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Evaluation of The Nuclear Data on(α,n)Reaction for Natural Molybdenum

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Abstract

The cross section evaluation for (α,n) reaction was calculated according to the available International Atomic Energy Agency (IAEA) and other experimental published data . These cross section are the most recent data , while the well known international libraries like ENDF , JENDL , JEFF , etc.

We considered an energy range from threshold to 25 MeV in interval (1 MeV).

The average weighted cross sections for all available experimental and theoretical(JENDL) data and for all the considered isotopes was calculated .

The cross section of the element is then calculated according to the cross sections of the isotopes of that element taking into account their abundance . A mathematical representative equation for each of the element and their isotopes are "formulated" they represent the variation of the cross section with energy .

The evaluated (α,n) cross sections which was used to calculate the neutron yield for (Mo) for the first time ,which are very important in nuclear technology .

Introduction

When two charged nuclei , overcoming their coulomb repulsion , a rearrangement of the constituents of the nucleus may occur . Thus the nuclear reaction takes place when an initial state involving nucleons is converted into different final state involving nucleons similar to the rearrangement of atoms in reacting molecules during a chemical reaction . Nuclear reactions are usually produced by bombarding a target nucleus with a nuclear projectile, in most cases a nucleon (neutron or proton) or a light nucleus such as a deuteron or an α-particle ….. etc [1].

If a target nucleus ***X*** is bombarded by a particle ***a*** , and result in a nucleus ***Y*** with emitted particle ***b*** , this is written as (2) :

$$X + a \rightarrow Y + b \qquad \text{------ (1)}$$

To shorten the notation a reaction of type (1) is designated by :

$$X\ (a\ ,b)\ Y \qquad \text{------- (2)}$$

In some cases ***b*** and ***Y*** have comparable masses (spallation or fission) , or are identical .

In most cases in which more than two products appears , it is possible to describe the process as a rapid sequence of two – product reactions [2]

$$a + X \rightarrow b_1 + Y_1$$
$$Y_1 \rightarrow b_2 + Y_2$$
$$Y_2 \rightarrow b_3 + Y_3 \qquad \text{------(3)}$$

The excited product nucleus usually decays very quickly to the ground state with the emission of γ-rays [3] .

Theory

For bombarding energies below 100 MeV, nuclear reactions usually produce two products [1]. They are of the type :

$$X + a \rightarrow Y + b \quad \text{------- (4)}$$

Where X = target (at rest in the lab. System)
a = bombarding particle
Y = heavy reaction product
b = light reaction product

Since the number of protons and neutrons remain unchanged in a reaction , all masses can be written as atomic masses if electron binding energy differences (of a few eV) are ignored . Conservation of energy , therefore gives for the above reaction:

$$M_a c^2 + T_a + M_x c^2 = M_b c^2 + T_b + M_y c^2 + T_y \quad \text{------- (5)}$$

Where T represents the laboratory kinetic energy of each particle .

The Q– value of the reaction is defined as the difference between the final and initial kinetic energies:

$$Q = T_b + T_y - T_a \quad \text{-------- (6)}$$

Or $$Q = [\, M_a + M_x - M_b - M_y \,]\, c^2 \quad \text{-------(7)}$$

If Q is positive , the reaction is said to be exo-ergic process , if Q is negative , it is endo-ergic process [1] .

A reaction cannot take place unless particles b and y emerge with positive kinetic energies , that is ,

$$T_b + T_y \geq 0 \quad \text{--------- (8)}$$

$$Q + T_a \geq 0 \quad \text{-------- (9)}$$

In figure (1) the lab. system $T_x= 0$, $P_a = (2m_aT_a)^{1/2}$ and $\upsilon_a = (2T_a/m_a)^{1/2}$,while in the C.M. system:

$$P_{c.m.} = P_a + P_x \quad \text{------ (10)}$$

and

$$V_{c.m.} = P_a / (m_a+ m_x) \quad \text{------ (11)}$$

$$Q_o = M_a c^2 + M_x c^2 - M_b c^2 - M_y c^2 = T_b + T_y - T_a \quad \text{------ (12)}$$

