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# Study of Properties for Ca (a, n)Ti Reactions and n-Yield for Ca Isotopes (A=41-50)

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**Abstract:**

In this study, ($^{44}$Ti – $^{53}$Ti) isotopes for one of intermediate elements (A>40) from Ca (α, n)Ti reactions with alpha energy from (10 to 50) MeV are used according to the available data of reaction cross sections obtained from Lab (TENDL-2012). The more recent cross sections data of Ca (α, n)Ti reaction is reproduced in fine steps of (0.5MeV), by using (MATLAB R2008b) program. These cross sections together with the stopping powers which calculated from the Zeigler formula by using SRIM-2013 have been used to calculate the n-yield for reaction by depend on Ca isotopes ($^{41}$Ca – $^{50}$Ca) as targets, and then clarify the behavior between the energies which corresponding to these cross sections and neutron yield for isotopes, and then we drowned the relationship between the n-yield for these reactions and symmetry at these energies. Was obtained on mathematical formulas and find constants those equations and these equations were calculated yield neutron and comparing with theoretical values also studying the properties of these isotopes, calculated binding energy and reduced mass and also were calculated Q- value and threshold energy for each reaction and the relative abundance of the isotopes of entering and leaving for alpha reactions. And then drawing scheduled and discusses the results.

**Keyword**: Binding energy, Cross-Section, Neutron Yield, stopping power, Asymmetry and empirical formula.

## 1-Introduction

The (α, n) gneutron sources with intermediate mass nuclei as a target, it has the high neutron yield. Due to many advantages of the (α,n)neutron source, such as their simplicity of installation, operation and low price compared to nuclear reactors, these neutron sources are used in activation analysis [1,2,3], calibration source [4], and industrial applications [5].

The binding energy can be calculated as the reduction in mass multiplied by the square of the velocity of light ($c^2$ = 931.494013 MeV/u) [6]:

$$B_{tot}(A,Z)=[ZM_P + NM_n – {}^{A}_{Z}M\ ]c^2 \quad \text{……………….(1)}$$

Where ( Z and N ) are the number of protons and neutrons, ($M_H$, $M_n$ and ${}^{A}_{Z}M$ ) are three masses of hydrogen atom, neutrons and nucleus respectively.

μ is the reduced mass calculated from the following equation [7]:

$$\mu= \frac{m1m2}{m1+m2} \quad \text{…………….(2)}$$

Where ($m_1$) and ($m_2$) are the atomic masses of the projectile and target nucleus, respectively.

The Q – value of the reaction X(α,n)Y, is defined as the difference between the initial and final rest mass energies [7]:

$$Q = [M_x + M_α – (M_Y + M_n)]\ c^2 \quad \text{……………(3)}$$

Where ($M_x$ , $M_α$ , $M_Y$ and $M_n$) represents the atomic masses of the target, incident particles, product nucleus and outgoing particle, respectively. From conservation law of energy [7].

The Q- value is positive, Q > 0, the reaction is said to be (exoergic) or (exothermic).

When Q- value is negative, Q < 0, the reaction is (endoergic) or (endothermic). For (exoergic) reactions, threshold energy is (zero) and for (endoergic) reactions, the threshold energy is given by [8]:

$$E_{thr} = - Q_0\ (1+ \frac{Ma}{Mx}) \quad \text{………………..(4)}$$

$$S_n = 931.5\,[M_y + M_n - M_x] \quad \text{..................(5)}$$

Where $S_n$ is separation energies of neutron [7].

**2- Cross section of the nuclear reaction**

To characterize the probability that a certain nuclear reaction will take place, it is customary to define an effective size of the nucleus for that reaction, called a cross section [7]. The reaction cross section data provides information of fundamental importance in the study of nuclear systems. The cross section is defined by [9]:

$$\sigma = R / I \quad \text{.................. (6)}$$

Were $R$ is the number of reactions per unit time per nucleus. $I$ is the number of incident particles per unit time per unit area,

The cross section has the units of area and is of the order of the square of nuclear radius. A commonly used unit is the barn: (1 barn = $10^{-24}$ $cm^2$)

In general, a given bombarding particle and target can react in a variety of ways producing a variety of light reaction products per unit time. The total cross section is then defined as [10]:

$$\sigma_{tot} = \sum_i \sigma_i \quad \text{------- (7)}$$

Where $\sigma_i$ is the partial cross section for the process.

**3-Asymmetry energy:**

The nuclear asymmetry energy, which is defined as the difference in energy per nucleon between the pure neutron matter and the symmetric nuclear matter, Asymmetry energy expresses the trend to particular stability of nuclei with $N = Z$ for small $A$. Light nuclei become less stable if $|N - Z|$ increases[7]. If we were to add more neutrons, they will have to be more energetic, thus increasing the total energy of the nucleus, so that it is more favorable to have an approximately equal number of protons and neutrons. The shape of the asymmetry term is [11]:

$$(E_S = (A - 2Z)^2/A) \quad \text{......... (8)}$$

It can be more easily understood by considering the fact that this term A goes to zero for A = 2Z and its effect is smaller for larger (A). Where N is the neutron number, Z is atomic number and A is the mass number.

