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Evaluation of Empirical Equations of Asymmetry Parameter for Magic Nuclei in Z for (n,α) Reaction of Incident Neutron Energy 14.5 MeV

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الخلاصة
الدراسه تتضمن تقسيم النوى السحريه الى مجموعتين، المجموعة الاولى لدراسه النوى المتوسطة والمجموعة الثانية تمثل النوى الثقيله. أذ تم حساب تصحيحات القشرة فضلا عن المقاطع العرضيه لتفاعلات النوى (n,α) والعدد الكتلي (A) لجميع النوى في المجموعات اذا كانت طاقه النيوترونات الساقطة $(14.5MeV)$. كما تم ايجاد المعادلات التجريبية لباراميتر التناظر $(N-Z)/A$ كداله للعدد الكتلي للمجموعتين كما في المعادلات ادناة:

$\frac{(N-Z)}{A} = 3E-05A^2 - 0.0037A + 0.206$ for A=42 to A=124 middle nuclei.

$\frac{(N-Z)}{A} = 0.0039A - 0.5929$ for A=204 to A=208 heavy nuclei.

Summary

In this study, the magic nuclei are divided into two groups: the middle group and the heavy group. The shell corrections were calculated for all nuclei. The relationship between cross sections for nuclear reactions (n,α) and the mass number (A) for all nuclei to incident neutrons (14.5 MeV) were calculated. We found empirical equations to asymmetry parameter (N-Z)/A as function of mass number and for those two groups:

$\frac{(N-Z)}{A} = 3E-05A^2 - 0.0037A + 0.206$ for A=42 to A=124 middle nuclei.

$\frac{(N-Z)}{A} = 0.0039A - 0.5929$ for A=204 to A=208 heavy nuclei.

Introduction:

The evaluated nuclear cross-section data are required for understanding the binding energy systematic, nuclear structure, the properties of the excited nucleus states in different energy ranges and refined nuclear models [1]. These data are necessary to develop more nuclear reaction models in order to explain nuclear reaction mechanisms. The nuclear reaction mechanisms are frequently needed to provide an estimation of the particle induced reaction-cross section, especially if the experimental data are not available or they are hopeless to measure the cross-section, due to experimental difficulty [2].

The systematic nuclear reaction is widely used for the reaction cross-section evaluation supplementing result of measurement and calculations by theoretical models [3]. A large number of empirical and semi-empirical cross-section formulas with different parameters have been proposed by several authors in the literature [4]. According to previously obtained empirical and semi- empirical results, the cross-sections for many nuclei significantly vary with the mass number A, neutron number N and proton number Z of the target nucleus [5].

Theory and Methods:

Using the pre-equilibrium exciton model in a "closed" and the phenomenological pick-up model [6,7], the following approximate formula for the non-equilibrium component of the (n,α) reaction cross-section can be written [8,9]:

$$\sigma_{(n,\alpha)}^{pre} = \sigma_{non}(E_n)(4/3)\frac{(2S_\alpha+1)\mu_\alpha R^2}{\pi^2\hbar^2 g^4 E_0^4\left\langle |M|^2\right\rangle}\left(\beta E_n + Q_{(n,\alpha)} - V_a\right)^3 \times \left[0.5C_1\left(\beta E_n + Q_{(n,\alpha)} - V_\alpha\right) + C_1\left(V_\alpha + Q_\alpha\right) + C_2\right] \quad \text{....... (1)}$$

Where σ_{non} is the cross-section of the non-elastic interaction of the incident neutron with a nucleus; E_n is the energy of primary neutron; S_α, μ_α and V_α are the spin, the reduced mass and the coulomb potential for the emitted $\alpha - particle$, correspondingly; $Q_{(n,\alpha)}$ is the energy of the (n,α) reaction equal to the difference between Q_n and Q_α where Q_n is the binding energy for neutron and Q_α is the binding energy for the $\alpha - particle$ in a compound nucleus; g is the single particle level density; $\left\langle |M|^2\right\rangle$ is the mean square of the matrix element of the residual interaction; E_0 is the energy of the excitation for the compound nucleus equal to $\beta E_n + Q_n; \beta = A/(A+1), A$ is the mass number of the target nuclei; R is the nucleus radius; C_1 and C_2 are parameters, which correspond to the approximation of the $\alpha - particle$ formation probability by a straight line $F_{1,3} = C_1(\varepsilon + Q_\alpha) + C_2$ where ε is the kinetic energy of the emitted $\alpha - particle$ [7].