Where Q_o is the Q-value of the reaction with the product nucleus Y (in the ground state) . On the other hand, many reactions leave Y in excited states, in that case:

$$Q = M_a c^2 + M_x c^2 - M_b c^2 - M_y^{*} c^2 = T_b + T_y - T_a \quad \text{------ (13)}$$

Then for ; $Q>0$

$$M_a c^2 + M_x c^2 > M_b c^2 + M_y^{*} c^2 \;;\; T_b + T_y - T_a > 0 \quad \text{----- (14)}$$

and for ; $Q<0$

$$M_a c^2 + M_x c^2 < M_b c^2 + M_y c^2 \;;\; T_b + T_y - T_a < 0 \quad \text{---- (15)}$$

So the $Q < 0$ process cannot occur spontaneously, which means that there is a threshold energy $T_{a(thr)}$ given by [1]:

$$T_{a(thr)} = E_{thr} = - Q\,(1 + M_a/M_x) \quad \text{------- (16)}$$

In general, the Q-value of reactions in terms of T_a, T_b, M_a, M_x, M_b, M_y, and angle (θ)is given by

$$Q = T_b(1+\frac{M_b}{M_y}) - T_a(1-\frac{M_a}{M_y}) - \frac{2}{M_y}(M_aT_aM_bT_b)^{1/2}\cos\theta \quad \text{------ (17)}$$

which is called the Q equation.

The Yield of neutron detected per incident particle , Y_n , for an ideal , thin , and uniform target and monoenergetic beam of energy E_b is given by [4] :

$$Y_n = (nt)\,\sigma(E_b)\,\varepsilon(E_b) \quad \text{-------- (18)}$$

Where :

(nt) is the a real number density of target atoms

σ is the reaction cross section

ε is the neutron-detection efficiency

For target which is not infinitesimally thin , the beam loses energy as it passes through the target , and the Yield is then given by :

$$Y_n = \int_{E_{thr}}^{E_b} \frac{\sigma(E')\varepsilon(E')\,f\,dE'}{\frac{dE}{dX}(E')} \quad \text{----------- (19)}$$

In which ($E_{thr} = E_b - \Delta E$)

Where :

ΔE is the energy loss of the beam in the target

f is the number of target atoms in each target molecule

$\frac{dE}{dX}(E')$ is the stopping power per target molecule .

If the target is sufficiently thick, and there exists one atom per each molecule (i.e., $f = 1$) and taking the efficiency $\varepsilon(E`) = 1$, then the resulting yield is called the thick-target yield which is given by [4] :

$$Y(E_b) = \int_{E_{thr}}^{E_b} \frac{\sigma(E)dE}{(dE/dX)} \quad \text{------ (20)}$$

Where (E_{thr}) is the reaction threshold energy.

The sets of experimental data were compared in given energy intervals . First , averaged cross-section values were determined by taking the characteristics of the excitation function of the reaction in equation into account , namely the structural characteristics of their alpha particle energy dependence . The averaging was done over energy intervals of 0.5 MeV in general for alpha particle energies up to 25 MeV.

Values for the weighted average cross-sections based on (n) measured values were determined for each energy interval using the expression for σ-bar[5] :

$$\bar{\sigma} = \frac{\sum_{i=1}^{n} w_i\,\sigma_i}{\sum_{i=1}^{n} w_i} \quad \text{-------- (21) , where :} \quad w_i = \frac{1}{(\Delta\sigma_i)^2}$$

Is the weight given to the experimental value on the basis of the fractional standard deviation[5]

$$\Delta \sigma_{FSD} = \frac{1}{\sqrt{\sum_{i=1}^{n} w_i}} \quad \text{-------- (22)}$$

Result and Discussion

Cross Section of $^{92}Mo(\alpha,n)^{95}Ru$ Reaction :

The reaction Q-value and threshold energy are (-9.0016 Mev,9.3936 Mev) respectively for the neutron emission reactions on (^{92}Mo) by α-particle bombardment.

