \qquad (14) \\ a_2 = 17.9439(1-1.7826(\frac{N-Z}{A})^2), \text{ MeV} \\ a_3 = 0.7053 \text{ MeV} \quad a_4 = 1.15298 \text{ MeV} . \end{cases}$$

Fitting eq. (9) to the measured data, five parameters were obtained as follows

C1=0.3482, C2=-1.033, C3=-0.2438,

C4=0.8569, C5=1.011 .

The comparison between fitted curve and measured data adopted are given by fig. 2.

The data far away from the fitted curve are marked.

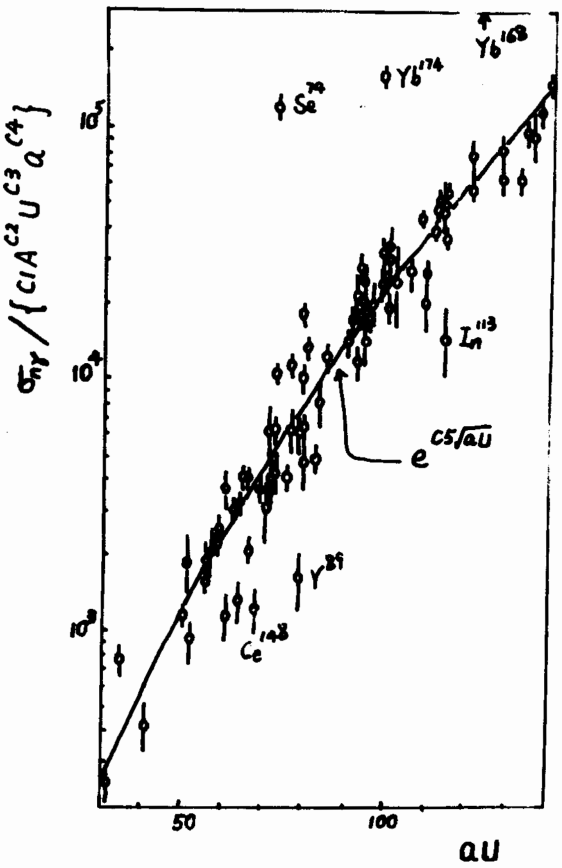

Fig. 2 The comparison between this systematics and measured data adopted by this work

On the bases of the systematics result, neutron capture cross sections at 25 keV for some nuclides for which no measured data available were predicted and shown in tab. 1.

Discussion

About 70% of data points are included in the region of 30% below and above the fitted curve in fig. 2, so a forecast error of ±30% (68% confidence level) is given for the value predicted by this systematics. And we may say that the forecast error is smaller than scattered scale of the measured data body presently.

References

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Tab. 1 Capture Cross Sections Predicted by the Systematics at 25 keV

Nuclide	this work mb	ref. 1, mb		Nuclide	this work mb	ref. 1, mb	
		A	B			A	B
Se^{74}	105 ±31	150±20	380 ±190	Te^{131}	153 ± 46		193 ±16
Se^{82}	21.1±6.3	14± 5	12 ± 3	Te^{132}	15.0±4.5	3.3±0.9	5.9 ±0.7
Kr^{82}	83.3±25.0	120±20	85 ± 42	Ba^{131}	591 ±177	1400	
Sr^{84}	158 ±47	160 30		Ba^{132}	307 92	540 40	
Pd^{102}	150 45	500 70	770 110	Ba^{133}	375 112	800	
Pd^{109}	220 66		660 90	Sm^{145}	315 94	1000	
Pd^{112}	82.1 24.6	200 60	190 20	Sm^{146}	284 85	160 20	150 25
Cd^{104}	184 55	700 70		Sm^{151}	727 218		1870 570
Cd^{109}	305 92		1240 220	Sm^{156}	220 66	120	
Cd^{115}	212 64		400 50	Gd^{152}	600 180		760 80
Cd^{117}	163 49		300 50	Gd^{154}	692 207	720	740 70
Cd^{118}	63.1 18.9	46 12	78 10	Gd^{159}	345 103		875 100
Sn^{110}	252 75	240 40		Dy^{156}	931 279		1750 240
Sn^{113}	372 111	840	1130 210	Dy^{158}	967 290		1350 170
Sn^{114}	237 71	150 25	196 23	Dy^{160}	647 190	620 90	700 70
Sn^{115}	288 86	600	560 90	Dy^{165}	246 74		500 50
Sn^{121}	156 50	140	173 20	Yb^{166}	1432 430		1150 120
Te^{120}	321 96	210 20		Yb^{168}	1064 320		900 90
Te^{127}	141 42	200	352 40	Yb^{169}	174 52	3100	2820 390
Te^{129}	72.4 21.7	76	257 24	Yb^{175}	253 76	430	370 30