According to the equilibrium emission rate for the particle with a kinetic energy ε_x is defined as follows [10]:

$$W_x^{eq}\alpha(2S_x+1)\mu_x\sigma_x^{inv}(\varepsilon_x)\varepsilon_x\rho_x(U_x)\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where S_x and μ_x are the spin and the reduced mass of the outgoing particle of the x-type, σ_x^{inv} is the inverse reaction cross-section, ρ_x is the nuclear level density for the residual nucleus, U_x is the excitation energy of the nucleus formed after the x-particle emission.

The nuclear level density can be obtained using the "constant temperature" model [11]: $\rho_x=\frac{1}{T_x}\exp\left[\left(U_x-U_{ox}\big/T_x\right)\right]\ldots\ldots\ldots\ldots\ldots\ldots(3)$

Where T_x and U_{ox} are the nuclear temperature and the energy shift, which can be expressed as functions of the atomic mass number and the shell correction to the mass formula [11].

Assuming that the probability of the neutron equilibrium emission predominates compared with the probabilities for other channels after the integration of Eq.(2) in the energy range corresponding to the $\alpha-particle$ emission one can obtain the following expression for the equilibrium component of the (n,α) reaction cross-section:

$$\sigma_{(n,\alpha)}^{eq}=\frac{(2S_\alpha+1)\mu_\alpha}{(2S_n+1)\mu_n}\exp\left\{\frac{\beta E_n+Q_{(n,\alpha)}-U_{o\alpha}-V_\alpha}{T_\alpha}-\frac{\beta E_n-U_{on}}{T_n}\right\}\ldots\ldots\ldots\ldots(4)$$

Taking into account that the average squared matrix element for tow-body interactions in Eq.(1) is the parameterized as $\left\langle|M|^2\right\rangle=KA^{-3}E_0^{-1}$, the single particle level density g is equal to A/m, where K and m are constants, assuming that the total probability of non-equilibrium processes change smoothly from one nucleus to another [12,13]. and that nuclear temperatures in Eq.(4) for $\alpha-particle$ and neutron channels are close $(T_\alpha\approx T_n)$, one can suggest the following systematic formula for the evaluation of the (n,α) reaction cross-section, for target nuclei with $18\le Z\le 50$ [8,14].

$$\sigma(n,\alpha)=\pi r_0^2\left(A^{1/3}+1\right)^2\exp\left(-160.6S^2-9.54131\times10^{-5}A^2+0.10398f_{ch,p}-1.4934\right)\ldots(5)$$

Thus:

$$f_{ch,p} = \frac{1}{0.10398}\left[\frac{\ln\sigma(n,\alpha)}{\pi r_0^2\left(A^{1/3}+1\right)^2} + 160.6S^2 + 9.54131\times10^{-5}A^2 + 1.4934\right] \quad ....(6)$$

For target nuclei with $Z > 50$ [14].

$$\sigma(n,\alpha) = \pi r_0^2\left(A^{1/3}+1\right)^2 A^{\frac{-1}{3}} \times\left(-2.194P + 1.0307\times10^{-2} f_{sh,p} + 0.57038\right)^3 \quad ....(7)$$

Thus:

$$f_{sh,p} = \frac{1}{1.0307}\times10^{-2}\left[\left\{\frac{\sigma(n,\alpha)}{\pi r_0^2\left(A^{\frac{1}{3}}+1\right)^2 A^{\frac{-1}{3}}}\right\}^{\frac{1}{3}} + 2.1946P - 0.57038\right] \quad ....(8)$$

where:

σ(n,α) = Cross section of the (n,α) reaction

S = (N – Z +1) / A.

