Interaction Samarium and Holmium with Charged Particles (Alpha particles)

Sameera Ahmed Ebrahiem and Sameer . H. AL- khalidi

Physics Department – College of Ibn Al-Haytham – University of Baghdad – Iraq

Abstract:

Present study focused on the nuclear properties of same nuclei for the Rare earth elements by account (interaction energy, energy threshold, the excess mass, energy and connectivity, the coulomb barrier and the proportion of packing), the cross- sections published in the international literature for the selection of the appropriate energies ground level interaction in a computer–based program (MATALAB7.6.0R2008a),in steps of energies (0.2MeV).The derivation of the equation quasi-experimental painted tabulated results linking cross-section a certain with energies, account of the neutron yield in according with the formula Zeigler neutron interactions using the program (SRIM 2013), to account for the ability of stopping power which drawn and tabulated the results as well, and its purpose is to determine the neutron energies for the production of isotopes that included in production of Laser used in medical, industrial and military fields, agricultural and computers. Consider account the inverse of the cross- sections of the interactions (n,α),in the ground state and using the equation of quasi-experimental cross sections drawn and tabulated the results obtained to get the cross section in direct method and simple.

Keywords : cross sections , stopping power, neutron yield, isotopes.

سميرة احمد إبراهيم ، سمير هاشم ألخالدي

قسم الفيزياء– كلية التربية – ابن الهيثم– جامعة بغداد

الخلاصة

تركزت الدراسة الحالية حول دراسة الخواص النووية لنوى عناصر الاتربة النادرة من حيث حساب (طاقة التفاعل ، طاقة العتبة ، فائض الكتلة وطاقة الربط ، وحاجز كولوم ونسبة الحزم او الرص) للعناصر (السماريوم والهولميوم)للتفاعلات, تم حساب المقاطع العرضية والمأخوذة من الادبيات العالمية وللمستوي الارضي وذلك بأستخدام برنامج الماتلاب (MATLAB 7.6 R 2008 a) وبخطوات طاقية معينة (0.2 MeV) . بالاعتماد على قيم التماثل والبرم (spin and parity) تم حساب العامل الاحصائي (The statistical g–factors)

لاشتقاق معادلات شبه تجريبية لحساب المقاطع العرضية بالتفاعل المعاكس وايضا تم حساب الحصيلة النيوترونية بالاعتماد على صيغة زكلرفي حساب قدرة الايقاف وقياس المقاطع العرضية لنفس المدى الطاقي للتفاعلات اعلاه .وكذلك تم حساب المقاطع العرضية العكسية للتفاعلات (نيوترون ، الفا) للعناصر المذكوره اعلاه كأهداف وللمستوى الارضي والتي رسمت وجدولت وتم مناقشاتها ضمن مناقشة النتائج .

Introduction:

(1):**The atomic mass of isotopic.**

In this study, mass excess and packing fraction in (keV) for each element by using equations(1),(2) and (3) respectively. In table(1) the abundance are given for isotopes [1]. The atomic mass is the mass of an atomic particle, subatomic particle, or molecule**,** units are expressed in (amu).It is defined as(1/12) of the mass of a single $^{12}_{6}C$ atom(at rest), http://en.wikipedia.org/wiki/Atomic_mass - cite_note-1

($1U=\frac{1}{12}M\,^{12}_{6}C=931.481MeV/c^2= 1.66043x10^{-27}$ Kg) known as eq.(1) . Also are given spin , parity (J^{π}) and half life in down table(1) [2,3] .

$M(A,Z) = Z\, M_H + (A-Z)\, M_n - M_D(Z,N)$ ....(1)

where : M_H, M_n = are masses of hydrogen atom and neutron respectively ,

M_D =Mass of daughter [4]

Mass excess: is an expression of the nuclear binding energy, relative to the binding energy per nucleon of $^{12}_{6}C$ http://en.wikipedia.org/wiki/Carbon-12. If the mass excess is negative, the nucleus has more binding energy than $^{12}_{6}C$,and vice versa [5].If a nucleus has a large excess of mass compared to a nearby nuclear species, it can decay, releasing energy known as: [5].

Mass excess = M - A = Excess energy/c^2 ....(2)

where : M = is the actual mass of the nucleus in (amu), A = is the mass number.

Packing fraction: is known as a way to expressing the variation of isotopic mass from hole mass number (atomic mass). Is given by:

$$\text{Packing fraction} = \frac{M - A}{A}$$ ....(3)

Table (1): The properties of nuclear used in the present work [2], [3].

Chem. Symbol	Elements	Atomic Mass(a.m.u) [2], [3]	Mass Excess (keV) (p.w) [2], [3]	Packing Fraction(p.w) [2], [3]	Abu.%	J^{π}	Half-life [3]
$^{1}_{0}n$	**neutron**	1.0086645	8070.5160	8070.516	………	$\frac{1}{2}^{+}$	616.300 ns
	Helium	4.002603	24250000	606.1736	99.999	0^{+}	stable
	Samarium	143.911995	- 81976.6575	-569.2823	3.1	0^{+}	stable
$^{147}_{64}Gd$	**Gadolinium**	146.919089	-75368.5965	-512.7115	100	7 /	38.06 h
$^{148}_{64}Gd$	**Gadolinium**	147.918110	-76280.535o	-515.4090	100	0^{+}	74.6 y
$^{165}_{67}Ho$	**Holmium**	164.930319	-64907.8515	-393.3809	100	7 /	stable
$^{168}_{69}Tm$	**Thulium**	167.934170	-61320.6450	-365.0038	≈100	3^{+}	93.1 d
$^{169}_{69}Tm$	**Thulium**	168.934211	-61282.4535	-362.6180	100	$\frac{1^{+}}{2}$	stable

The Q-value and threshold energy for(α,n) interaction have been calculated for interaction maintained in table (2) using equations(4) and(6) respectively, in comparison with the experimental results are in very good agreement [2].

