



The Empirical Formulae for a Set of (d, n) Reactions to Determine the Neutron Yields Using Light Elements

Ramadhan Hayder Abdullah

Department of Physics, College of Science, Salahaddin University, Hawler, Kurdistan region, IRAQ

Abstract: In the present work, The cross-sections of (d,n) reactions available in the literature as a function of deuteron energies for light elements such as ^{10}B , ^{12}C and ^{14}N have been rearranged for deuteron energies from near threshold energy up to 10 MeV in steps of (0.050 MeV) using the MATLAB computer program. The obtained data were used to calculate the weighted average cross sections using the excel program. The stopping powers of deuteron energies from (near threshold energy to 10 MeV) for the above light elements have been calculated using the bethe formula. The obtained data of weighted average cross sections and the stopping powers are taken into consideration and used to calculate the neutron yields ($n/10^6\text{d}$) of the above light elements using the quick basic program.. The polynomial expressions have been used to fitting the calculated neutron yields ($n/10^6\text{d}$) of the mentioned light elements to determine the adopted neutron yields from the best fitting equations with minimum CHISQ. The results of the present work are found to be, within associated uncertainties, in good agreement with the published values of the previous work. The aim of the present work is to determine the neutron yields ($n/10^6\text{d}$) of (d,n) reactions theoretically.

Keyword: Cross-Section, Neutron Yield, stopping power, empirical formula, light elements

I. Introduction

The cross -sections of (d, n) reactions for different targets have been measured as a function of deuteron energies by several authors.. The cross-sections of $^{10}\text{B}(\text{d},\text{n})^{11}\text{C}$ reaction as a function of deuteron energies have been calculated by Wohlleben [1], Gushovskij [2] and Michelmann [3] (from 0.55 to 3.1 MeV), (from 2.93 to 10.99 MeV) and (from 0.4794 to 5.019 MeV) respectively While, the cross sections of $^{12}\text{C}(\text{d},\text{n})^{13}\text{N}$ reaction have been determined by Brill [4], Michelmann [5] and Firozbakht [6] from (1.4435 to 19.011 MeV), (0.5233 TO 6.005 MeV) and (0.6 to 22.1 MeV) respectively. The cross sections of $^{14}\text{N}(\text{d},\text{n})^{15}\text{O}$ reaction have been calculated by VeraRuiz [7], Sajjad [8], Koehl [9] and Tackas [10] from (0.6 to 14.35 MeV), (1.08 to 12.28 MeV), (1.552 to 7.0339 MeV) and (0.7 to 14.2 MeV) respectively. While the cross sections of $^9\text{Be}(\alpha,\text{n})^{12}\text{C}$ reaction have been measured by Gibbon [11] and Heaton [12] from (1.66 to 10.3 MeV) and (1.7 to 10 MeV) respectively. The aim of the present work is to determine the neutron yields ($n/10^6\alpha$) of (d,n) reactions theoretically.

II. THEORY

The Q_0 -value of the nuclear reaction is defined as the difference between the initial and final masses [13]:

$$Q_0 = [M_d + M_x - (M_n + M_Y)] \times 931.5 \text{ MeV} \quad (1)$$

Where, M_d , M_x , M_Y and M_n are the bombarding particle, target nucleus, product nucleus and neutron masses respectively . If Q_0 is positive, the reaction is exoergic, and If Q_0 is negative, the reaction is endoergic.

The threshold energy is the minimum kinetic energy of the alpha particles to occur the reaction, and it relates to the Q-value of reaction through this equation [13]:

$$E_{\text{thr.}} = -Q_0 \left(1 + \frac{M_d}{M_x} \right) \quad (2)$$

The neutron yield can be calculated using the equation given by [14]:

$$Y(E) = \int_{E_{\text{th}}}^{E_d} \frac{\sigma(E)}{dE/dx} dE \quad (3)$$

Where, E_{th} is the threshold energy of the reaction, E_d is the bombarding energy. $\sigma(E)$, is a cross section in mb and (dE/dx) is stopping power of the target in $[\text{MeV}/(10^{21} \text{ atoms}/\text{cm}^2)]$.