P = (N – Z + 0.5) / A.

$f_{sh,p} = (dw_n - \delta_n) - (dw_\delta - \delta_\alpha)$, where dw_n and dw_α are shell corrections [15],for nuclei (Z,A) and (Z- 2, A-3) respectively, also δ_n and δ_α are pairing correction for nuclei (Z,A) and (Z-2 , A-3) calculated as follows :

$\delta = 12A^{\frac{-1}{2}}$ for even -even nuclei.

$\delta = 0$ for nuclei with odd.

And $\delta = -12A^{\frac{-1}{2}}$ for odd-odd nuclei, $r_0 = 1.3\,fm$, which corresponds to the πr_0^2 value equal to 53.093mb; N,Z and A are number of neutrons , protons and nucleon in the target nuclei, respectively.

The (n,α) reaction cross section, obtained from the analysis of experimental data for 120 nuclei with $Z \geq 18$ used to obtain the cross sections and any others parameters as in table -1:[16]

Table 1: The (n,α) reaction cross sections at the incident energy 14.5 MeV for stable nuclei with atomic numbers from 18 to 83 and ^{99}T obtained from the analysis of experimental data $(\sigma \pm \Delta\sigma)$, and cross section calculated using the systematic [16].

Z	A	Cross-section(mb)	Z	A	Cross-section(mb)	Z	A	Cross-section(mb)
18	36	142.0	42	100	2.86 ± 0.29	62	149	4.15
18	38	61.3	43	99	6.06 ± 0.61	62	150	3.21 ± 0.34
18	40	10.8±1.7	44	96	32.4	62	152	1.81 ± 0.23
19	39	13.0±26.0	44	98	16.9	62	154	0.833 ± 0.083
19	40	103.0	44	99	15.4	63	151	2.27 ± 1.27
19	41	33.3 ±3.3	44	100	8.24	63	153	1.56 ± 0.16
20	40	128.0 ± 13.0	44	101	7.35	64	152	3.78
20	42	72.7	44	102	6.46 ± 0.82	64	154	2.33
20	43	58.7	44	104	3.12 ± 0.31	64	155	2.87
20	44	27.7±2.8	45	103	6.00	64	156	3.84 ± 1.91
20	46	3.54	46	102	17.6	64	157	1.88
20	48	1.25±0.33	46	104	8.93	64	158	1.84 ± 0.47
21	45	56.4±5.6	46	105	8.40	64	160	0.64
22	46	76.5±16.9	46	106	5.28 ± 0.53	65	159	2.22 ± 0.29
22	47	66.9	46	108	2.73 ± 0.27	66	156	3.79
22	48	34.0±3.9	46	110	0.84	66	158	2.71
22	49	19.6	47	107	6.79	66	160	1.94
22	50	8.63 ±0.86	47	109	3.29	66	161	2.30
23	50	38.0±1.5	48	106	18.6	66	162	1.93 ± 0.34
23	51	16.5±1.7	48	108	9.83	66	163	1.47
24	50	99.7±10.0	48	110	4.88	66	164	1.11 ± 0.30
24	52	36.2±3.6	48	111	4.61	67	165	0.763 ± 0.079
24	53	44.2±3.7	48	112	2.54 ± 0.36	68	162	3.30
24	54	11.8±1.2	48	113	2.14	68	164	2.35
25	55	24.0±2.4	48	114	0.889 ± 0.089	68	166	1.63
26	54	91.1±9.1	48	116	0.46	68	167	1.87
26	56	43.9±4.4	49	113	4.45 ± 0.47	68	168	1.66 ± 0.26
26	57	31.0±4.0	49	115	2.39 ± 0.24	68	170	0.613 ± 0.097
26	58	19.8±2.0	50	112	44.9 ± 10.0	69	169	1.50 ± 0.13
27	59	31.4±3.1	50	114	5.50	70	168	2.73
28	58	109.0±11.0	50	115	5.08	70	170	2.02
28	60	62.8±6.3	50	116	1.88 ± 0.24	70	171	2.28
28	61	44.4±4.2	50	117	2.45 ± 0.19	70	172	1.68 ± 0.33
28	62	23.4±2.3	50	118	1.18 ± 0.12	70	173	1.46
28	64	3.77±0.38	50	119	0.999 ± 0.087	70	174	1.16 ± 0.14
29	63	44.4±4.4	50	120	0.450 ± 0.045	70	176	0.547 ± 0.120
29	65	8.69±1.48	50	122	0.221 ± 0.024	71	175	1.33
30	64	36.4±10.1	50	124	0.079 ± 0.013	71	176	2.23 ± 0.55
30	66	30.2	51	121	3.08	72	174	2.42
30	67	27.1	51	123	1.81	72	176	1.77
30	68	9.02±0.90	52	120	7.09	72	177	1.98
30	70	3.69	52	122	4.72	72	178	1.86 ± 0.37
31	69	20.2±2.0	52	123	5.66	72	179	1.28
31	71	5.06±0.78	52	124	3.08	72	180	0.848 ± 0.151
32	70	35.4	52	125	3.84	73	181	0.644 ± 0.064
32	72	17.4±3.7	52	126	1.88 ± 0.38	74	180	1.88