Q-value : is known as the difference in mass energy of the product and reactants, get by:

$$\mathbf{Q} = [(m_a + M_X) - (m_b + M_Y)]c^2 \quad \text{.........................(4)} \quad \text{or}$$

The $Q_{\text{-value}}$ of any decay is defined as the sum of kinetic energy after the decay ($T_b + T_Y$) minus the some of kinetic energy before the decay ,as given by:

$$\mathbf{Q = T_b + T_Y - T_a} \quad \text{............ ....(5)}$$

Where : $\mathbf{M_x}$ = is the mass of aim nucleus , $\mathbf{m_a}$ = is the mass of bombarding particle,

$\mathbf{M_Y}$ = is the mass of heavy nucleus , $\mathbf{m_b}$ = is mass of the light particle,

T = is the kinetic energy .

If **Q > 0**, the reaction is called (exothermic) .If **Q < 0** , the reaction is called endothermic or (endoergic), which the process cannot occur spontaneously [6].

The threshold energy : is defined as the minimum energy required just to emit the electron from metal surface, given by: [6].

$$T_{th} = |Q| \frac{m_a + M_x}{M_x} \qquad \text{.................................(6)}$$

Reduce mass and Binding energy to the aim particles and for interaction particles are also calculated in table (2) using eq.(7) ,(8) respectively. And calculated in present work coulomb barrier by using eq.(9)[7].

$$\textbf{Reduce mass } (\mu) = \frac{m_a + M_x}{M_x} \qquad \text{.. ....(7)}$$

where : m_1= is the atomic mass of the projectile , M_2 = is the atomic mass of the aim. **Binding energy** B(A, Z):of a nucleus is equal to the mass transformed into energy when the (**Z**) protons and the N =A - *Z* neutrons got together and formed the nucleus[6].

$$BE(A, Z) = [ZM_P + NM_n - M_N(A, Z)]\, c^2 \qquad \text{. ... .(8)}$$

Coulomb barrier: is the strength of electrostatic repulsion that the alpha particle must overcome to enter the target nucleus and react [8].

$$\textbf{Coulomb barrier} \text{ (MeV)} = \frac{Z_1 Z_2 e^2}{r_0 \left(A_1^{1/3} + A_2^{1/3}\right)} \qquad \text{................(9)}$$

where $Z_I = 2$, $A_l = 4$, $e^2 = 1.44$ MeV.fm, $r_0 = 1.2$ fm, and Z_2 and A_2 referred to the aim nucleus Marion [9] .

Table(2): Q-value , threshold energy , binding energy, reduce mass and coulomb barrier for (α,n) interaction (in the ground state).

REEs interaction(α,n)	Q_0- Value (MeV)(P.W)	Threshold Energy(MeV) (P.W)	Binding Energy (MeV) (p.w)	Reduced Mass(amu)	Coulomb Barrier (MeV) [10]
	− 12.2538	**12.5942**	**1195.6761**	**3.8942**	**21.7897**
	− 9.2330	**9.4568**	**1344.1805**	**3.9077**	**22.7368**

Separation energy:The separation energy of neutron (S_n) has been calculated in the present work to compound nucleus to (α,n) interaction shown in table (3) , by equations (10) and calculated of the separation energy of alpha particle (S_α) to compound nucleus in (n,α) interaction shown in it, by using equations(11). Separation energy is known the energy required to remove (or separate) the most loosely proton or a single neutron $S_n\,({}^{A}_{Z}X)$ in the nucleus ${}^{A}_{Z}\square$,equal the difference in binding energies between ${}^{A}_{Z}\square$ and ${}^{A-1}_{Z}X$, is given by : [5].

$$S_n = [\, M_Y + M_{\square} - M_{\square} \,]\, c^{\square} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(10)$$

Or : $$S_{\square} = [\, m\,({}^{A-1}_{Z}X) + m_{\square} - m\,({}^{A}_{Z}\square)\,]\, c^{\square}$$

Separation energy for an alpha particle is[6].

$$S_{\alpha} = [\, M_Y + M_{\square} - M_{\square} \,]\, c^{\square} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(11)$$

Or : $$S_{\square} = B_{\alpha} = [M\,(A-4\,,\,Z-2) + M_{\alpha} - M(A\,,\,Z)]\, c^{\square}$$

Table(3): Separation energy of neutron (S_n) and Separation energy of α-partical (S_α) (present work).

