Neutron yield for (^{70}Zn) by bombarding of alpha particles

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Abstract

The objectives of this research were to calculate the cross sections of ^{73}Ge(n,α)^{70}Zn reaction by inverse reaction, the stopping powers for α-particle with (Zn) element and n-Yield.

The Q-value and threshold energies for (α,n) Reaction have been calculated for (Zn) element were (-3.908642931MeV) and (4.13237799MeV) respectively for the neutron emission from ^{70}Zn which was bombard by α-particle .

In order to get the mathematical equation that represents the cross sections as a function of α-particle energy , the computer program (Mat-lab version 7.6) was used.

The cross section of ^{70}Zn(α,n)^{73}Ge reaction have been plotted in fin steps from (6.2-9.0) MeV of alpha particle energy by P.H.Stelson , F.K.Mc. . We observed that the high probability to produce ^{70}Zn by bombarding ^{73}Ge with fast neutron (4.6983)MeV and semi empirical formula.

These cross sections together with the stopping powers were calculated from the Zeigler formula were used to calculate the n-yield for reaction .

Key words :Cross Section, Stopping Power, Charge Particles Interaction ,Neutron Yield.

Neutron yield for (^{70}Zn) by bombarding of alpha particles

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الحصيلة النيوترونية ل ^{70}Zn بواسطة قصفها بجسيمات ألفا

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الخلاصة

إن أهداف البحث هو حساب المقاطع العرضية لتفاعل $^{73}Ge(n,\alpha)^{70}Zn$ باستخدام التفاعل العكسي ,وقدرة التوقف لجسيمات الفا باستخدام عنصر الزنك (Zn) وكذلك حساب انتاج الحصيلة النيوترونية .تم حساب قيمة طاقة التفاعل (Q-value)وطاقة العتبة لتفاعل (α,n) لعنصر الزنك (Zn) والتي كانت (- 3.9086429MeV) و (4.13237799 MeV)على التوالي ,لانبعاث النيوترون من ^{70}Zn والذي تم قصفه بواسطة جسيمات الفا.

ولغرض حساب المعادلة الرياضية والتي تمثل المقطع العرضي كدالة لطاقة جسيمات الفا ثم استخدام برنامج الماتلاب نسخة (7.6). وقد تم رسم المقطع العرضي لتفاعل $Ge^{73}(\alpha,n)Zn^{70}$ بخطوات دقيقة لطاقات جسيمة بيتا من MeV (6.2 – 9.0) .

قد تم حساب ناتج النيوترونات بأستخدام قيم المقاطع العرضية مع قيم قدرة التوقف المحسوبة بواسطة صيغة زيكلر .

الكلمات الدالة: المقطع العرضي , قدرة الإيقاف , تفاعل الجسيمات المشحونة , الحصيلة النيوترونية.

Introduction

1-Cross Section of Nuclear Reactions:

Suppose a given reaction A(a,b)B is occurring at a certain rate .If the nuclei in the target act independently, the event rate (or reaction rate)per nucleus exposed to the beam (R) is proportional to the incident flux (Φ)[1]. The constant of proportionality is called the cross section (σ) ,which can be written as:

$$\sigma = \frac{event\ \ rate\ \ per\ \ nucleus}{incident\ \ flux}$$

$$\sigma = \frac{R}{\phi} \qquad \text{----------- (1)[1]}$$

The cross section has units of area and has traditionally been measured in units of the (10^{-28}) barn [2]. If the cross-section of the reaction ***A(α,n)B*** is measured as a functions of T**α** (T**α** = Kinetic energy of α-particle) the cross–section of the inverse reaction ***B(n,α)A*** can be calculated as a function of Tn (Tn = Kinetic energy of neutron) using the reciprocity theorem [3] which states that :

$$\frac{\sigma_{(\alpha,n)}}{g_{(\alpha,n)}\bar{\lambda}_{\alpha}^{2}}=\frac{\sigma_{(n,\alpha)}}{g_{(n,\alpha)}\bar{\lambda}_{n}^{2}} \qquad \textbf{------------(2)}$$