for light elements whose cross sections (σ_0) have been measured, can be given by a relationship [15] The weighted averages of the cross sections

$$\sigma_o \text{ (mb)} = \frac{\sum_i \frac{\sigma_i}{\Delta_i^2}}{\sum_i \frac{1}{\Delta_i^2}} \quad (4)$$

$$\Delta \sigma_o = \pm \frac{1}{\sqrt{\sum_i \frac{1}{\Delta_i^2}}} \quad (5)$$

Where (σ_i), ($\Delta \sigma_o$) and (Δ_i) are the cross sections, uncertainty and the errors of the i^{th} references respectively[12]:

The Polynomial fit expression of the following form have been considered in the present work to fit the neutron yields [16]:

$$Y(n/10^6 d) = \sum_{i=0}^N C_i E^i \quad (6)$$

Where ($C_1, C_2, C_3, \dots$) are free parameters, and $i = 0, 1, 2, 3, \dots, N$.

The weighted average (adopted) data have been computer fitted to the above expression using Matlab computer programs. The set of parameters, giving minimum value of (CHISQ) in the following expression has been used to calculate the neutron yield (y_0) [16]:

$$\chi^2 = \frac{1}{(N-m)} \sum_i \left(\frac{Y_{\text{exp}}^i - Y_{\text{cal}}^i}{\Delta Y_{\text{exp}}^i} \right)^2 \quad (7)$$

Where N is the no. of data points, m is the no. of parameters in fitting. Y_{exp} is the weighted average (adopted) of n-yield. Y_{cal} is the calculated neutron yield from the equation of fitting.

III. Data Reduction and Analysis

The atomic masses of ref. [17] have been taken into consideration to calculate the Q-value and the threshold energy using the equations (1 and 2) respectively. The obtained results of the mentioned reactions are presented

The cross sections of $^9\text{Be}(\alpha, n)^{12}\text{C}$ reaction have been calculated by Gibbon [11] and Heaton [12], in Table (I). the data interpolated and analyzed to obtain the cross sections in fine steps (0.05 MeV) and taken into consideration to determine the weighted average of cross sections. The results are shown in Fig.(I). The obtained results of the weighted average of cross sections and the stopping power of Ziegler formula [18] are used to calculate the neutron yields ($n/10^6 \alpha$) using the equation (3). The results are shown in Fig. (II) and presented in Table (II). The obtained results are compared with those of previous work such as Nakasima [19], Murata [20], Ahmed [21], Abdullrahman [22] and Abdullah [23]. It is clear from Table (II) that the results of the present work, within the associated uncertainties, in good agreement with those of references [19, 20, 21, 22 and 23] respectively. The slight differences may be attributed to differences in atomic masses used in the mentioned references. This indicates that the equation (3) has been applied correctly to determine the neutron yields ($n/10^6 \alpha$). In the same manner the equation (3) has been used to determine the neutron yields ($n/10^6 d$) of (d,n) reactions.

Table (1): The Q-Value and threshold energy of the (d,n) reactions

Reactions	Q-Value (MeV)	Threshold Energy(MeV)
$^{10}\text{B}(\text{d}, \text{n})^{11}\text{C}$	6.466003524	-7.76664
$^{12}\text{C}(\text{d}, \text{n})^{13}\text{N}$	-0.280003311	0.327
$^{14}\text{N}(\text{d}, \text{n})^{15}\text{O}$	5.072004459	-5.80153

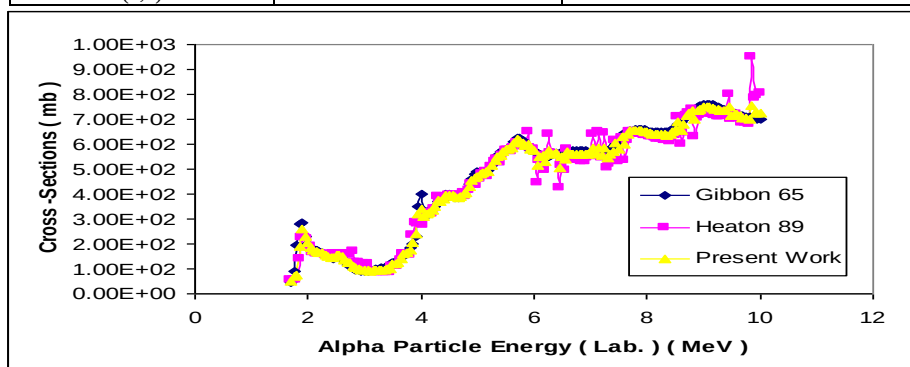


Fig. (I)The cross-Section of $^9\text{Be}(\alpha, n)^{12}\text{C}$ reaction as a function of alpha particle energy