**4-Stopping power:**

Many different names have been used for the quantity dE/dX names like energy loss, specific energy loss, differential energy loss, or stopping power. The stopping power dE/dX, defined as the energy lost by the incident particles per unit path length, total stopping power ($S_t$) is the sum of the electronic stopping power ($S_e$), due to inelastic interaction with the target electrons, and the nuclear stopping power ($S_n$) induced by elastic collisions between the projectiles and the target nucleus[12].

$$S_t = S_e + S_n \quad \text{... ... ... ... (9)}$$

If the energy per atomic mass unit E/M of the incident particles is high, the nuclear contribution compared to the electronic one is negligible, that mean Nuclear stopping is only important at incident energies E < 100 keV, at higher energies nuclear stopping becomes negligible so $S_t = S_e$ [12,13].

**4-1- Electron Stopping**: The electronic stopping of α in elements $S_e$ is derived from the stopping power of protons $S_p$ for the same velocity by using[14]:

$$S_e = S_p(\gamma_\alpha Z_\alpha)^2 \quad \text{... ... ... ... .. (10)}$$

$Z_\alpha$ is the alpha charge(α) and $\gamma_\alpha$ can be obtained from the simple polynomial fit.

$$\gamma_{\alpha}^{2} = 1 - exp\left[-\sum_{i=0}^{5} C_i E^i\right] \quad \ldots\ldots\ldots\ldots(11)$$

With E represent alpha energy in keV/amu. $C_i$ is coefficient. Note $S_t$ can be converted to units of MeV/(mg/cm$^2$) by multiplying by 0.6022/M$^2$.

**4-2- Nuclear Stopping:** The energy loss of the incident ion per unit Length $S_n$ depends on the ion energy. The nuclear energy loss is small at very high energies, because fast particle have less interaction time with the scattering nucleus. Thus the nuclear energy loss tends to dominant towards the end of the range when ion has lost much of its energy, And The nuclear stopping $S_n$ in eV/10$^{15}$ atoms/cm2 for He-ions with incident energy E (in keV) is given by[15]:

$$S_n = \frac{8.462 * 10^{15} Z_1 Z_2 M_1 S_n(\varepsilon)}{(M_1 + M_2)\left(Z_!^{0.23} + Z_2^{0,23}\right)} \quad \ldots\ldots\ldots.(12)$$

Where $M_1$, $Z_1$ refer to the ion and $M_2$, $Z_2$=substrate atom mass and atomic number. And the reduced ion energy $\varepsilon$, is defined as:

$$\varepsilon = \frac{32.53 M_2 E}{Z_1 Z_2 (M_1 + M_2)(Z_!^{0.23} + Z_2^{0,23})} \quad \ldots\ldots..(13)$$

For $\varepsilon$ >30 keV, unscreened nuclear stopping is used, and $S_n(\varepsilon)$ simplifies to

$$S_n(\varepsilon) = \frac{ln\varepsilon}{2\varepsilon} \quad \ldots\ldots\ldots\ldots\ldots..(14)$$

**5- Neutron Yields:**

The Yield of neutron (Y) detected per incident particle (alpha), for an ideal, thin, and uniform target and monoenergetic particles beam of incident energy $E_b$ is given by [16].

$$Y = (nt)\sigma(E_b)\eta(E_b) \quad \ldots\ldots\ldots.(15)$$

Where n: is the number of target atoms per unit volume, t is the target thickness, σ is the reaction cross section, $\eta$ is the alpha-detection efficiency. If the target is sufficiently thick, and there exist one atom per each molecule and taking the efficiency $\eta$ =1, then the resulting alpha yield is called the thick-target yield which is given by [17,18].

$$\mathrm{Y} = \mathrm{N}\int_{0}^{\mathrm{E_o}} \frac{\sigma_{(\mathrm{E})}}{\mathrm{dE/dX}}\,\mathrm{dE} \quad \ldots\ldots\ldots\ldots\ldots(16)$$

Where, **N** is the atomic number of target per unit volume, which is defined as follows:

$$\mathrm{N} = \frac{\mathrm{w\rho N_A}}{\mathrm{A}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(17)$$

Where, $w$ is the abundant in the combination, $\rho$ is the combination density, A is the mass number, $N_A$ is the Avogadro's number, $\sigma_{(E)}$ is the cross section, dE/dX is the incident particle initial energy. For natural elements and if only one stable isotope is available in nature, then [19]

$$Yo = Y(E) \quad ------ \quad (18)$$

where (Yo) is the neutron yield per 10$^6$ bombarding particle for the natural element.