Where $\sigma_{(\alpha,n)}$ and $\sigma_{(n,\alpha)}$ represent cross- sections of *(α,n)* and *(n,α)* reactions respectively , g is a statistical factor and $\bar{\lambda}$ is the De–Broglie Wave Length divided by 2π and is given by

$$\bar{\lambda}=\frac{\hbar}{MV} \qquad \textbf{------------(3)}$$

Where ħ is Dirac constant (h /2π) , h is plank constant , *M* and *V* are mass and velocity of α or n particle . From eq.(3),we have

$$\bar{\lambda}^{2}=\frac{\hbar^{2}}{2MT} \qquad \textbf{------------(4)}$$

Where *T* is kinetic energy , the statistical g-factors are givens by[3]

$$g_{(\alpha,n)}=\frac{2J_{c}+1}{(2I_{A}+1)(2I_{\alpha}+1)} \qquad \textbf{-------------(5)}$$

I_{α} =Orpetal angular momentum for alph particle .

I_{A}= Orpetal angular momentum for target.

J_{c}=Totel angular momentum for compound neucluse.

2- Interaction of Neutrons with Matter:

In great contrast to other nuclear particles, which carry charge, the neutron, because it lacks charge, can pass through the otherwise impenetrable barrier of the atomic electrons and actually collide with nuclei of atoms and be scattered in the process or be captured by the nucleus of an atom[4]. Collision of neutrons with nuclei can result in scattering of the neutrons and recoil nuclei with conservation of momentum (elastic scattering) or loss of kinetic energy of the neutron as gamma radiation (inelastic scattering). The capture of a neutron by a nucleus of an atom may result in the emission of other nuclear particles from the nucleus (non elastic reactions) or the fragmentation of the nucleus into two (nuclear fission)[4].

The relative probabilities of the various types of neutron interactions change dramatically with neutron energy[4]. In somewhat of an oversimplification, we will divide neutrons into two categories on the basis of their energy, either "fast neutrons7' or "slow neutrons," and discuss their interaction properties separately. The dividing line will be at about 0.5 eV , or about the energy of the abrupt drop in absorption cross section in cadmium (the *cadmium* cutoff energy)[2].

3-Fast Neutron Interactions:

The probability of most neutron-induced reactions potentially useful in detectors drops off rapidly with increasing neutron energy. The importance of scattering becomes greater, however, because the neutron can transfer an appreciable amount of energy in one collision. The secondary radiations in this case are *recoil nuclei,* which have picked up a detectable amount of energy from neutron collisions. At each scattering site, the neutron loses energy and is thereby *moderated* or slowed to lower energy[2].

If the energy of the fast neutron is sufficiently high, *inelastic scattering* with nuclei can take place in which the recoil nucleus is elevated to one of its excited states during the collision[2].The nucleus quickly de-excites, emitting a gamma ray, and the neutron loses a greater fraction of its energy than it would in an equivalent elastic collision. Inelastic scattering and the subsequent secondary gamma rays play an important role in the shielding of high energy neutrons but are an unwanted complication in the response of most fast neutron detectors based on elastic scattering[2].

4- Interaction of Alpha particle with Matter:

Alpha particle, interact with matter primarily through coulomb forces between their positive charge and the negative charge of the orbital electrons within the absorber atoms. Although interactions of the particle with nuclei (as in Rutherford scattering or alpha-particle-induced reactions) are also possible, such encounters occur only rarely and they are not normally significant in the response of radiation detectors. Instead, charged particle detectors must rely on the results of interactions with electrons for their response[2].

5-Stopping Power:

Stopping Power is defined as the average energy dissipated by ionizing radiation in a medium per unit path length of travel of the radiation in the medium. It is, of course, impossible to predict how a given charged-particle will interact with any given atom of the absorber medium. Also, when we consider that the columbic forces of charged particles will interact simultaneously with many atoms as it travels through the absorbed medium, we can only predict an average effect of energy loss per particle distance of travel. Taking into account the charge, mass and speed (energy) of the particle, and the density and atomic number of the absorbing medium, Bethe (1933,1953) derived the formula for calculating the stopping power resulting from columbic interactions of heavy charged particles (e.g., alpha particles, protons, and deuterons) traveling through absorber media[4].