RREs of (α,n) interaction	Compound Nuclide	S_n (MeV)	Inverse of (n,α interaction)	Compound Nuclide	S_α (MeV)
	${}^{148}_{64}Gd$	8.984	${}^{147}_{64}Gd(n,\alpha)^{\square 44}_{62}Sm$	${}^{148}_{64}Gd$	-3.271
	${}^{169}_{69}Tm$	8.033	${}^{168}_{69}Tm\,(n,\alpha)^{165}_{67}Ho$	${}^{169}_{69}Tm$	-1.200

Cross section: The probability is expressed quantity cross section you should be when goes the particle (Electron, Photon, Nuclei, $\alpha -$ particle, Proton) to any part of medium , it may be a specific probability to interact with the electrons or with the nuclei present in that medium . The concept of a neutron cross section is used to expressed the likelihood of interaction between an incident neutron and a aim nucleus, in coupling with the neutron flux [11]. Consider a mono energetic neutrons parallel beam incident on aim thickness **(t),** the microscopic cross section (barn)[12] shows as:

$$\sigma = R / I \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(12)$$

where: σ = The microscopic cross section (barn $=10^{-24}$ cm^2 $=10^{-28}$ m^2) ,

R= The count of interactions per unit time per nucleus, but (R = I N A , unit of (interaction / s)),
I = The count of incident particles per unit time per unit area (n / m^2s)

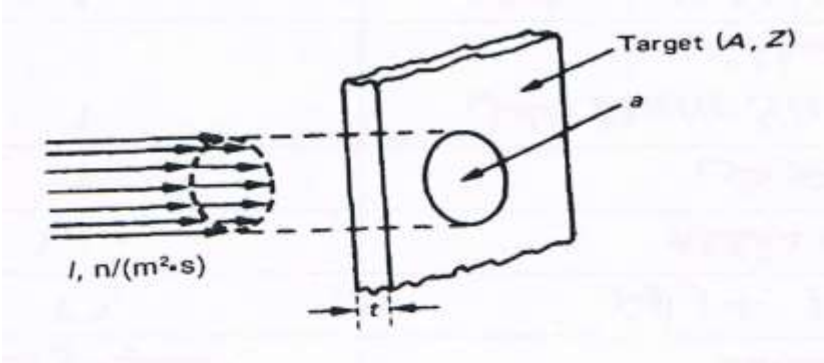

Fig.(1) :A parallel neutron beam hitting a thin the aim , a = area of the aim struck by the beam [12

The probability of a neutron interacting with a nucleus for a particular interaction is dependent to not only the type of nucleus involved, but also the energy of the neutron [11]. Neutron cross sections are defined separately for each type of interaction and isotope [12]. The sum of the all the microscopic cross sections, σ_T such as:

$$\sigma_T = \sigma_{\square} + \sigma_{\square} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(13)$$

where : $\sigma_{\square}$ = is the elastic scattering cross sections,
$\sigma_{\square}$ = is the absorption cross sections,

Another form of the cross section, is the macroscopic cross section $\sum_{\square}^{\square}$, defined by :

$$\Sigma = N\,\sigma \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(14)$$

where: Σ = are the macroscopic cross sections (cm^{-1}), N= is the atom density of medium (atoms/cm^3) , σ = is the microscopic cross-sections (cm^2/ atoms) .

Nuclear Stopping Power (S_n)**:** In passing through matter, fast charged particles ionize the atom or molecule which faces [6] .Therefore, the fast particles progressively lose energy in many small steps. Stopping power we mean the rate energy loss of the particle per unit path length designated by (-dE / dx), in units (MeV.cm^{-1} or J.m^{-1}) [6] . Depending on the energy lost by charged particles, stopping power is divided into:
1- Collision stopping power: rate of energy loss of the sum of soft and hard collisions

(collision interactions).

2- Radioactive stopping power: rate of energy loss of radioactive interactions i.e. fundamentally from bremstrahlung productions [7]

The total stopping power $\mathbf{S_t}$ $\mathbf{(-dT / dx)}$, is the sum of the electronic stopping power and nuclear stopping power shown as :

$$S_t = S_e + S_n \qquad \text{...................(15)}$$

where : S_e= stopping power with the aim electron,

S_n= stopping power with the aim nuclei, S_n in units of eV/(10^{-15} atoms/cm^2), any projectile with energy T (keV), is given by [5].

$$\mathbf{S_n}(\epsilon) = \frac{8.462\, Z_1 Z_2 m_1 S_n(\epsilon)}{(m_1 + m_2)(Z_1^{0.23} + Z_2^{0.23})} \qquad \text{..................... ....(16)}$$

$$\epsilon = \frac{32.53\, \mathbf{m_1 m_2} \left(\mathbf{T} \frac{}{\mathbf{m_1}}\right)}{\mathbf{Z_1 Z_2}(m_1 + m)(Z_1^{0}.23 + Z_2^{0}.23)} \qquad \text{...................... ....(17)}$$

where : T= ion energy in keV, $\varepsilon \leq 30$ keV,

$\mathbf{m_1}, \mathbf{m_2}$ = are the projectile and the aim masses (amu),

Z_1, Z_2 = are the projectile and the aim atomic number .

$$\mathbf{S_n}(\epsilon) = \frac{\ln(1 + 1.1383\, \epsilon)}{2[\varepsilon + 0.01321\varepsilon^{0.21226} + 0.19593\varepsilon^{0.5}]} \qquad \text{.,.. ....(18)}$$

Unscreened nuclear stopping is used, and S_n (ϵ) simplifies to,

$$\mathbf{S_n}(\epsilon) = \frac{\ln \varepsilon}{2\varepsilon} \qquad \text{.................................(19)}$$

where : ε = is the reduced ion energy, and defined as.