**6- Results and Discussion:**

The target (Calcium) has 24 isotopes, which are $^{34}$Ca to $^{57}$Ca. For this study ($^{41}$Ca - $^{50}$Ca) that have four stable isotopes of observations ($^{42}$Ca, $^{43}$Ca, $^{44}$Ca and $^{46}$Ca) table (1), in addition to isotope ($^{48}$Ca) with the long half-life that for all practical purposes it can be considered stable as well as the rare $^{46}$Ca, are theoretically unstable on energetic grounds, but their decay has not been observed. Calcium also has a cosmogenic isotope, radioactive $^{41}$Ca, which has a half-life of 102,000 years. $^{41}$Ca is produced by neutron activation of $^{40}$Ca. $^{41}$Ca has received much attention in stellar studies because it decays to $^{41}$K, a critical indicator of solar-system anomalies. The most stable artificial radioisotope is $^{45}$Ca, with a half-life of 163 days [20]. The atomic mass Isotopes of elements (Ca and Ti) mentioned in this study have been taken [21] to calculate the binding energy are listed in table (1) as well as abundance[22] ,spin ,parity[23] and half life[20] **.**

Table (1): The atomic mass of isotopes used in the present work and another data.

| isotopes | Atomic Mass(amu) [21] | B.E(MeV) P.W | Abundance % [22] | Half-life [20] | Spin & Parity [23] |
|---|---|---|---|---|---|
| $^{41}$Ca | 40.96228 | 352.5606 | - | $1.02*10^5$ y | $7/2^-$ |
| $^{42}$Ca | 41.95862 | 364.0414 | 0.647 | Stable | $0^+$ |
| $^{43}$Ca | 42.95877 | 371.9744 | 0.135 | Stable | $7/2^-$ |
| $^{44}$Ca | 43.95548 | 383.1057 | 2.086 | Stable | $0^+$ |
| $^{45}$Ca | 44.95619 | 390.5206 | - | 136 d | $7/2^-$ |
| $^{46}$Ca | 45.95369 | 400.9152 | 0.004 | Stable | $0^+$ |
| $^{47}$Ca | 46.95455 | 408.1917 | - | 4.536 d | $7/2^-$ |
| $^{48}$Ca | 47.95253 | 418.1371 | 0.187 | 6e+18 y | $0^+$ |
| $^{49}$Ca | 48.95567 | 423.2837 | - | 8.718 m | $3/2^-$ |
| $^{50}$Ca | 49.95752 | 429.6367 | - | 13.9 s | $0^+$ |
| $^{44}$Ti | 43.95969 | 377.835 | - | 60.2y | $0^+$ |
| $^{45}$Ti | 44.95813 | 387.3637 | - | 3.08056h | $7/2^-$ |
| $^{46}$Ti | 45.95263 | 400.5529 | 8.25 | Stable | $0^+$ |
| $^{47}$Ti | 46.95176 | 409.4333 | 7.44 | Stable | $5/2^-$ |
| $^{48}$Ti | 47.94795 | 421.0601 | 73.72 | Stable | $0^+$ |
| $^{49}$Ti | 48.94787 | 429.2026 | 5.41 | Stable | $7/2^-$ |
| $^{50}$Ti | 49.94479 | 440.142 | 5.18 | Stable | $0^+$ |
| $^{51}$Ti | 50.94661 | 446.5146 | - | 5.767m | $3/2^-$ |
| $^{52}$Ti | 51.9469 | 454.323 | - | 1.67m | $0^+$ |
| $^{53}$Ti | 52.94973 | 459.7584 | - | 32.7s | $3/2^-$ |

We explain same properties of Ca(p,n)Ti reactions from calculated banding energy (BE), Q-value (Q), reduced mass (μ), threshold energy ($E_{thr}$) and separation energies of neutron (n), and we lasted in Table (2), from this tables we found that same of this reactions are exoergic and the others are endoergic, in addition to other characteristics.