The formulas for the stopping power of heavy charged particles (e.g., protons, deuterons, and alpha particles) due to columbic interactions (i.e., ionization and electron orbital excitation) are most clearly defined as the following:

$$\frac{dE}{dX} = 4\pi\varphi r_o z^2 \frac{mc^2}{\beta^2} NZ \left[\ln\left(\frac{2mc^2}{I}\beta^2\gamma^2\right) - \beta^2 \right] \text{ ---------- } \mathbf{(6)}$$

Where

dE=dx : is the particle stopping power in units of MeV/m

r_o : is the classical electron radius =2.818*10 ^{15} m

z: is the charge on the particle (z=1 for p, d, β^-, β^+ and z=2 for α),

mc^2: is the rest energy of the electron= 0.511MeV

N: is the number of atoms per m^3 in the absorber material through which the charged particle travels

$$\mathbf{N=\rho(N_A/A)} \text{ ------------(7)}$$

Where

ρ: is the absorber density (e.g., for NaI, $\rho=3.67 g. cm^{-3}$)

N_A: is Avogadro's number=$6.022*10^{23}$ atoms per mol

A and Z are the atomic weight and atomic number, respectively, of the absorber

$$\gamma=\frac{(T+Mc^2)}{Mc^2}=\frac{1}{\sqrt{1-\beta^2}} \qquad \text{--------- (8)}$$

Where

T :is the particle kinetic energy in MeV

M is the particle rest mass (e.g., proton=931.5MeV/c^2, deuteron=2(931.5) MeV/c^2, alpha particle= 4(931.5) MeV/c^2, and β^-or β = 0.511 MeV/c^2,

β: is the relative phase velocity of the particle=v/c, the velocity of the particle in the medium divided by the speed of light in a vacuum = $\sqrt{1-\left(\frac{1}{\gamma^2}\right)}$

I: is the mean excitation potential of the absorber in units of eV approximated by the equation

$$I=\left(9.76+58.8Z^{-1.19}\right)Z \qquad \text{------------(9)}$$

When Z>12 [4]

6-Neutron Yields:

The neutron yield for (α,n)source may be solved using complicated transport equations and solved through Carlo Methods. Those equations can be simplified to algebraic and light calculus expressions .The algorithm for finding the exact neutron yield is explained in great detail in Wilson et.al.(1999) , but the important equations of that document are presented here[5].

The probability of an alpha particle with energy E_α , undergoing an (α,n) reaction with target nucleus *i* ,before it comes to rest , can be expressed by[5] :

$$P_i(E\alpha)=\int_0^{E\alpha}\frac{Ni\,\sigma\, i(E)}{-(\frac{dE}{Dx})}dE \qquad \text{---------(10)}$$

Where :

Ni :is the atom density of the target

σi : is the cross section of the target at energy E

:is the materials stopping power.

Since all (α,n) problems involve more than one material (emitters target ,impurities ,progeny ,additional targets and emitters) ,it is more accurate to describe the neutron output in terms of the stopping cross sections ε(E)[5]:

$$P_i(E\alpha)=\frac{Ni}{N}\int_0^{E\alpha}\frac{\sigma i\, g(E)}{\varepsilon(E)}dE \quad \text{------------ (11)}$$

Where N is the total atom density of the system and ε(E)is defined as:

$$\varepsilon(E)=\frac{1}{\sum_{j=1}^{J} Nj}\sum_{j=1}^{J} Nj\frac{-1}{N}\frac{dE}{dx} \quad \text{----------- (12)}$$

and J is the number of elemental constituents .

it may be necessary to also separate the cross section σi into G cross sections each representing the (α,n) cross section of a neutron leaving the nucleus in energy level g :

$$Pi(E\alpha)=\frac{Ni}{N}\sum_{g=0}^{G}\int_0^{E\alpha}\frac{\sigma i\, g(E)}{\varepsilon(E)}dE \quad \text{--------------- (13)}$$

Where σ_{ig} is the cross section of an (α,n) reaction leaving the nucleus in energy level[5] .