32	73	12.1	52	128	1.17	74	182	1.20
32	74	7.89±3.14	52	130	0.66	74	183	1.41
32	76	2.52±0.29	53	127	2.69	74	184	0.789 ± 0.079
33	75	10.7±1.1	54	124	7.10	74	186	0.542 ± 0.054
34	74	38.7	54	126	5.01	75	185	1.41 ± 0.50
34	76	16.5	54	128	3.43	75	187	0.529 ± 0.053
34	77	15.3	54	129	4.24	76	184	2.17
34	78	7.41±0.78	54	130	2.28	76	186	1.54
34	80	3.29±0.33	54	131	2.91	76	187	1.76
34	82	0.70	54	132	1.47	76	188	0.94
35	79	12.5±1.2	54	134	0.90	76	189	1.15
35	81	4.48±0.59	54	136	0.53	76	190	0.678 ± 0.085
36	78	41.1	55	133	1.43 ± 0.27	76	192	0.22
36	80	19.4	56	130	5.81	77	191	0.828 ± 0.437
36	82	8.06	56	132	4.11	77	193	0.44
36	83	7.09	56	134	2.81	78	190	1.72
36	84	3.03	56	135	5.58 ± 1.53	78	192	1.06
36	86	1.00	56	136	1.87	78	194	1.19 ± 0.20
37	85	5.97±0.60	56	137	2.96 ± 0.83	78	195	0.81
37	87	2.02	56	138	2.32 ± 0.23	78	196	0.560 ± 0.096
38	84	21.3	57	138	2.94	78	198	0.16
38	86	9.26	57	139	1.98 ± 0.20	79	197	0.373 ± 0.037
38	87	8.12	58	136	4.71	80	196	1.05
38	88	3.54	58	138	3.30	80	198	0.66
39	89	6.27+0.63	58	140	2.28	80	199	0.83
40	90	13.7+1.4	58	142	5.97 ± 0.60	80	200	0.461 ± 0.461
40	91	11.8	59	141	3.03	80	201	0.50
40	92	9.32+0.93	60	142	5.58 ± 0.56	80	202	0.19
40	94	4.63+0.46	60	143	5.23	80	204	0.07
40	96	2.32+0.33	60	144	4.05 ± 0.57	81	203	0.39
41	93	8.85+0.89	60	145	3.67	81	205	0.519 ± 0.082
42	92	25.7+2.6	60	146	3.42 ± 0.34	82	204	0.722 ± 0.082
42	94	13.0+2.6	60	148	1.56 ± 0.33	82	206	0.556 ± 0.056
42	95	12.9+1.7	60	150	0.73	82	207	0.366 ± 0.033
42	96	7.98+1.77	62	144	5.63	82	208	0.395 ± 0.075
42	97	8.41+0.99	62	147	5.61	83	209	0.590 ± 0.059
42	98	6.02+0.60	62	148	3.54			