Table (2): Calculated results for Ca(α,n)Ti reactions

| Reaction Type | Q – value (MeV) P.W | threshold energy (MeV) P.W | reduced mass (amu) P.W | separation energies (MeV) P.W |
|---|---|---|---|---|
| $^{41}$Ca(a,n)$^{44}$Ti | 377.835 | 3.55327 | 3.646306 | 8.362935 |
| $^{42}$Ca(a,n)$^{45}$Ti | 387.3637 | 5.684025 | 3.654029 | 11.48078 |
| $^{43}$Ca(a,n)$^{46}$Ti | 400.5529 | 0.073388 | 3.661453 | 7.933008 |
| $^{44}$Ca(a,n)$^{47}$Ti | 409.4333 | 2.382606 | 3.668543 | 11.13131 |
| $^{45}$Ca(a,n)$^{48}$Ti | 421.0601 | 2.208718 | 3.675371 | 7.414908 |
| $^{46}$Ca(a,n)$^{49}$Ti | 429.2026 | 0.243427 | 3.681905 | 10.39459 |
| $^{47}$Ca(a,n)$^{50}$Ti | 440.142 | 3.732079 | 3.688204 | 7.276487 |
| $^{48}$Ca(a,n)$^{51}$Ti | 446.5146 | 0.14511 | 3.694243 | 9.945467 |
| $^{49}$Ca(a,n)$^{52}$Ti | 454.323 | 2.734626 | 3.700084 | 5.146565 |
| $^{50}$Ca(a,n)$^{53}$Ti | 459.7584 | 1.739391 | 3.705701 | 6.353007 |

The cross-section of Ca(α,n)Ti reactions for isotopes ($^{44}$Ti - $^{53}$Ti) available in the literatures Labs (TENDL-2012)[24] has been taken into consideration and re-plotted, interpolated and analyzed by using the MATLAB computer program to obtain the cross-section for energy range (10 - 50) MeV in fine steps of (0.5MeV) as shown in figure (1).

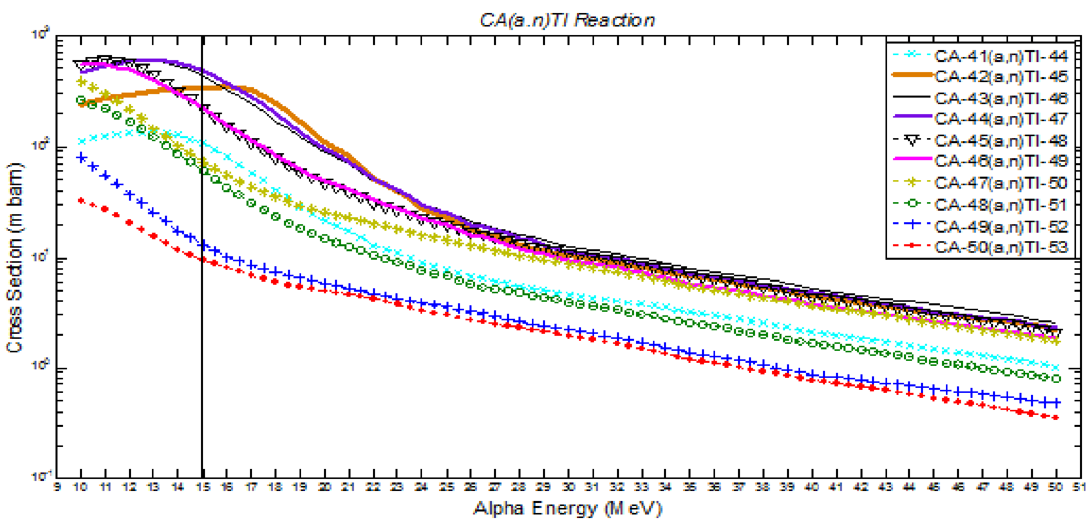



Figure (1): Cross sections of Ca(α,n)Ti reactions for Ti isotopes ($^{44}$Ti-$^{53}$Ti) after interpolation

We note from this figure that the best area of stability for the probability interaction involving all the curves start at energy approximately 15MeV (solid line) to 50MeV, an area that we have adopted for the calculations to get best results. After that, and depending on the energies of the incident Alpha and the targets of calcium isotopes ( A= 41-50 ) and using the program ( SRIM 2013) [25] was calculated stopping power at these energies . It is the ability of the stopping power with cross-sections at corresponding energies we calculated the neutron yields (n/$10^6$d) theoretically, shown in figure (2).