The latest cross sections of $^{92}Mo(\alpha,n)^{95}Ru$ reaction available in literature have been measured and declared by Denzler [6] , Esterlund [7] , Levkovskij [8] and Graf [9] . These data have been plotted , spline interpolated and recalculated in steps of (1 MeV) from threshold energy to (25 MeV) of the α-particle energy by using Matlab program .

The weighted average cross sections and the corresponding error are calculated by using eq. (21) , (22) respectively . The evaluated cross sections from ref. [6] , [7] ,[8] and [9] are listed too in table (1) .

Fig. (2) shows the corresponding cross sections with an empirical formula .

Cross Section of $^{94}Mo(\alpha,n)^{97}Ru$ Reaction :

The reaction Q-value and threshold energy are (-7.94387 Mev, 8.28246 Mev) respectively for the neutron emission reactions on (^{94}Mo) by α-particle bombardment.

The cross sections of the $^{94}Mo(\alpha,n)^{95}Ru$ reaction have been published as a function of α-energy by Levkovskij [8] and Graf [9] .

These data have been plotted , spline interpolated and recalculated in steps of (1MeV) from threshold energy to (25 MeV) of the α-particle energy by using Matlab program .

The weighted average cross sections and the corresponding error are calculated by using eq. (21) , (22) respectively . The reproduced cross sections from ref.[8] and [9] are listed too in table (2) . Fig. (3) shows the corresponding cross sections with an empirical formula .

Cross Section of $^{100}Mo(\alpha,n)^{103}Ru$ Reaction :

The reaction Q-value and threshold energy are (-4.57193 Mev,4.75509 Mev) respectively for the neutron emission reactions on (^{100}Mo) by α-particle bombardment, and the cross sections of the $^{100}Mo(\alpha,n)^{103}Ru$ reaction have been published as a function of α-energy by Graf [9] and Esterlund [7] .

These data have been plotted , spline interpolated and recalculated in steps of (1 MeV) from threshold energy to (25 MeV) of the α-particle energy by using Matlab program .

The weighted average cross sections and the corresponding error are calculated by using eq. (21) , (22) respectively . The reproduced cross sections from ref. [9] and [7] are listed too in table (3) . Fig. (4) shows the corresponding cross sections with an empirical formula .

The Natural Molybdenum

Natural Molybdenum Composed of (14.84%) of ^{92}Mo , (9.25 %) of ^{94}Mo , (15.92%) of ^{95}Mo , (16.68%) of ^{96}Mo , (9.55%) of ^{97}Mo , (24.13%) of ^{98}Mo , and (9.63%) of ^{100}Mo .

The threshold energies of $^{92}Mo(\alpha,n)^{95}Ru$ reaction , $^{94}Mo(\alpha,n)^{97}Ru$ reaction and $^{100}Mo(\alpha,n)^{103}Ru$ reaction lies in the range of our work . The isotopes ^{95}Mo , ^{96}Mo , ^{97}Mo and ^{98}Mo does not reacte with α-particle , for this reason the cross section of $^{nat}Mo(\alpha,n)Ru$ are calculated from the cross sections of ^{92}Mo , ^{94}Mo and ^{100}Mo and the results are listed in table (4) in step of (1 MeV) . Fig. (5) shows the corresponding cross sections with an empirical formula.