Results and discussion:

In this work, table-1 is used to calculate asymmetry parameter for magic nucleus in Z for (n,α) reaction of incident neutron energy 14.5 MeV, perhaps table-1 contains stable nuclei with atomic numbers from 36 to 98 and by using this table, we can make another table as below:

Table-2: The (n,α) Reaction Cross Sections of the Incident Energy 14.5 MeV for Stable Magic Nuclei by Z with Mass Number from 42 to 208.

Z (magic number)	A	N	Cross section (mb)	$(N-Z)/A$ Asymmetry parameter	Type of nuclei
20	42	22	72.7	0.047619	Middle nuclei
20	43	23	58.7	0.0697674	Middle nuclei
20	44	24	27.7	0.090909	Middle nuclei
20	46	26	3.54	0.1304347	Middle nuclei
20	48	28	1.25	0.166666	Middle nuclei
28	58	30	109	0.0344827	Middle nuclei
28	60	32	62.8	0.0666666	Middle nuclei
28	61	33	44.4	0.0819672	Middle nuclei
28	62	34	23.4	0.0967741	Middle nuclei
28	64	36	3.77	0.125	Middle nuclei
50	112	62	44.9	0.1071428	Middle nuclei
50	114	64	5.5	0.122807	Middle nuclei
50	115	65	5.08	0.1304347	Middle nuclei
50	116	66	1.88	0.137931	Middle nuclei
50	117	67	2.45	0.1452991	Middle nuclei
50	118	68	1.18	0.1525423	Middle nuclei
50	119	69	0.999	0.1596638	Middle nuclei
50	120	70	0.450	0.166666	Middle nuclei
50	122	72	0.221	0.1803278	Middle nuclei
50	124	74	0.079	0.1935483	Middle nuclei
82	204	122	0.722	0.1960784	Heavy nuclei
82	206	124	0.556	0.2038835	Heavy nuclei
82	207	125	0.366	0.2077294	Heavy nuclei
82	208	126	0.395	0.2115384	Heavy nuclei

In this work, we classify it into two groups (middle and heavy group) for Z magic number. We calculate $(f_{sh,p})$ shell corrections for nuclei in table-2, by using Eq.(6) for target nuclei with atomic number $18 \le Z \le 50$,

and by using Eq.(8) for target nuclei with $Z > 50$, in this calculation, we neglect $(\Delta\sigma)$ as in table-3 below:

Table-3: Shell Corrections for Stable Magic Nuclei by Z with Mass Number from 42 to 208.

Z (magic number)	A	N	Cross section (mb)	$f_{sh,p}$ (shell corrections)	Type of nuclei
20	42	22	72.7	-1.943438565	Middle nuclei
20	43	23	58.7	1.44521205	Middle nuclei
20	44	24	2.7.7	0.767195774	Middle nuclei
20	46	26	3.54	-3.254039806	Middle nuclei
20	48	28	1.25	5.226765218	Middle nuclei
28	58	30	109.0	-1.954322933	Middle nuclei
28	60	32	62.8	-0.619876389	Middle nuclei
28	61	33	44.4	0.289385939	Middle nuclei
28	62	34	23.4	-1.095517519	Middle nuclei
28	64	36	3.77	-7.729426082	Middle nuclei
50	112	62	44.9	11.19111369	Middle nuclei
50	114	64	5.5	-2.749693406	Middle nuclei
50	115	65	5.08	-0.192543522	Middle nuclei
50	116	66	1.88	-6.31194056	Middle nuclei
50	117	67	2.45	-0.410900645	Middle nuclei
50	118	68	1.18	-3.581115297	Middle nuclei
50	119	69	0.999	-1.426490776	Middle nuclei
50	120	70	0.450	-5.248076514	Middle nuclei
50	122	72	0.221	-4.137073847	Middle nuclei
50	124	74	0.0791	-5.779070373	Middle nuclei
82	204	122	0.722	-16.61078525	Heavy nuclei
82	206	124	0.556	-14.64893586	Heavy nuclei
82	207	125	0.366	-13.40713798	Heavy nuclei
82	208	126	0.395	-12.66681246	Heavy nuclei