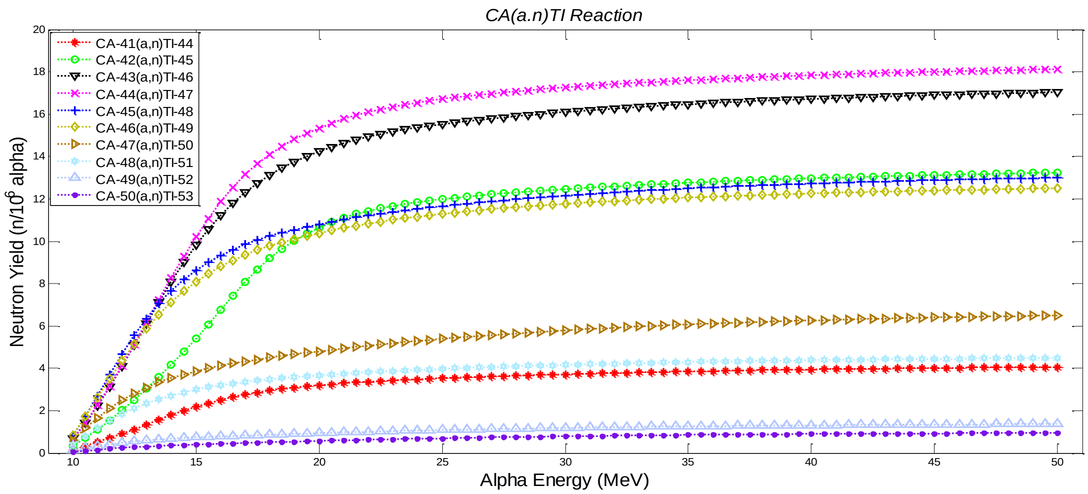



Figure (2): The neutron yield of Ca(α,n)Ti reaction at energy rang (10-50)MeV for Ca mass number (41-50)

We know increasing the mass number with proven atomic number for calcium isotopes that meaning an increase in the number of neutrons and the result will directly affect in the asymmetry energy , which was calculated for calcium isotopes , which we used to extract the empirical formula between the mass number and neutron yield shown in figure (3), for the incident Alpha energies (10-15) MeV in fine steps of (5 MeV).

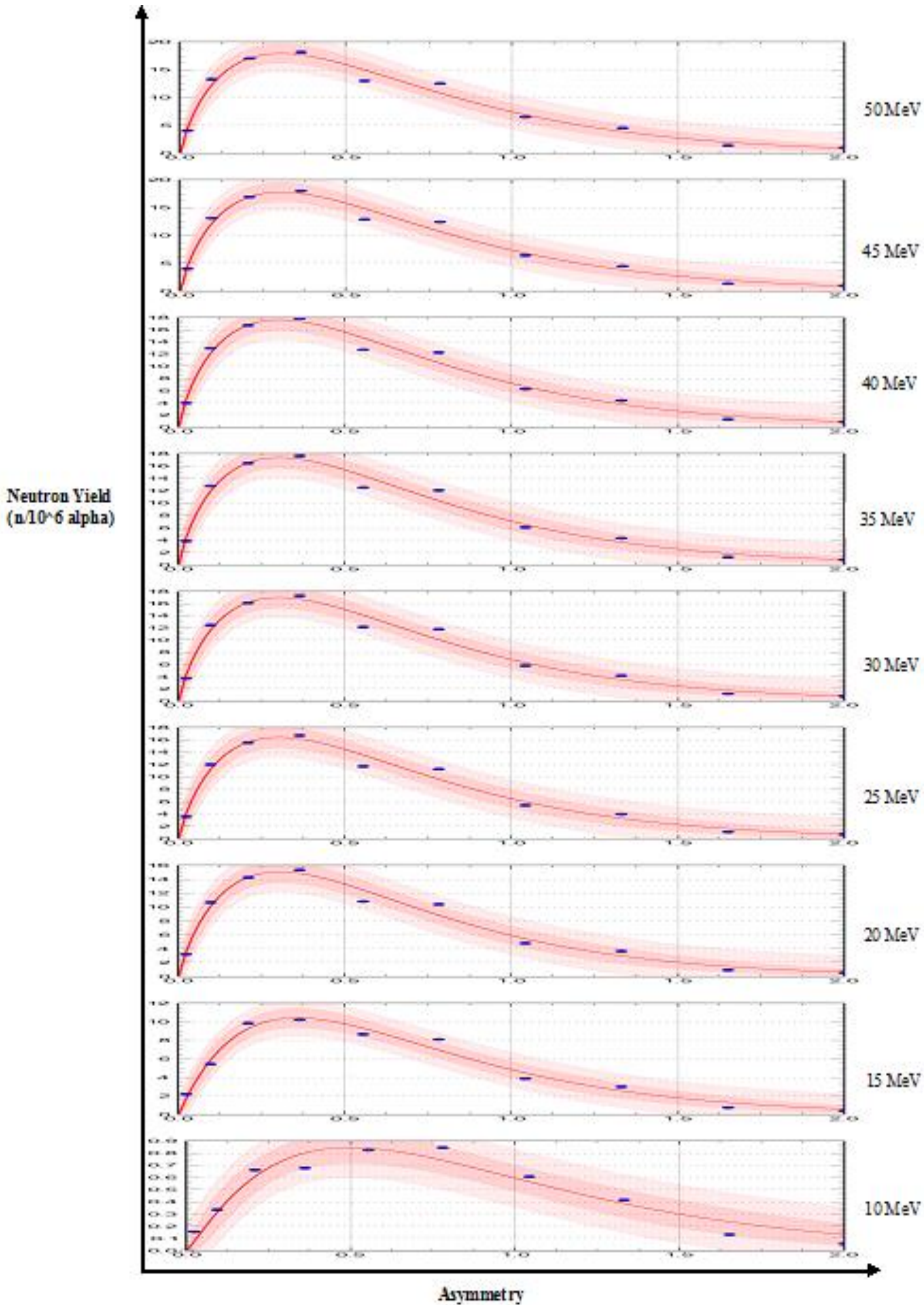



Fig (3).The neutron yield with asymmetry of Ca target isotopes for different Alpha energy induced reactions at (10 – 50) MeV