The neutron yields of the following (α ,n) reactions have been obtained using equation (21) ,and the results are plotted in fig. (6)

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Table (1) : The Cross Section of $^{92}Mo(\alpha,n)^{95}Ru$ Reaction as afunction of α-particle

E_α(MeV)	Cross Section (mb)				Weighted average cross section(mb)	error(mb)
	Denzler 15%[6]	Esterlund 12%[7]	Levkovskij 10%[8]	Graf 10%[9]		
9.0	----	0.55	34.4286	----	0.5624	0.066
10.0	----	3.01	62.2308	----	3.2088	0.3606
11.0	----	5.47	98.3846	----	5.8818	0.6549
12.0	36.6	21.1773	161.5	6	7.334	0.5803
13.0	75.2222	50.1318	193.8182	32	41.361	2.7136
15.0	286	163.1789	313	175.5	198.1799	11.61
16.0	327.4286	226.6667	366.2	302.2857	290.0498	16.6522
17.0	459.0667	278.3333	433	443	373.4472	21.5654
18.0	414.25	324.0588	486.9	532	421.6858	24.2863
19.0	626.6	365.8235	463.2	553	461.3275	26.4888
20.0	479.8	365.5	445.3333	574	448.0994	25.6441
21.0	498.3333	358	470	554	451.1607	25.8257
22.0	346.2857	312.2857	376.8	453.0909	367.9672	20.9695
23.0	327	261.2	290	352.1818	300.557	17.0776
24.0	296.0000	207.6923	250.0000	278.00	248.2944	14.1265
25.0	162.0000	164.6154	193.2857	210.50	183.7526	10.4315

Table (2) : The Cross Section of $^{94}Mo(\alpha,n)^{95}Ru$ Reaction as afunction of α-particle

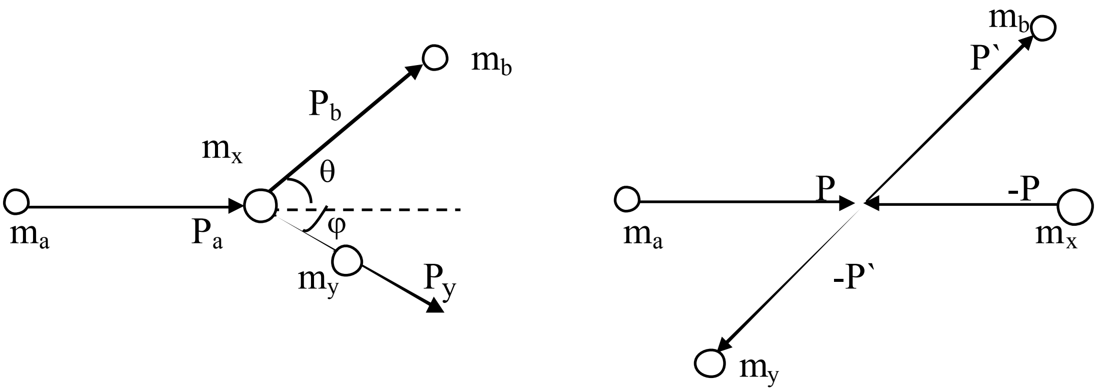
E_α(MeV)	Cross Section (mb)		Weighted average cross section(mb)	error(mb)
	Levkovskij 10%[8]	Graf 18%[9]		
12	203.5	11	12.8053	1.9707
13	236	53.5	79.5498	8.9163
14	374	96	144.9056	15.6866
15	379.9091	283	345.2724	30.4541
16	391.2	470	405.0812	35.5076
17	507.25	686	533.0592	46.9203
18	528.6	702	554.4254	48.765
19	515.8	678	540.3828	47.5108
20	472.3333	654	497.5242	43.8364
21	401.8	583.4444	424.9937	37.5272
22	347.6	512.8889	368.1227	32.5306
23	258	442.3333	275.516	24.5436
24	247.6	370	262.4631	23.208
25	221.2857	295	232.1932	20.4259

Table (3) : The Cross Section of $^{100}Mo(\alpha,n)^{103}Ru$ Reaction as afunction of α-particle