The nuclear stopping power (S_n) of the α-particle with different energy ranges have been presented by Ziegler[5] as follows: .

$$\mathbf{S_n} = 1.593\, \varepsilon^{\frac{1}{2}} \quad \text{for } (\epsilon < 0.01) \qquad \text{......................(20)}$$

$$\mathbf{S_n} = 1.37\, \varepsilon^{\frac{1}{2}} \left[\frac{\ln(\epsilon + e^{1})}{1 + 6.8\,\varepsilon + 3.4\,\varepsilon^{\frac{1}{2}}}\right] \quad \text{for } (0.01 \leq \epsilon \leq 10) \qquad \text{.........(21)}$$

$$\mathbf{S_n} = (\ln \epsilon\; 0.47)/2 \quad \text{for } (\epsilon > 10) \qquad \text{...................(22)}$$

Electronic Stopping Power(Se): Electronic stopping indicates into the slowing down of a projectile ion, because the inelastic collisions between bound electrons in the medium and the ion moving through it [9]. At high projectile energies, the ion is removed of its electrons and the state can to a good approximation be seen as coulomb scattering between the ion and electrons in the aim [13].

$$\left(\frac{1}{S_e}\right)=\left(\frac{1}{S_{Low}}\right)+\left(\frac{1}{S_{High}}\right) \qquad \text{.........................(23)}$$

$$S_{Low}=A_1T^{A_2} \qquad \text{... ....(24)}$$

$$S_{High}=\left(\frac{A_3}{T/1000}\right)\ln[1+\left(\frac{A_4}{T/1000}\right)+\left(\frac{A_5T}{1000}\right)] \qquad \text{... ....(25)}$$

these formulae are valid for alpha energy range (1keV -10 MeV) with **T** for high energy,

$$S_{\square}=\exp[\,A_6+A_{\square}\left(\ln\frac{1}{T}\right)+A_{\square}\left(\ln[(1/T)]^{2}\right)+A_{\square}\left(\ln[(1/T)]^{3}\right)\,] \qquad \text{..................(26)}$$

where : T= is the ion energy in MeV unite , $\mathbf{A_i}$ = are coefficients given by Ziegler [5].Alpha particles generally have a kinetic energy of about 5 MeV, and a speed in the neighborhood about 5% of the speed of light [14] .The calculation for heavier charge particles like(p, d, and α), for the following as [12].

$$\frac{dE}{\square x}\,(\text{MeV / m})=4\pi r_0^2 Z^2\,\frac{mC^2}{\beta^2}\,N\,Z\left[\ln\left(\frac{2m_o C^2}{I}\beta^2\gamma^2\right)-\beta^2\right] \qquad \text{....................(27)}$$

where: $r_{\square}$ = e^2/m_oc_2 = 2.818 X 10^{-15} m = classical electron radius,

$4\pi r_0^{\square}$ = 9.98 x 10^{-29} m^2 ≈10^{-28} m^2 = 10^{-24} cm^2,

m_oc^2 = rest mass energy of the electron = 0.511 MeV,

$\gamma = (T + Mc^{\square}) / Mc^{\square} = 1/\sqrt{1-\beta^2}$,

T = kinetic energy = $(\gamma - 1)Mc^2$,

M= rest mass of the particle,

β = v/c (c= speed of light in vacuum = 2.997930 X lo^8 m/s ≈ 3 x lo^8 m/s,

N = $\rho(N_A/A)$ (N_A=Avogadro's a count= 6.022* $10^{3□}$ atoms/mol, A= atomic weight, Z = atomic a count of the medium)

z = charge of the incident particle (z =1 for e-, e+, p, d; z = 2 for α)

I = mean excitation potential of the medium.

An approximate equation for; I, which gives good results for

Z > 12, is I(eV) = (9.76 + 58.8 $Z^{\uparrow}(-1.1\square)$) Z

Neutron Yield : yield of a nuclear interaction is the ratio of an events of a count the nuclear interaction to a count of particles incident per $1cm^2$ of a thin aim and a homogeneous particle flux [15]. And the probability of an accelerating beam transiting through the aim ,and occur nuclear (α,n) interactions produce (N) light particles per unit time, point out to fig.(2) the yield Y(x) is given by [8].

$$Y(x) = I_o N_a \sigma x \qquad \ldots\ldots(28)$$

where : I_o = is a count of incident particles per unit time per unite area,

N_a = is the a real count density of the aim atomic,

σ = is the cross section, and x = is the thickness.

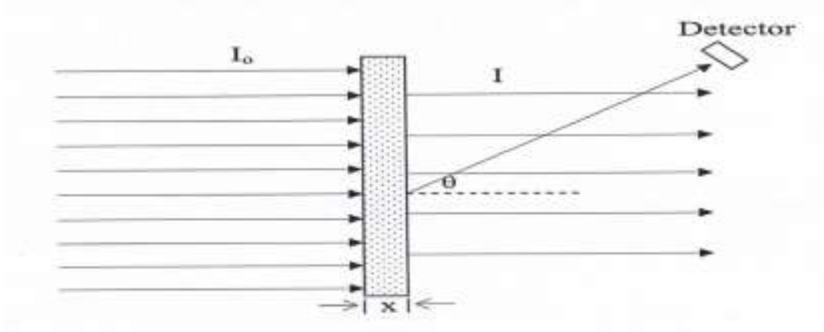

Fig (2): A schematic diagram illustrating the definition of total cross section in terms of the reduction of intensity [8].