And the formula that was extracted by fitted for all these curves:

$$Y = \alpha\beta^{\ Es} Es^{\gamma} \quad \ldots \ldots.\ (19)$$

Where Y represent neutron yield. Es represent asymmetry energy. α, β and γ represents the first coefficients by different values for each energy as shown in Table (3).

Table (3) **:**Primary coefficients at different incident alpha energies when fitted curve between yield and asymmetry to get find coefficients

| Alpha energy(MeV) | A | β | Γ |
|---|---|---|---|
| 10 | 5.847246 | 1.02E-01 | 1.13795 |
| 15 | 7.72E+01 | 6.27E-02 | 9.83E-01 |
| 20 | 9.68E+01 | 6.11E-02 | 8.48E-01 |
| 25 | 1.01E+02 | 6.40E-02 | 8.24E-01 |
| 30 | 1.02E+02 | 6.71E-02 | 8.13E-01 |
| 35 | 1.02E+02 | 6.93E-02 | 8.05E-01 |
| 40 | 1.02E+02 | 7.08E-02 | 7.99E-01 |
| 45 | 1.02E+02 | 7.19E-02 | 7.95E-01 |
| 50 | 1.02E+02 | 7.27E-02 | 7.92E-01 |

From this table we draw the relationship between energy and the different values for each coefficient, the fitted expressions for each coefficient give us following formulas:

$$\alpha = B1\ e^{(B2\ E)} + B3\ e^{(B4\ E)} \quad \ldots \ldots ..(20)$$

$$\beta = B5\ E^{B6} + B7\ e^{(B8\ E)} \quad \ldots \ldots \ldots ..(21)$$

$$\gamma = B9\ (E - B10)^{B11} \quad \ldots \ldots \ldots\ \ (22)$$

And gives the following values of parameters: [ B1 = -2443.5, B2 = -0.30519, B3 = 102.46, B4=0.97403*$10^{-04}$, B5 = 0.9665, B6 = -0.5926, B7 = -0.27937, B8 = -0.05020, B9 = 0.8961345, B10 = 1.49268, B11 = -0.03539].

We have obtained formula of a set of Ca(α,n)Ti reactions has been used to calculate the neutron yields for each Ca isotopes at energy rang between (15 – 50) MeV and compared with the adopted neutron yields calculated from the fitting expressions and shown to be in a good agreement, the comparison of result shown in table (4)

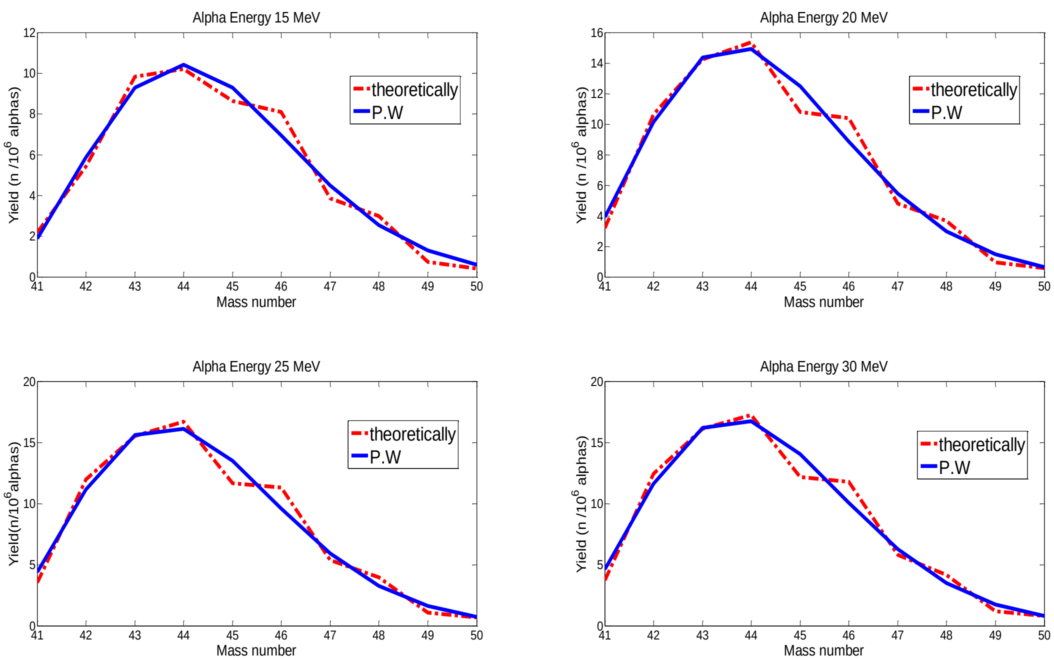
 

Table (4).The comparison between the value of neutron yield from theoretically and present work (empirical formula)