E_α(MeV)	Cross Section (mb)		Weighted average cross section(mb)	error(mb)
	Graf 10%[9]	Esterlund 18%[7]		
10.8	64	22.4256	34.2574	3.4142
11	66.0909	25.8412	39.1738	3.8038
12	76.5455	42.9189	59.8871	5.4375
13	87	56.124	73.8521	6.5923
14	88	68.5432	81.4393	7.1643
15	89	74.0185	84.3775	7.4007
16	82	65.7194	76.7161	6.7392
17	75	55.7701	68.1114	6.0083
18	64.4444	42.8749	55.583	4.9466
19	54.4706	33.8233	45.291	4.0595
20	46.8235	27.4323	37.6425	3.3976
21	39.75	22.7893	31.5364	2.8546
23	28.6957	----	28.6957	2.8696
24	26.087	----	26.087	2.6087
25	23.6364	----	23.6364	2.3636

Table (4) : The Cross Section of $^{nat}Mo(\alpha,n)Ru$ Reaction

E_α(MeV)	Cross Section (mb)			
	Mo-92	Mo-94	Mo-100	Mo-nat
9	0.5624	----	----	0.0835
10	3.2088	----	----	0.4762
11	5.8818	----	39.1738	4.6453
12	7.334	12.8053	59.8871	8.04
13	41.361	79.5498	73.8521	20.6083
14	75.6147	144.9056	81.4393	32.4676
15	198.1799	345.2724	84.3775	69.4731
16	290.0498	405.0812	76.7161	87.9012
17	373.4472	533.0592	68.1114	111.2867
18	421.6858	554.4254	55.583	119.2152
19	461.3275	540.3828	45.291	122.8079
20	448.0994	497.5242	37.6425	116.1439
21	451.1607	424.9937	31.5364	109.3011
22	367.9672	368.1227	26.2536	91.1859
23	300.557	275.516	28.6957	72.8513
24	248.2944	262.4631	26.087	63.6369
25	183.7526	232.1932	23.6364	51.0229



(a) Laboratory system. **(b) C.M. system.**

Fig. (1):The nuclear reaction observed in laboratory and center of mass coordinates