Experimentally, the yield of neutrons detected per incident particle, Y_n, for an ideal , thin and uniform aim and mono-energetic beam of energy(E)[8] is given by

$$Y_n = (N^{\alpha}\ x)\ \sigma\,(\mathbf{E}_{\alpha})\ \eta\,(\mathbf{E}_{\alpha}) \qquad \ldots\ldots(29)$$

where: $\mathbf{E}_{\alpha}$ = is the rate energy of (E_1) and (E_2), η= is the neutron-detection efficiency. If the aim is sufficiently thick, and there exist one atom per each molecule (i.e., *i* = 1) and taking η(E`) = 1, then the resulting yield is called the thick- the aim yield which is given by [16].

$$Y(E_a) = \int_{E_{thr}}^{E_a} \frac{\sigma(E)dE}{dE/dx} \qquad \ldots\ldots(30)$$

where: E_{th} = is the interaction threshold energy . Thus, by measuring the yield at two closely spaced energies (E_1) and (E_2), one can determine the rate value of the integrand over this energy interval as follows [16].

$$\frac{\mathbf{Y}\left(\mathbf{E_1}\right) - \mathbf{Y}\left(\mathbf{E_2}\right)}{\mathbf{E_1} - \mathbf{E_2}} = [(\sigma\,(\mathbf{E}))/(\mathbf{dE}\,/\,\mathbf{dX})\,]_{\mathbf{E_1}\alpha} \qquad \ldots\ldots(31)$$

If there exist more than one isotope that can be involved in the nuclear interaction and the cross sections are calculated as a function of incident energy for each isotope, then [8].

$$\mathbf{Y_o} = \frac{\mathbf{b_1}}{\mathbf{c}_{□}}\,\mathbf{Y}_{□}(E) + \frac{\mathbf{b_2}}{\mathbf{c}_{□}}\,\mathbf{Y}_{□}\,(E) + \qquad \ldots\ldots(32)$$

Where : $\mathbf{Y_o}$, Y_1, Y_2 are neutron yield as a function of energy .

Discution:

1-The cross section ,stopping power and neutron yield:

A – $^{144}_{62}\mathrm{Sm}\,(\alpha, n)\,^{147}_{64}\mathrm{Gd}$ **interaction:**

The cross section of interaction have been plotted, spline interpolated and recalculated in fine steps (0.2MeV) for alpha energy from **(13.5 to 24.9) MeV** , using Matlab program, from the results, we get the equation of **quadratic** degree for plotted shown in fig.(3) as follows:

$$\sigma = 2.3 * 10^{-7} * E^{\square} + E + 0.00025 \quad \ldots\ldots\ldots\ldots (33)$$

The stopping power of **Samarium** element for alpha particles include are calculated in the same range of alpha energy and in the same interval of energy (0.2 MeV). These data are plotted in fig.(4), and we get equation of **quadratic** degree as follows:

$$-\frac{dE}{dX} = 2 * 10^{-7} * E^{\square} + 1 * E + 0.00024 \quad \ldots\ldots\ldots\ldots (34)$$

By using eq. (31) the cross sections and stopping power with the same interval (0.2 MeV) of alpha particle have been calculated the neutron yield in unite (neutron/10^6 α-particle). The results are plotted in fig.(5).

B- interaction:

The cross section of interaction have been plotted, spline interpolated and recalculated in fine steps (0.2MeV) for alpha energy from **(19.5 to 37.7) MeV**, using Matlab program. From the results we get the equation of **quadratic** degree for plotted shown in fig.(6) as follows:

$$\sigma = 3.3 * 10^{-5} * E^{\square} - 0.0029 * E + 0.094 \quad \ldots\ldots\ldots\ldots (35)$$

The stopping power **of Holmium** element for alpha particles include are calculated in the same range of alpha energy and in the same interval of energy (0.2 MeV) .These data are plotted in fig.(7)and we get equation of **quadratic** degree as follows:

$$-\frac{dE}{dX} = 3 * 10^{-5} * E^{\square} - 0.0027 * E + 0.091 \quad \ldots\ldots\ldots\ldots (36)$$

Using equations (31) the cross sections and stopping power with the same interval (0.2 MeV) of alpha particle have been calculated the neutron yield in unite (neutron/10^6 alpha particle).The results are plotted in fig.(8).

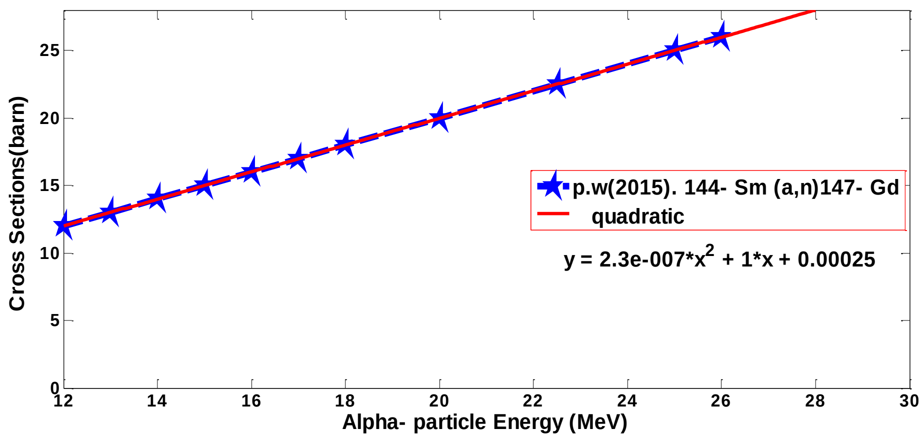

Fig.(3):The cross sections of interaction by fitting and interpolation .