| Energy = 15 MeV | | | | Energy = 20 MeV | | | |
|---|---|---|---|---|---|---|---|
| **Mass number** | **Yield Theory** | **Yield P.W** | **Error %** | **Mass number** | **Yield theory** | **Yield P.W** | **Error %** |
| 41 | 2.18867 | 1.875161 | 14.32418 | 41 | 3.20474 | 3.907576 | 21.93112 |
| 42 | 5.42244 | 5.875613 | 8.357366 | 42 | 10.64807 | 10.14735 | 4.70242 |
| 43 | 9.82835 | 9.291508 | 5.462174 | 43 | 14.23652 | 14.37318 | 0.959958 |
| 44 | 10.21789 | 10.42822 | 2.058432 | 44 | 15.34688 | 14.91081 | 2.841392 |
| 45 | 8.62891 | 9.294011 | 7.707824 | 45 | 10.80398 | 12.49172 | 15.62149 |
| 46 | 8.0914 | 6.93943 | 14.23696 | 46 | 10.38187 | 8.859522 | 14.66352 |
| 47 | 3.86349 | 4.476616 | 15.86974 | 47 | 4.80287 | 5.466787 | 13.82334 |
| 48 | 2.99153 | 2.547835 | 14.83169 | 48 | 3.66805 | 2.991006 | 18.45788 |
| 49 | 0.74096 | 1.297684 | 75.13545 | 49 | 0.94081 | 1.469829 | 56.23022 |
| 50 | 0.40149 | 0.598549 | 49.08188 | 50 | 0.56736 | 0.655953 | 15.61499 |
| **Energy = 25 MeV** | | | | **Energy = 30 MeV** | | | |
| **Mass number** | **Yield Theory** | **Yield P.W** | **Error %** | **Mass number** | **Yield theory** | **Yield P.W** | **Error %** |
| 41 | 3.53422 | 4.401344 | 24.53508 | 41 | 3.71933 | 4.641864 | 24.80378 |
| 42 | 11.98828 | 11.14888 | 7.001821 | 42 | 12.45565 | 11.60991 | 6.790001 |
| 43 | 15.52517 | 15.61059 | 0.550194 | 43 | 16.09663 | 16.19124 | 0.587763 |
| 44 | 16.7124 | 16.11056 | 3.601168 | 44 | 17.26257 | 16.71971 | 3.144735 |
| 45 | 11.664 | 13.48164 | 15.58331 | 45 | 12.15842 | 14.04487 | 15.51561 |
| 46 | 11.2959 | 9.579684 | 15.19326 | 46 | 11.76259 | 10.04365 | 14.61359 |
| 47 | 5.38913 | 5.936669 | 10.16007 | 47 | 5.78998 | 6.277498 | 8.420034 |
| 48 | 3.97639 | 3.268718 | 17.79685 | 48 | 4.1632 | 3.492541 | 16.10921 |
| 49 | 1.08544 | 1.619353 | 49.18864 | 49 | 1.18837 | 1.751301 | 47.37001 |
| 50 | 0.69718 | 0.729686 | 4.662535 | 50 | 0.78872 | 0.799968 | 1.426141 |
| **Energy = 35 MeV** | | | | **Energy = 40 MeV** | | | |
| **Mass number** | **Yield Theory** | **Yield P.W** | **Error %** | **Mass number** | **Yield theory** | **Yield P.W** | **Error %** |
| 41 | 3.85423 | 4.797047 | 24.46186 | 41 | 3.94866 | 4.913645 | 24.4383 |
| 42 | 12.75922 | 11.89569 | 6.767874 | 42 | 12.96944 | 12.10191 | 6.689002 |
| 43 | 16.46886 | 16.55235 | 0.506971 | 43 | 16.72051 | 16.80365 | 0.497228 |
| 44 | 17.6065 | 17.11241 | 2.806309 | 44 | 17.83939 | 17.37873 | 2.582251 |
| 45 | 12.49658 | 14.42662 | 15.44457 | 45 | 12.72349 | 14.6824 | 15.39598 |
| 46 | 12.0592 | 10.37419 | 13.97283 | 46 | 12.25577 | 10.59536 | 13.54796 |
| 47 | 6.07058 | 6.531188 | 7.587541 | 47 | 6.25962 | 6.701858 | 7.064936 |
| 48 | 4.29358 | 3.665456 | 14.62937 | 48 | 4.38087 | 3.782847 | 13.65079 |
| 49 | 1.26043 | 1.856542 | 47.29437 | 49 | 1.30789 | 1.928789 | 47.4733 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 50 | 0.85331 | 0.857622 | 0.505349 | 50 | 0.89588 | 0.897691 | 0.202153 |
| **Energy = 45 MeV** | | | | **Energy = 50 MeV** | | | |
| **Mass number** | **Yield Theory** | **Yield P.W** | **Error %** | **Mass number** | **Yield theory** | **Yield P.W** | **Error %** |
| 41 | 4.01701 | 5.007862 | 24.6664 | 41 | 4.06912 | 5.08692 | 25.01279 |
| 42 | 13.1233 | 12.26031 | 6.57599 | 42 | 13.24044 | 12.38518 | 6.459445 |
| 43 | 16.90252 | 16.98211 | 0.470853 | 43 | 17.03839 | 17.10627 | 0.398389 |
| 44 | 18.00729 | 17.55157 | 2.530756 | 44 | 18.13329 | 17.65094 | 2.660052 |
| 45 | 12.88477 | 14.83611 | 15.14458 | 45 | 13.00449 | 14.90661 | 14.62666 |
| 46 | 12.39539 | 10.72159 | 13.50343 | 46 | 12.49965 | 10.76838 | 13.85052 |
| 47 | 6.39549 | 6.796473 | 6.269779 | 47 | 6.49844 | 6.826232 | 5.044161 |
| 48 | 4.44348 | 3.847073 | 13.42207 | 48 | 4.49111 | 3.865223 | 13.93613 |
| 49 | 1.34276 | 1.968185 | 46.57755 | 49 | 1.37101 | 1.97868 | 44.32277 |
| 50 | 0.92646 | 0.919597 | 0.740821 | 50 | 0.94905 | 0.925284 | 2.504209 |