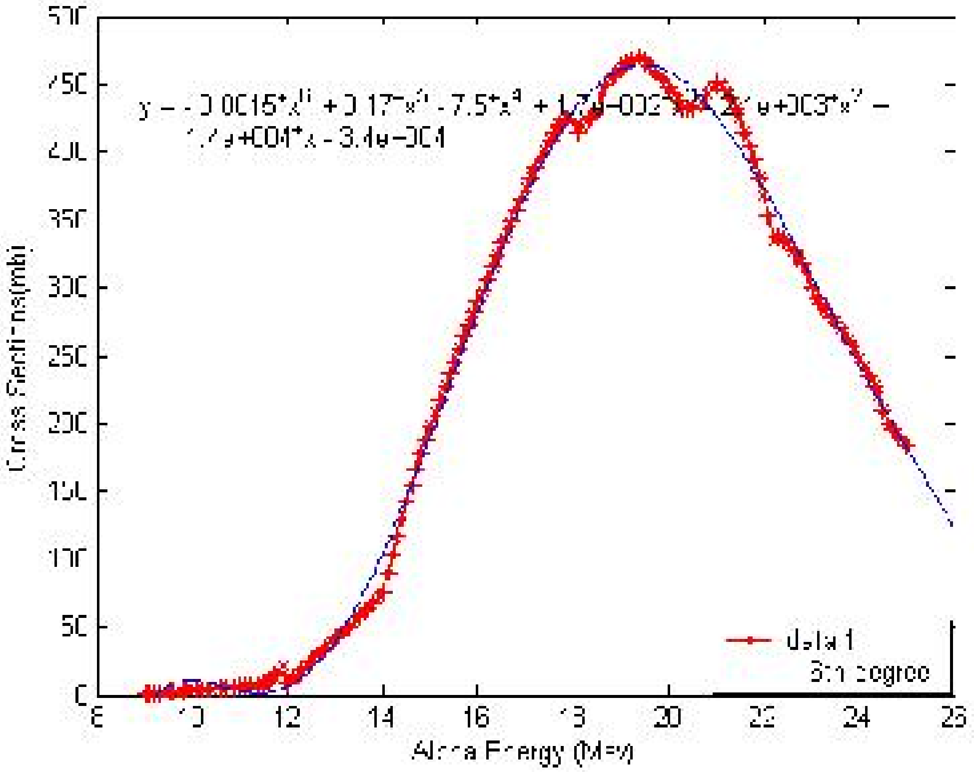


Fig.(2): Cross Sections of $^{92}Mo(\alpha,n)^{95}Ru$ Reaction

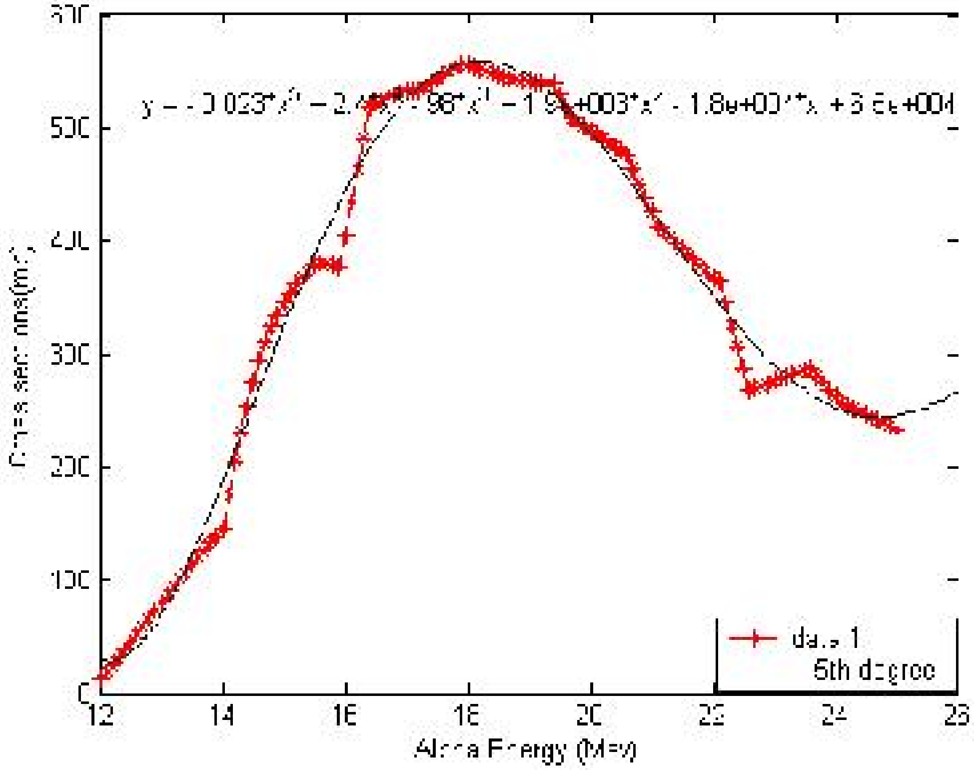


Fig.(3): Cross Sections of $^{94}Mo(\alpha,n)^{95}Ru$ Reaction

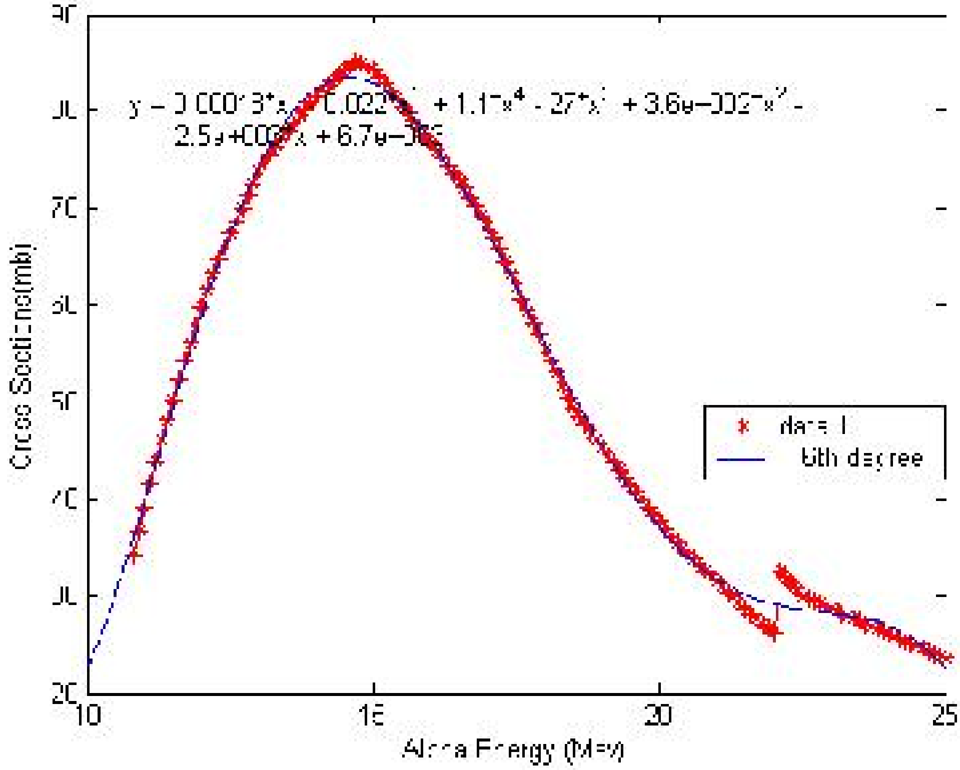


Fig.(4):Cross Sections of $^{100}Mo(\alpha,n)^{103}Ru$ Reaction

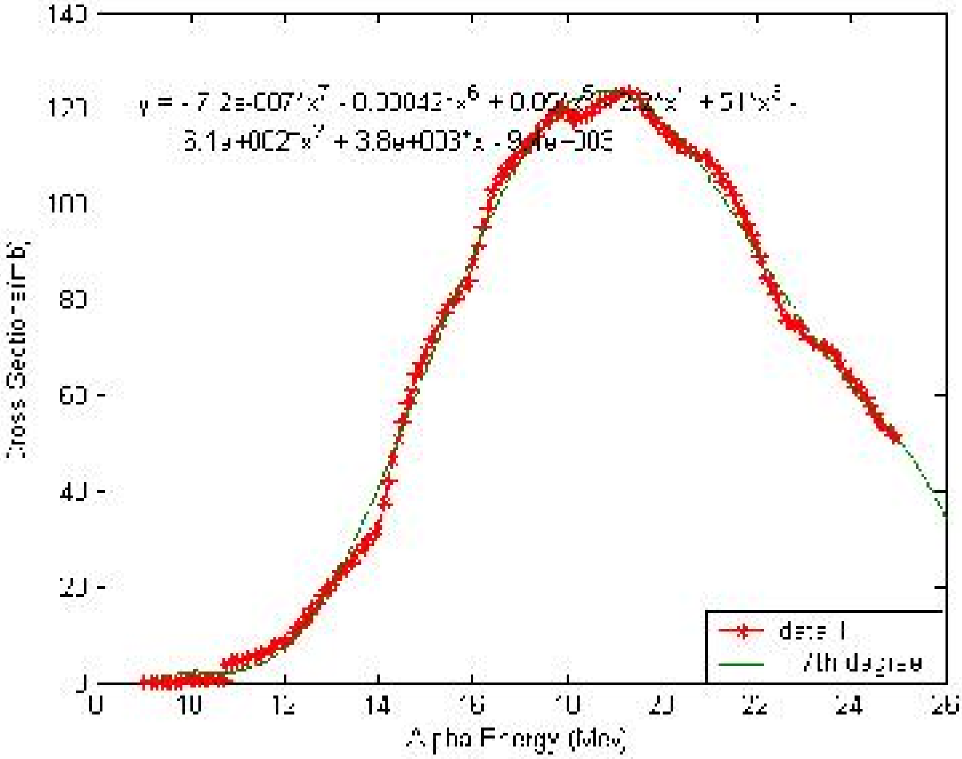


Fig.(5): Cross Sections of $^{nat}Mo(\alpha,n)Ru$ Reaction

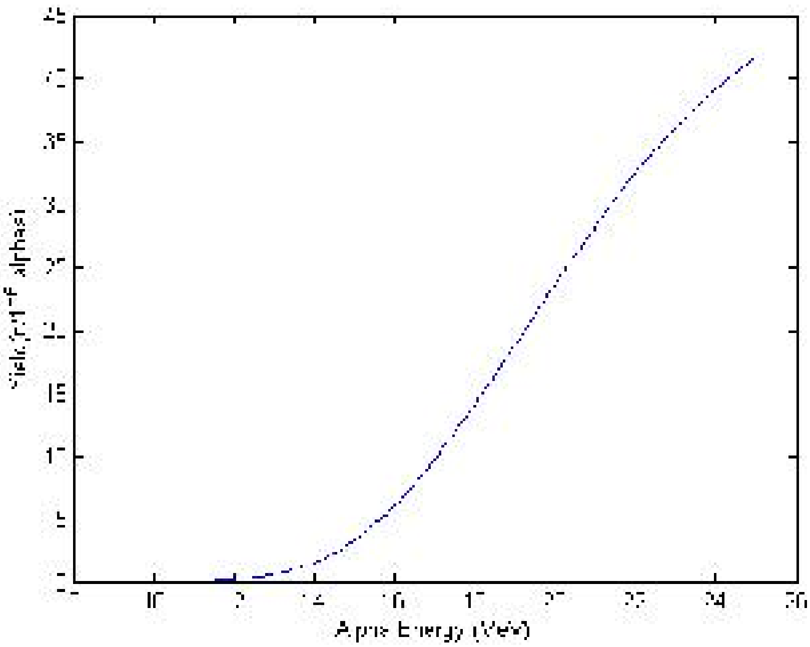


Fig.(6): Neutron Yield for ^{nat}Mo