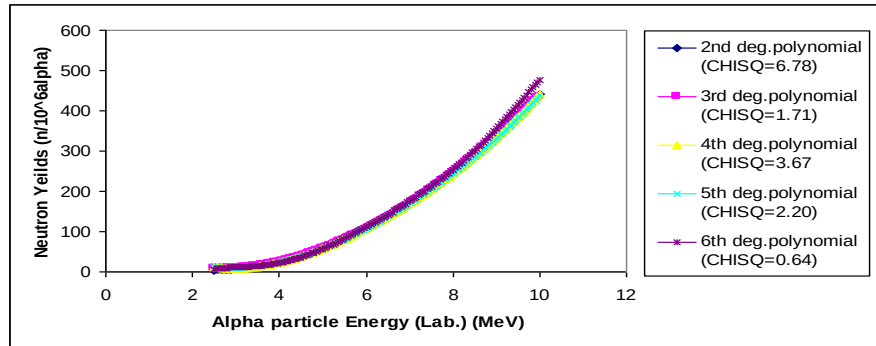


Fig. (II): The neutron yields ($n/10^6\alpha$) of ${}^9\text{Be}(\alpha, n){}^{12}\text{C}$ reaction as a function of alpha particle energy

Table (II): Comparison between the present and the previous work for ${}^9\text{Be}(\alpha, n){}^{12}\text{C}$ reaction

Energy MeV	Nakasima (1992) $\pm$ Error	Murata (2003) $\pm$ Error	Ahmed (2006) $\pm$ Error	Abdull-rahman (2007) $\pm$ Error	Abdullah (2007) $\pm$ Error	Present work $\pm$ Error
2.5	8.590 $\pm$ 0.859	6.793 $\pm$ 0.6793	7.040 $\pm$ 0.362	7.393 $\pm$ 0.276	7.794 $\pm$ 0.271	6.963 $\pm$ 0.348
2.75	11.79 $\pm$ 1.179	7.739 $\pm$ 0.7739	8.004 $\pm$ 0.412	8.728 $\pm$ 0.327	9.031 $\pm$ 0.316	9.847 $\pm$ 0.492
3	15.09 $\pm$ 1.509	9.065 $\pm$ 0.9065	9.344 $\pm$ 0.481	10.284 $\pm$ 0.386	10.55 $\pm$ 0.368	11.39 $\pm$ 0.569
3.25	16.39 $\pm$ 1.639	10.94 $\pm$ 1.094	11.22 $\pm$ 0.578	12.140 $\pm$ 0.454	12.50 $\pm$ 0.434	12.73 $\pm$ 0.636
3.5	18.19 $\pm$ 1.819	13.55 $\pm$ 1.355	13.83 $\pm$ 0.712	14.536 $\pm$ 0.542	15.10 $\pm$ 0.521	14.69 $\pm$ 0.735
3.75	20.29 $\pm$ 2.029	17.14 $\pm$ 1.714	17.40 $\pm$ 0.896	17.770 $\pm$ 0.661	18.51 $\pm$ 0.635	17.82 $\pm$ 0.891
4	23.99 $\pm$ 2.399	21.92 $\pm$ 2.192	22.12 $\pm$ 1.139	22.582 $\pm$ 0.840	23.36 $\pm$ 0.801	22.44 $\pm$ 1.122
4.25	30.99 $\pm$ 3.099	28.07 $\pm$ 2.807	28.16 $\pm$ 1.449	28.971 $\pm$ 1.078	29.72 $\pm$ 1.019	28.69 $\pm$ 1.435
4.5	41.49 $\pm$ 4.149	35.70 $\pm$ 3.570	35.61 $\pm$ 1.833	36.632 $\pm$ 1.363	37.69 $\pm$ 1.292	36.58 $\pm$ 1.829
4.75	48.49 $\pm$ 4.849	44.83 $\pm$ 4.483	44.48 $\pm$ 2.289	44.593 $\pm$ 1.659	46.41 $\pm$ 1.589	46.02 $\pm$ 2.301
5	57.99 $\pm$ 5.799	55.39 $\pm$ 5.539	54.68 $\pm$ 2.814	55.224 $\pm$ 2.053	56.64 $\pm$ 1.938	56.87 $\pm$ 2.844
5.25	68.49 $\pm$ 6.849	67.25 $\pm$ 6.725	66.09 $\pm$ 3.402	66.482 $\pm$ 2.472	68.02 $\pm$ 2.327	68.95 $\pm$ 3.447
5.5	82.99 $\pm$ 8.299	80.25 $\pm$ 8.025	78.54 $\pm$ 4.042	78.835 $\pm$ 2.931	81.09 $\pm$ 2.774	82.06 $\pm$ 4.103
5.75	97.99 $\pm$ 9.799	94.22 $\pm$ 9.422	91.89 $\pm$ 4.730	92.294 $\pm$ 3.432	95.26 $\pm$ 3.260	96.03 $\pm$ 4.802
6	113.0 $\pm$ 11.30	109.0 $\pm$ 10.90	106.0 $\pm$ 5.456	106.366 $\pm$ 3.958	109.8 $\pm$ 3.758	110.7 $\pm$ 5.537
6.25	127.0 $\pm$ 12.70	124.6 $\pm$ 12.46	120.8 $\pm$ 6.218	119.211 $\pm$ 4.435	124.6 $\pm$ 4.264	126.1 $\pm$ 6.303
6.5	142.0 $\pm$ 14.20	140.9 $\pm$ 14.09	136.3 $\pm$ 7.015	133.208 $\pm$ 4.961	140.1 $\pm$ 4.793	142 $\pm$ 7.098
6.75	157.0 $\pm$ 15.70	157.8 $\pm$ 15.78	152.4 $\pm$ 7.844	146.206 $\pm$ 5.450	156.2 $\pm$ 5.341	158.4 $\pm$ 7.922
7	171.8 $\pm$ 17.18	175.5 $\pm$ 17.55	169.2 $\pm$ 8.709	160.413 $\pm$ 5.993	172.7 $\pm$ 5.906	175.6 $\pm$ 8.779
7.25	189.0 $\pm$ 18.90	193.8 $\pm$ 19.38	186.6 $\pm$ 9.604	173.686 $\pm$ 6.501	189.9 $\pm$ 6.494	193.5 $\pm$ 9.674
7.5	206.0 $\pm$ 20.60	212.9 $\pm$ 21.29	204.8 $\pm$ 10.54	188.099 $\pm$ 7.067	207.9 $\pm$ 7.108	212.3 $\pm$ 10.62