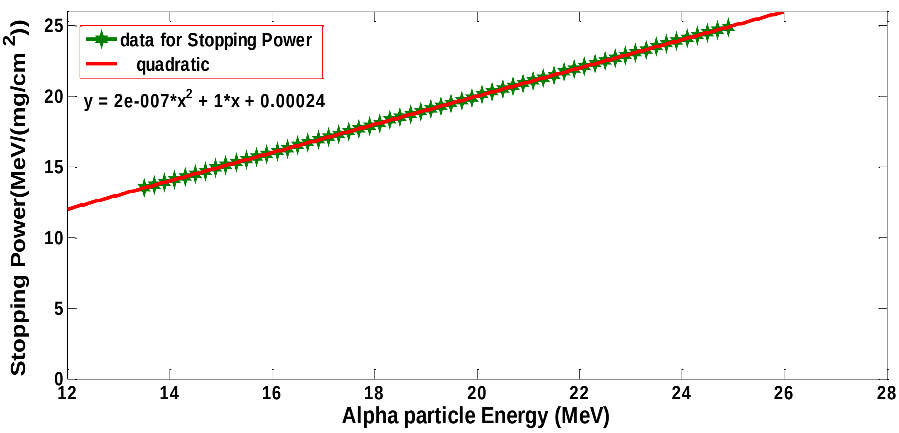

Fig.(4) :The stopping power for interaction (p.w).

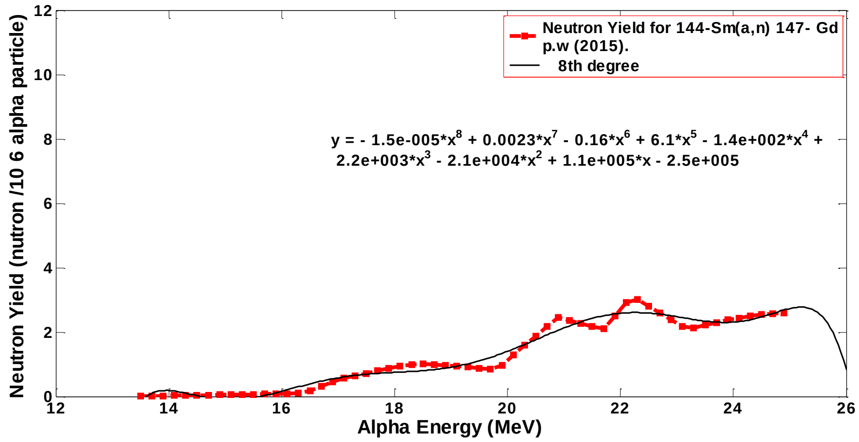

Fig.(5): The Neutron Yield for interaction (p.w).

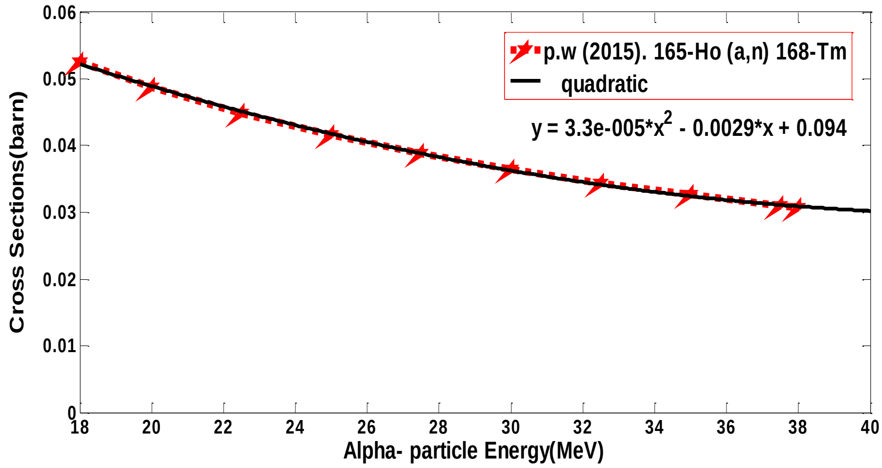

Fig.(6): The cross sections ofinteraction by fitting and interpolation.