مجلة ابن الهيثم للعلوم الصرفة والتطبيقية المجلد 23 (3) 2010

تقييم المعطيات النووية لتفاعلات (α,n) الخاصة لعنصر المولبديوم

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الخلاصه

ان قيمة المقاطع العرضية لتفاعلات (α,n) قد تم حسابها وفقا للمعلن من سجلات الوكالة الدولية للطاقة الذرية وهي احدث وادق مصدر من مصادر المقاطع العرضية ، بينما تؤشر سجلات المكتبات العالمية المشهورة، مثل ENDF ، JENDL ، JEFF الى ان بعض المقاطع العرضية للنظائر التي تم تناولها قد تم اعدادها في زمن سابق .

أخذت القياسات المطلوبة للمقاطع العرضية للمدى الطاقي من طاقة العتبة والى (25MeV) وبخطوات طاقية (1MeV) ومن ثم ايجاد المعدل الموزون للمقاطع العرضية لكل طاقة من طاقات جسيمات الفا الساقطة وتم جدولة جميع البيانات المستحصلة النظائركافة .

حسبت المقاطع العرضية للعناصر بالاعتماد على المقاطع العرضية المحسوبة لكل نظير من العنصر وعلى وفرة هذه النظائر في الطبيعة . واستبطت المعادلات الرياضية لكل نظير قيد الدراسة والتي تمثل تغير المقطع العرضي بدلالة الطاقة .

استخدمت هذه المقاطع العرضية المستحدثة لحساب الحصيلة النيوترونية .