By using table-2 when A=42 to A=124 empirical equation by least-square fitting method:

$$\sigma(n,\alpha) = 1900.35e^{-0.0415A}$$

The relationship between cross section (mb) and mass number A, explained as in fig.1 for middle nuclei

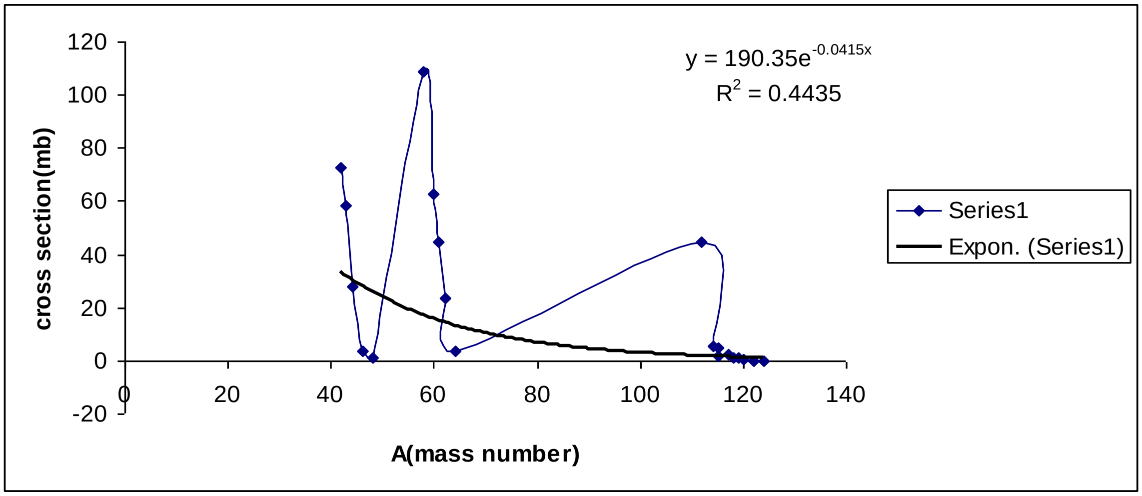

Fig .(1): The Relationship Between Cross-Section and Mass Number for Middle Nuclei.

And by using table-2, when A=204 to A=208 the relationship between $\sigma(n,\alpha)$ and mass number (A) as in fig .2 for heavy nuclei, the empirical equation by least-square fitting method:

$$\sigma(n,\alpha) = 0.0012A^2 - 0.9714A + 111.98$$

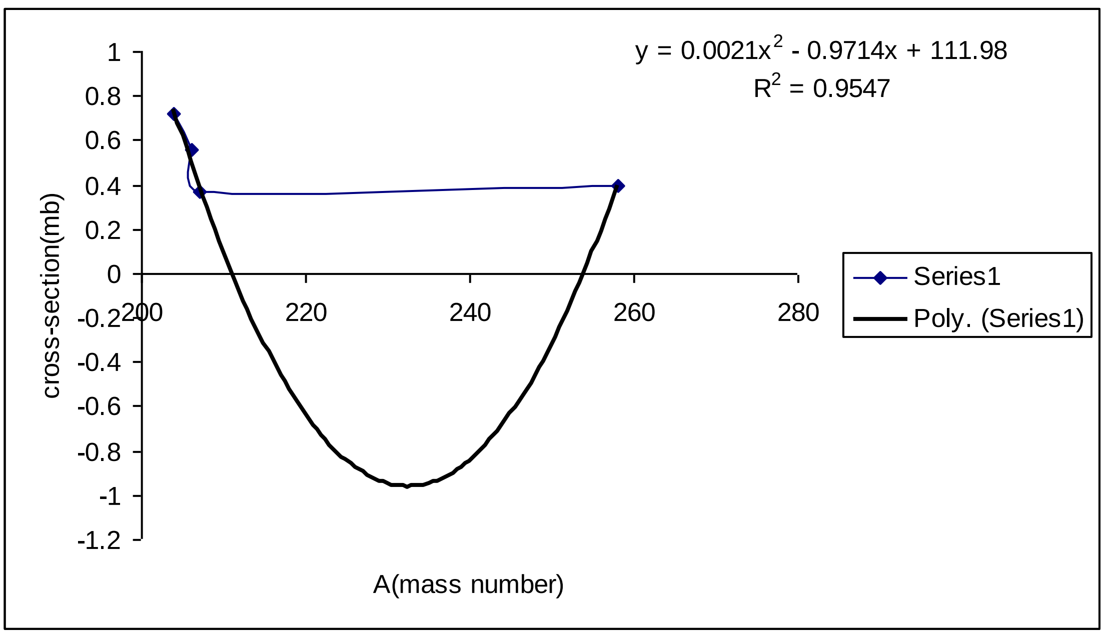

Fig.2: The Relationship Between $\sigma(n,\alpha)$ and Mass Number (A) for Heavy Nuclei.

In this work, we conclude empirical equations by least-square fitting method to calculate asymmetry parameter for magic nucleus in Z for (n,α) reaction of incident neutron energy 14.5 MeV by using table-2 as shown below:

$\frac{(N-Z)}{A}=3E-05A^2-0.0037A+0.206$ for A=42 to A=124 as in fig.3 for middle nuclei.

$\frac{(N-Z)}{A}=0.0039A-0.5929$ for A=204 to A=208 as in fig.4 for heavy nuclei.

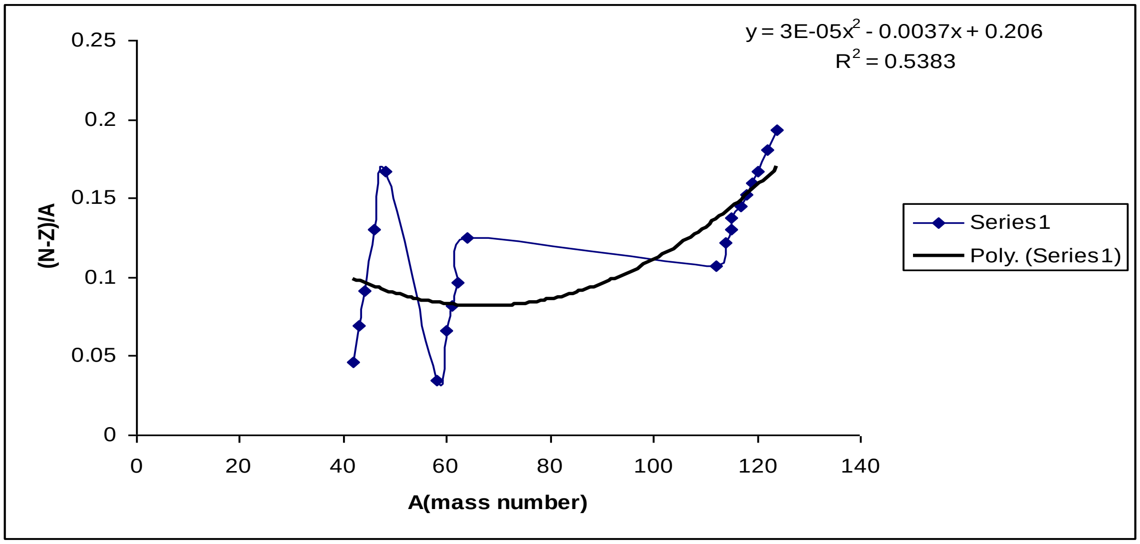

Fig.3: Asymmetry Parameter for A=42 to A=124 Middle Nuclei.