The comparison shows that the calculated results are in agreement to the behavior of the theoretical curve range, there is a simple systematic deviation as shown in Figure (4) for all Ca isotopes at different energy.



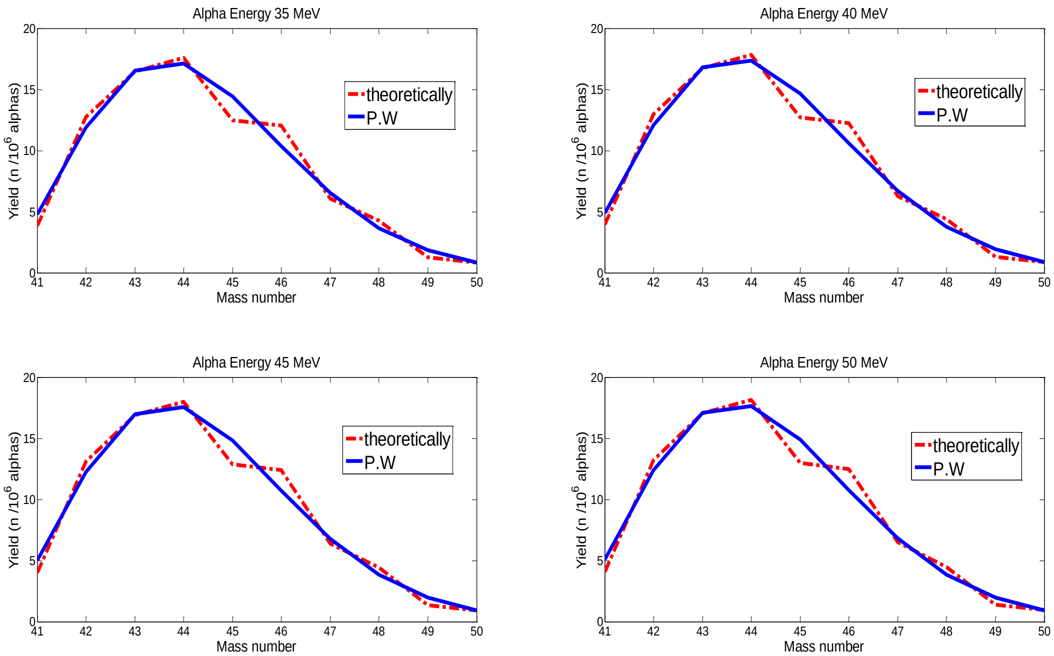



Figure (4): The comparison between neutron yields calculated from the theoretically relationship and fitting expressions for Ca(a,n)Ti

The reason of the deviation is the large interval of long energy rang. It is noted that the neutron yield for energies between (10-14) was not included with the rest of the table because of the big difference between the theoretical values and the calculated values from empirical formula, this reason was determined the area of energy in the figure (1) at the beginning of the work.

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