Result and Discussion:

By using semi empirical formula the evaluated cross sections as a function of alpha energy from (6.2-9.0) MeV of present work are listed in Table (1). From these data which were plotted and we get the mathematical equation which represents the cross sections as a function of alpha energy Fig.(1) as follows:

$y = -0.62*x^4 + 22*x^3 - 2.7*10^2*x^2 + 1.5*10^3*x - 2.9*10^3$----------(14)

Where y=cross sections of (alpha,n)(mbarn) x=alpha energy(MeV)

In Fig. (1)[6] we observed that the cross sections were smoothly increased and the maximum cross section in this range of energy is equal to (53.0mbarn) when alpha energy is equal to (9.0MeV).In order to calculate the neutron energy by depending on alpha particle we derived the equation as follows:

$T_n = 0.9589409(T_\alpha - 4.13237799)$ ----------(15)

Where T_α=kinetic of alpha particle(MeV) T_α=kinetic of neutron energy (MeV)

By using the compound theory and depending on the atomic mass of isotopes mentioned in this study which have been taken from the latest nuclear wallet cards released by the National Nuclear Data Center(NNDC) [7] and abundances are given for stable isotopes from the reference of International Atomic Energy Agency (IAEA) [8].Tthe mathematical formula is driven from ^{70}Zn(alpha ,n)^{73}Ge reaction for ground state to get the cross sections of ^{73}Ge(n, Alpha)^{70}Zn reaction as follows:

$$\sigma_{n,\alpha} = 0.039682 \frac{T\alpha}{Tn} \sigma_{\alpha,n} \qquad \text{------------(16)}$$

The calculated the cross sections of neutron as a function of energy range between (1.9827-4.6676) MeV are (0.0239 - 4.6983)mbarn respectively. These data are plotted in Fig.(2) and listed in Table (1) . We observed that the high probability to produce ^{70}Zn by bombarding ^{73}Ge with fast neutron (4.6983)MeV and semi empirical formula is obtained as follows:

$$X_n = - 0.05*T^4 + 1*T_n{}^3 - 5.5*T_n{}^2 + 12*T_n - 9.4 \quad \text{------------(17)}$$

Where **X_n=cross sections of neutron(mbarn)** **T_n= neutron energy(MeV)**

Srim program(2008) is used to calculate the stopping power[9]as shown in Fig.(3) and are listed in table(1) .And by depending on the equation(16) the cross sections is produced for ^{70}Zn(alpha ,n)^{73}Ge reaction which have been used to obtain the neutron yield as shown in Fig. (4) and are listed in Table(1) .

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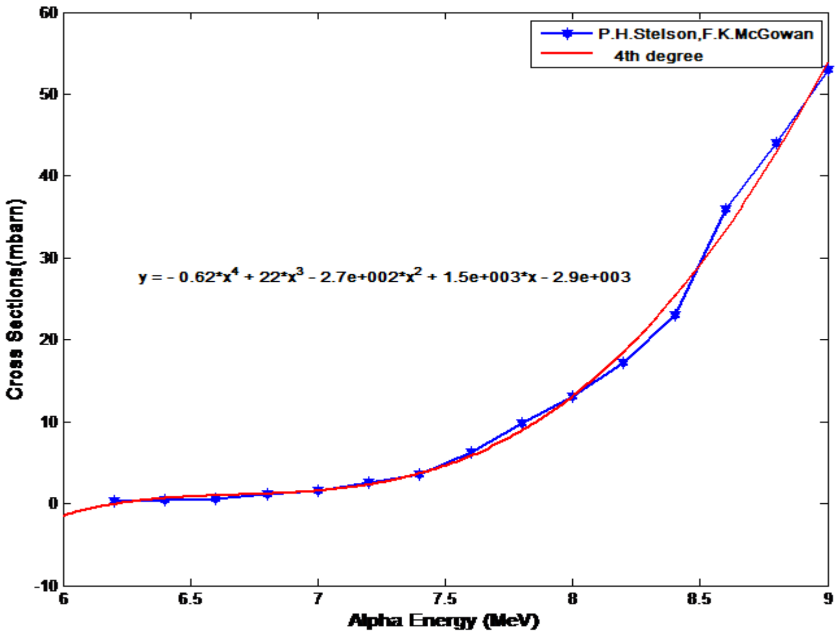