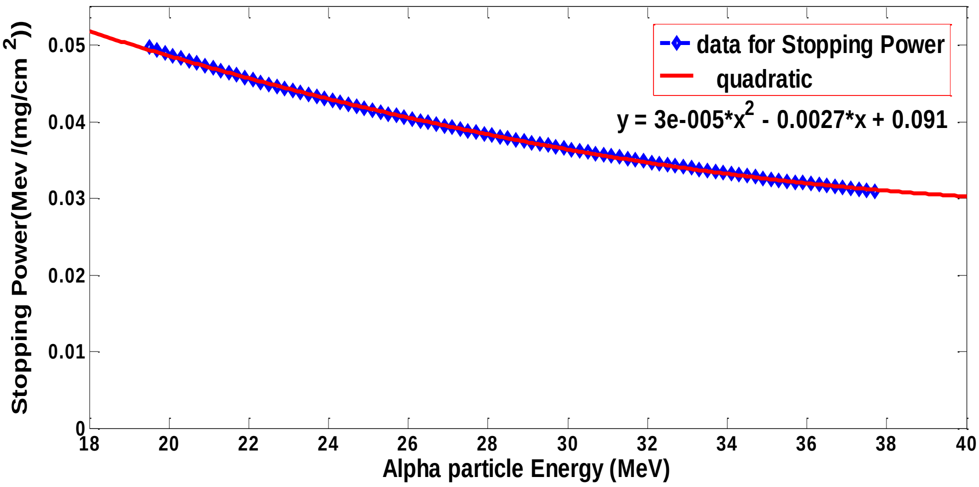

Fig.(7) :The stopping power for interaction (p.w).

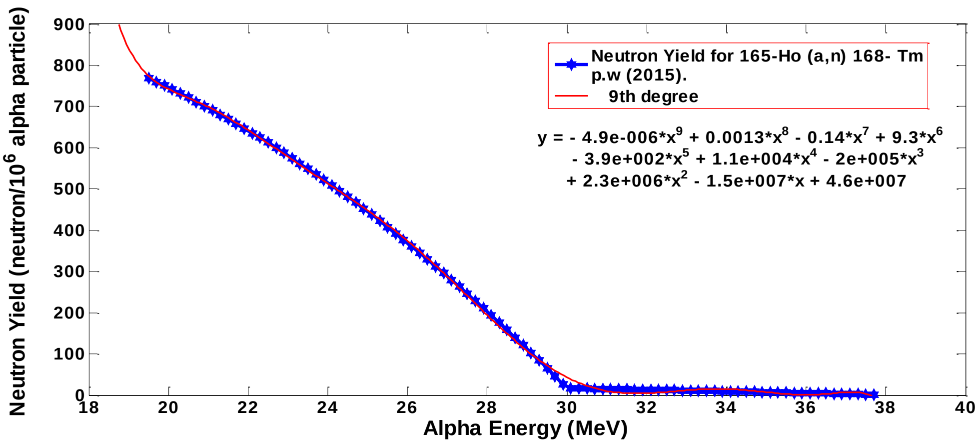

Fig. (8) :The Neutron Yield forinteraction (p.w).

2-The reciprocal cross sections of (α,n) interactions: The evaluated cross sections of (n,α) interactions for the aim heavy isotopes,we depending on parity and spin of isotopes in the ground state which is given in table (1) [9] , of calculation the g-statistical factor for every interaction by using equation (37) and (38). The statistical g-factors are givens by [17].

$$g_{\alpha,n} = \frac{2J_c + 1}{(2I_X + 1)(2I_\alpha + 1)} \qquad \text{……………………..(37)}$$

And

$$g_{n,\alpha} = \frac{2J_c + 1}{(2I_Y + 1)(2I_n + 1)} \qquad \text{……………………(38)}$$

The conservation rules of the momentum that ,shown as in table(3-1) :

$$I_\alpha = S_\alpha + l_\alpha \qquad \text{…………...………..(39)}$$

$$I_n = S_n + l_n \qquad \text{……….……………(40)}$$

where: I_α , = is the total angular momentum of α- particle and neutron ,

S_α, S_n = is spin of α-particle(S_α = 0) , and neutron ($S_n = {}^1/_2$) ,

l_α , = is the orbital angular momentum of α-particle ,and neutron.

Table(3-1):Total angular momentum and orbital angular momentum of α-particle and neutron.

Reaction	I_X	I_α	J_C	l_α	l_n	I_Y	I_n
	0	0	0	0	3	$^7/_2$	$^7/_2$
	$^7/_2$	3	$^1/_2$	3	2	3	$^5/_2$

We applied the reciprocity theory of interaction to get the semi empirical formula for the interactions in eq.(41) .

$$\sigma_{(n,\alpha)} = \frac{g_{n,\alpha} M_\alpha T_\alpha}{g_{\alpha,n} M_n T_n} \sigma_{(\alpha,n)} \qquad \text{………………………(41)}$$

1- interaction .

The cross sections for interaction of neutron energy (13.3000 to 25.4000) MeV, we calculated using the reciprocity theory eq.(41) as follows:

$$\sigma_{n,\alpha} = 0.062003 \frac{M_\alpha T_\alpha}{M_n T_n} \sigma_{\alpha,n} \qquad \text{.................(42)}$$

From eq.(37) and (38) we get that, $g_{\alpha,n}=1$ **and** $g_{n,\alpha}= {}^{1}/_{64}$ .The evaluations of cross sections are plotted in fig.(9) also get semi- empirical formula of **Linear** degree by using computer program (MATALB 7.6 R2008a).

2- interaction.

The cross sections forinteraction of neutron energy (19 to 38) MeV , we calculated, using the reciprocity theory eq.(41) as follows:

$$\sigma_{n,\alpha} = 5.29096 \frac{M_\alpha T_\alpha}{M_n T_n} \sigma_{\alpha,n} \qquad \text{......................(43)}$$

From eq.(37) and (38) we get that, $g_{\alpha,n}= {}^{1}/_{28}$ **and** $g_{n,\alpha}= {}^{1}/_{21}$.The evaluations of cross sections are plotted in fig.(10) also get semi-empirical formula of **quadratic** degree by using computer program (MATALB 7.6 R2008a).