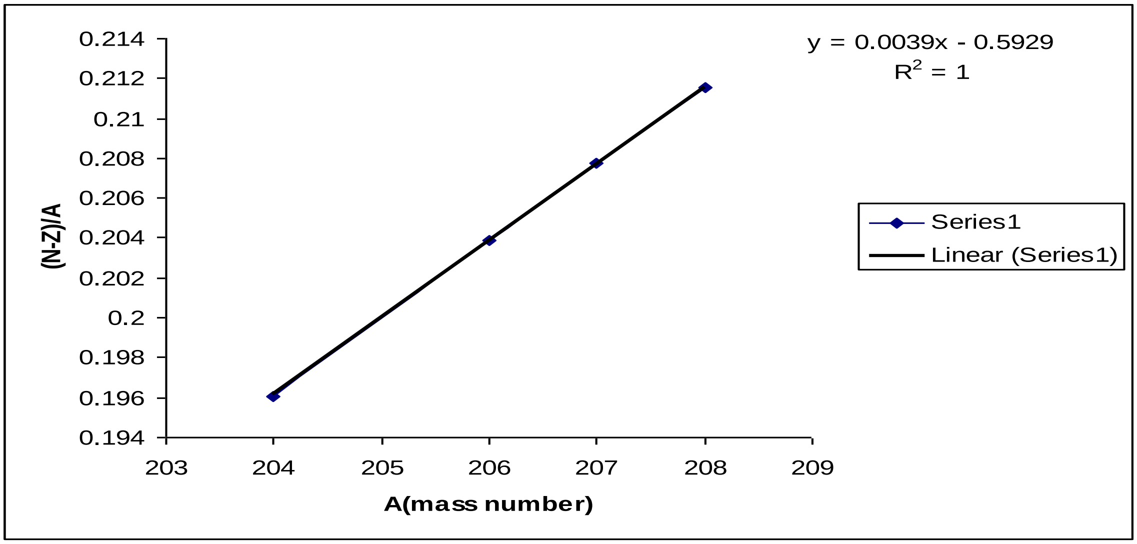

Fig.4: Asymmetry Parameter for A=204 to A=208 Heavy Nuclei.

The magic nuclei which have Z or N are equal to (2,8,28,50,82,126). In this study, we choose the nuclei which have (Z) magician number because the required information was found in table -2, and the reason for choosing this nuclei to add knowlage about probability of making nuclear reaction for that nuclei from type $\sigma(n,\alpha)$ and cause of known behavior to that nuclei from asymmetry parameter and also shell corrections

$(f_{sh,P})$, and as result for that we divide this nuclei into tow groups: one of them expresses the middle nuclei group $(40 < A < 140)$ and the other group expresses heavy nuclei $(A > 140)$.

From table -2, we realize that, middle group one, gets high values for cross section reaction $\sigma(n,\alpha)$ of incident neutron energy 14.5 MeV compared with low values for the same cross sections for heavy nuclei, in other words, the area interactions in energy between middle nuclei and incident neutron are every high which simplify and occur the nuclear reaction (n,α).

Also the factor of shell corrections of middle nuclei is bigger than the heavy nuclei as shown in table-3.

The asymmetry parameter for middle nuclei is proportional and expositional with mass number as in fig.(3), also that the values of asymmetry parameter are small while cross sections is high. We found the asymmetry parameter values for heavy nuclei were big compared with middle nuclei fig.(4) that means, the asymmetry parameter affects with cross section values for that nuclei.

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