Figure (1):The cross sections of ^{70}Zn(alpha,n)^{73}Ge reaction

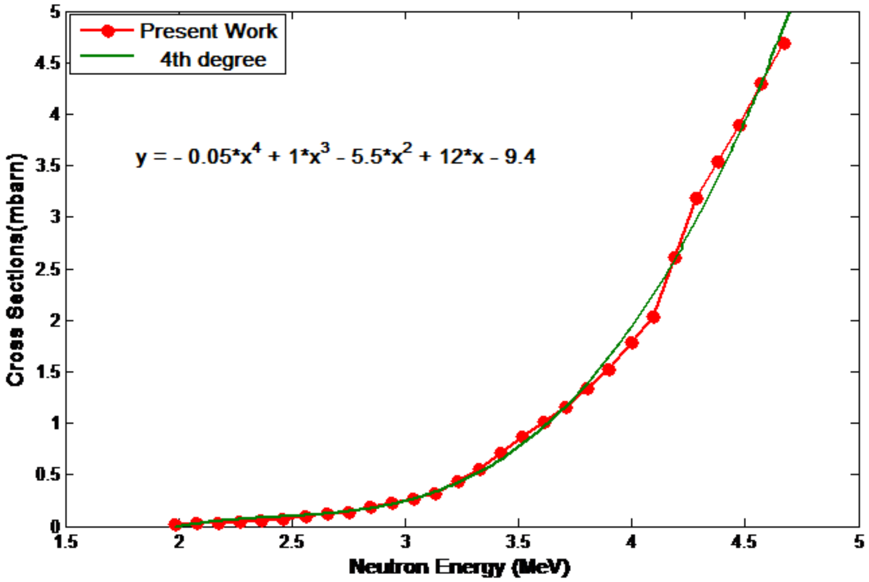

Figure (2):The cross sections of ^{73}Ge(n,Alpha)^{70}Zn reaction

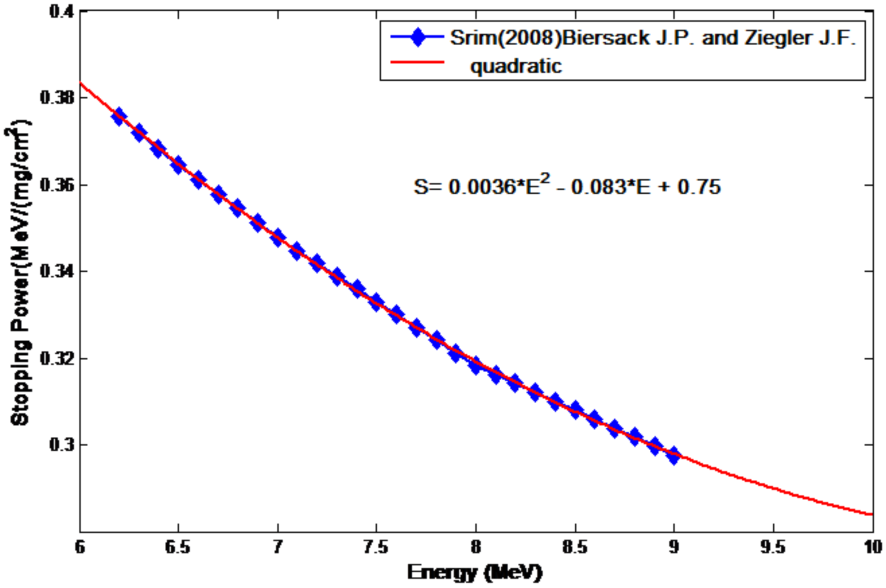

Figure (3): Stopping power for alpha particle of zinc element

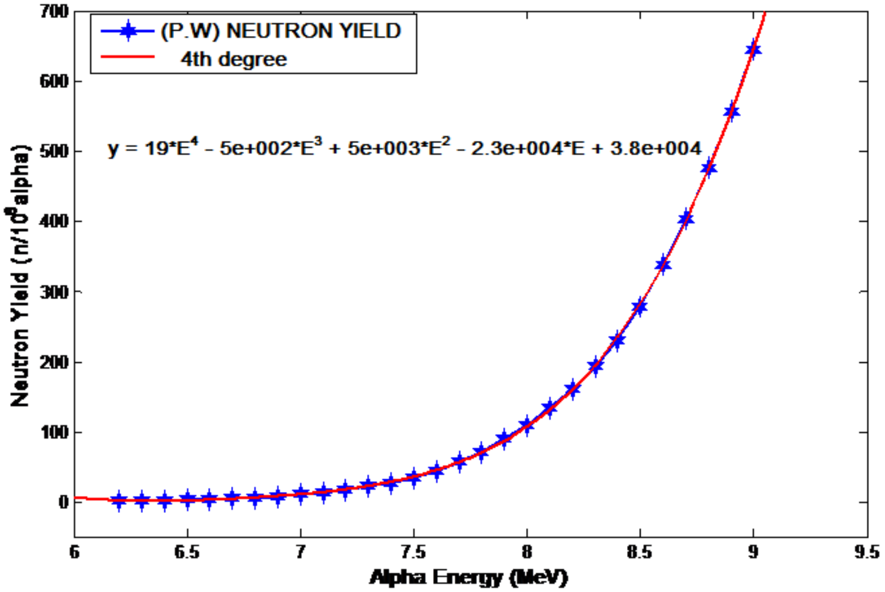

Figure (4):Neutron yield for ^{70}Zn(alpha,n) ^{73}Ge reaction

Table(1): The cross sections of ^{70}Zn(alpha,n) ^{73}Ge reaction as a function of α-particle energy.

Cross sections(mb)	Neutron energy(MeV)	Yield (neutron/10^6)	Stopping power (MeV/(mg/cm^2))	Cross sections(mb)	α-energy (MeV)
0.0239	1.9827	0.3593	0.3758	0.27	6.2
0.0284	2.0785	0.7893	0.372	0.32	6.3
0.0328	2.1744	1.2916	0.3683	0.37	6.4
0.0448	2.2703	1.9842	0.3646	0.505	6.5
0.0567	2.3662	2.8701	0.3612	0.64	6.6
0.0776	2.4621	4.0928	0.3578	0.875	6.7