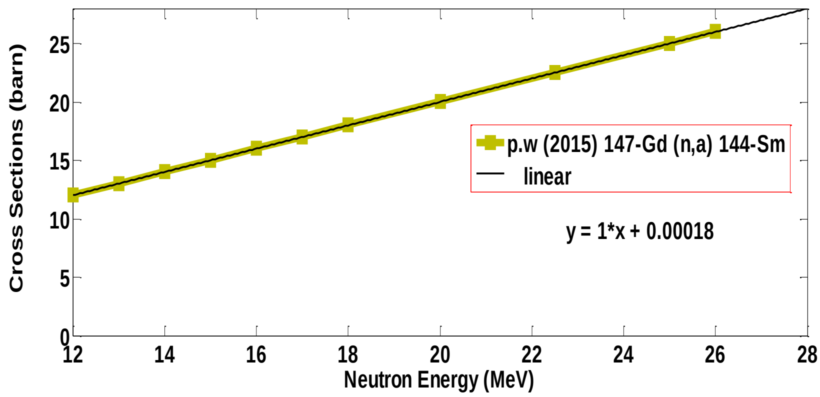

Fig.(9): The cross section of interaction.

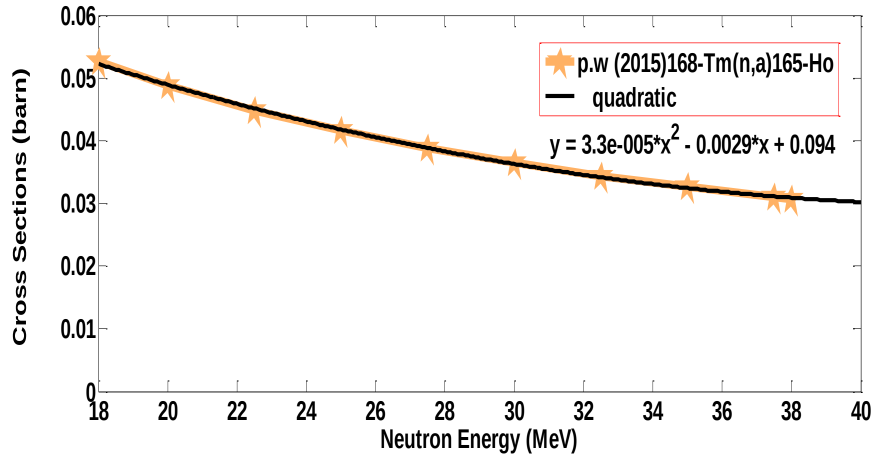

Fig.(10):Thecross section of interaction.

References :

1- H. Robin;" Fusion", Cambridge University Press, Cambridge, (1990).

2-- J.K.Tuli.; "Nuclear Wallet Cards for Radioactive Nuclides", National Nuclear Data Center NNDC,(2005).

3- P.De.Bievre,P.D.P.Taylor and B.Richard Firestone .;"Table of Isotopes ", 8th Edition.(1999).

4- P.Sigmund .;" Stopping of heavy ions", Springer Tracts in Modern Physics ,204 ,(2004).

5- H.H.Andersen and J.F. Ziegler.;" Hydrogen Stopping Powers and Ranges in All Elements, the Stopping and Ranges of Ions in Matter" P. Press, New York .(1977).

6- G. Abebe ; " Stopping power and range of Protons of various energies in Different mediums " Dep. of Physics, Addis Ababa University(2007).

7- M.S.Gadkari , H.B.Patel, D.J.Shah, and N.L. Singh.;" Study of preequilibrium decay in (a,xn) interactions in holium up to70 MeV", J,PS,55: 147,(1997).

8- E.B.Norman, T.E.Chupp, P.J.Grant & G.L.Woodruff . Phy Rev. C30, 1339, (1984).

9- J.B.Marion and F.C.Young .;" Nuclear interaction Analysis ", By John wiley and Sons , Inc .New York .(1968).

10-- F.O.Denzler, F. Rosch, and S.M.Qaim .;" Excitation functions of a- and ^{3}He particle induced nuclear interactions on highly enriched ^{144}Sm and ^{147}Sm: Comparative evaluation of production routes For 147Gd ", J,RCA,69. Pp.209,(1995)

11- D.C. Washington .;" Nuclear physics and Reactor Theory "," Doe Fundamentals Handbook ",U.S Department of Energy, 20585, (1993).

12- T.S. Nicholas ;"Measurement and Detection of Radiation ",2nd Edition. Taylar & Francis.(1995).

13- B. Marie.;"Effects of nuclear and electronic stopping power on ion irradiation of silicon-based compounds ", REPOR SERIES IN PHYSICS of the Universityof Helsinki . Finland.(2012).

14- S. K . Krane .;" Introductory Nuclear Physics ", by co. John Wiley & Sons. Inc.(1988).

15- J. Blatt , and V. Weisskopf.;" Teoreticheskaia Iadernaia fizika", Moscow.(1954).

16- R.H.Abdull ,Ph.D . Thesis . University of Baghdad. (1999).

17- R.L. Macklin and J.H. Gibbons . ;phys. Rev. 165 ,1147, (1968).