The cross-sections of (d,n) reactions for light element such as (${}^{10}\text{B}$, ${}^{12}\text{C}$ and ${}^{14}\text{N}$) available in the literatures has been taken into consideration and re-plotted, interpolated and analyzed by using the MATLAB computer program to obtain the cross-section in fine steps of (0.05MeV). The weighted average of the modified cross-sections of ${}^{10}\text{B}(\text{d}, \text{n}){}^{11}\text{C}$, ${}^{12}\text{C}(\text{d}, \text{n}){}^{13}\text{N}$ and ${}^{14}\text{N}(\text{d}, \text{n}){}^{15}\text{O}$ reactions whose cross section (σ) and uncertainty of (σ) is ($\Delta\sigma$) has been calculated by using eqns. (4) and (5) respectively, the results are shown in Fig.(III). The obtained results of the weighted average of the cross sections and the stopping powers of bethe formula [24] are taken into consideration and used to calculate the neutron yields ($n/10^6\text{d}$) of (d,n) reactions as a function of deuteron energies in lab. system using eqn. (3). The results are shown in Fig.(IV) and also the obtained results of the neutron yields have been used as the input data, Excel computer programs (Format Trend line) Polynomial fit expressions of the form:

$$Y = C_0 + C_1X + C_2X^2 + \dots + C_NX^N = \sum_{i=0}^N C_iX^i \quad (8)$$

$$C_{ij}E^j \sum_{j=0}^n \quad \text{and} \quad C_i = \quad (9)$$

have been considered in the present work. Subsequently, by combining the above eqns. (8) and (9), the following expression can be obtained:

$$Y = \sum_{i=0}^N \left(\sum_{j=0}^n C_{ij} E^j \right) X^i \quad (10)$$

where Y is the neutron yields ($n/10^6 d$), E is the energy of deuteron in lab. system C_{ij} ($C_{00}, C_{01}, \dots$) are free parameters, ($i=0, 1, 2, 3, \dots$), ($j=0, 1, 2, 3, \dots$), and X is representing the physical quantities; (atomic number(Z)), for each time of expression establishments. The Excel computer programs were used to obtain the best fit formulae corresponding to different energy ranges from near threshold energy up to 10 MeV in lab. system. In each step, the data of these ranges was excluded till an acceptable value of the coefficient of determination $R^2 \approx 1$ was reached. Thus the final expressions of the following form can be obtained to calculate the neutron yields ($n/10^6 d$):

$$Y[n.yields(n/10^6 d)] = \sum_{i=0}^N \left(\sum_{j=0}^n C_{ij} E^j \right) X^i \quad (11)$$

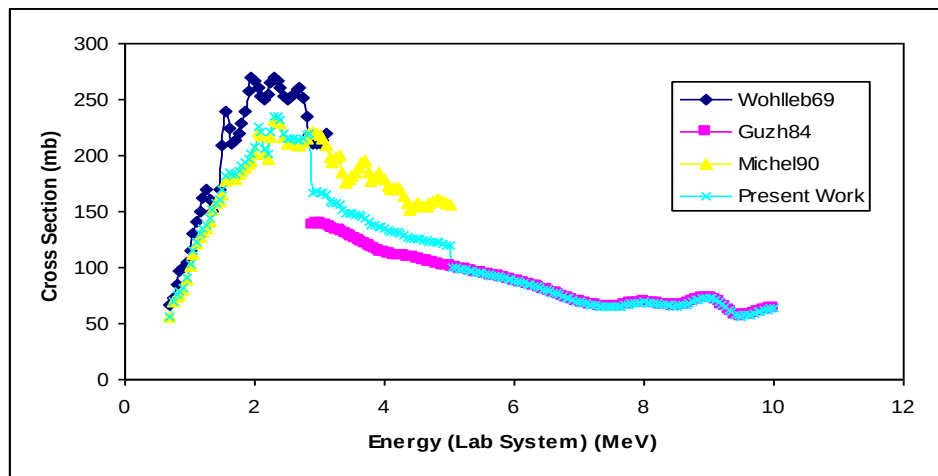


Fig.(III) (a) : The cross-sections of $^{10}\text{B}(d,n)^{11}\text{C}$ reaction as a function of deuteron energy for i^{th} reference in lab. system

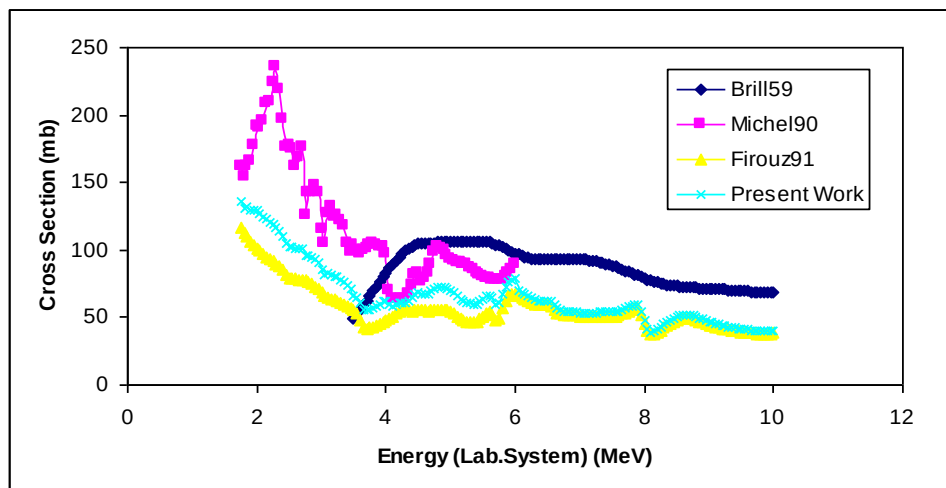


Fig.(III) (b) : The cross-sections of $^{12}\text{C}(d,n)^{13}\text{N}$ reaction as a function of deuteron energy for i^{th} reference in lab. system