0.0984	2.558	5.6587	0.3544	1.11	6.8
0.1206	2.6539	7.5958	0.3511	1.36	6.9
0.1427	2.7498	9.9112	0.3477	1.61	7
0.1866	2.8457	12.9644	0.3447	2.105	7.1
0.2305	2.9416	16.768	0.3418	2.6	7.2

0.2748	3.0374	21.3424	0.3388	3.1	7.3
0.3191	3.1333	26.7012	0.3359	3.6	7.4
0.4388	3.2292	34.1347	0.333	4.95	7.5
0.5585	3.3251	43.6799	0.33	6.3	7.6
0.7136	3.421	55.9863	0.3271	8.05	7.7
0.8687	3.5169	71.104	0.3241	9.8	7.8
1.015	3.6128	88.9288	0.3212	11.45	7.9
1.1613	3.7087	109.5109	0.3182	13.1	8
1.343	3.8046	133.4691	0.3162	15.15	8.1
1.5247	3.9005	160.8478	0.3141	17.2	8.2
1.7818	3.9963	193.0541	0.3121	20.1	8.3
2.0389	4.0922	230.1522	0.31	23	8.4
2.6151	4.1881	278.0533	0.3079	29.5	8.5
3.1913	4.284	336.903	0.3059	36	8.6
3.5459	4.3799	402.7354	0.3038	40	8.7
3.9004	4.4758	475.6459	0.3017	44	8.8
4.2994	4.5717	556.5663	0.2997	48.5	8.9
4.6983	4.6676	645.6076	0.2976	53	9.0