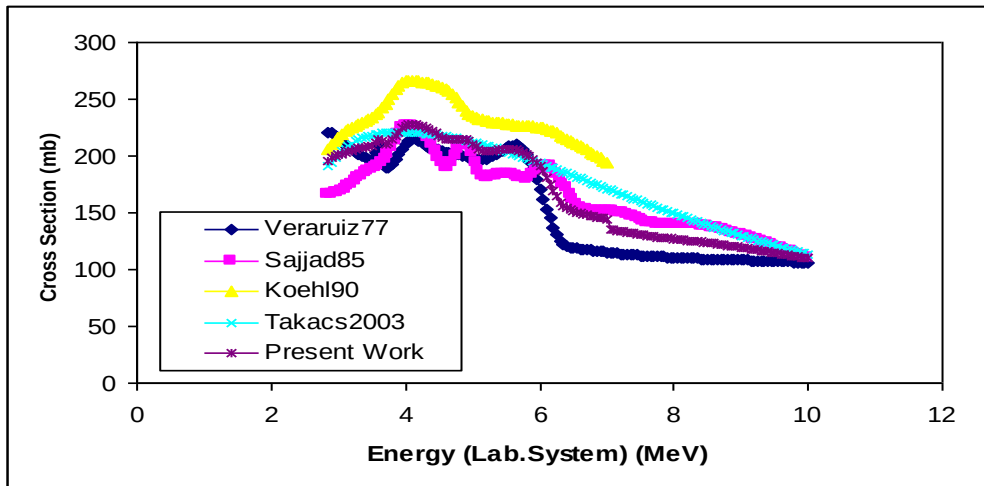


Fig.(III) (c) : The cross-sections of $^{14}\text{N}(\text{d},\text{n})^{15}\text{O}$ reaction as a function of deuteron energy for i^{th} reference in lab. system .

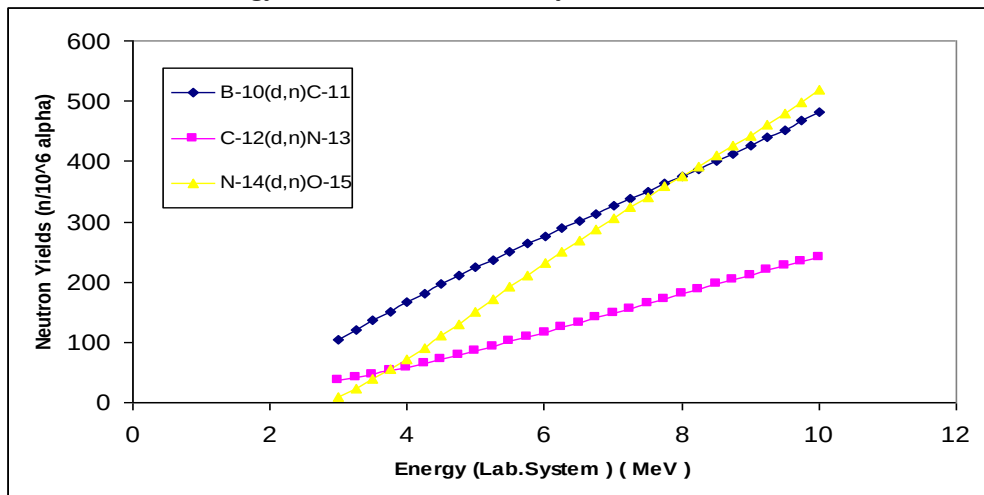


Fig.(IV): The neutron yields ($\text{n}/10^6\text{d}$) of $^{10}\text{B}(\text{d},\text{n})^{11}\text{C}$, $^{12}\text{C}(\text{d},\text{n})^{13}\text{N}$ and $^{14}\text{N}(\text{d},\text{n})^{15}\text{O}$ reactions as a function of deuteron energies in lab. system .

IV. The Results and Discussion

A. The Empirical Formula:

The adopted neutron yields have been used to obtain the fitting parameter by using the polynomial expressions (6), (7) and (9) by the following steps:

1. The polynomial expressions were used in eqn. (6) to fit the calculated neutron yields of the studied light elements of (d,n) reactions to determine the adopted neutron yields from the best fitting with minimum CHISQ (χ^2) using eq. (7). The obtained best fitting equations of the mentioned reactions are present in equations (12, 13, and 14) respectively for the above reactions.

$$^{10}\text{B}(\text{d},\text{n})^{11}\text{C}: Y_5 = -0.0153E^5 + 0.514E^4 - 6.3078E^3 + 33.78E^2 - 18.848E - 10.639 \quad (\chi^2=0.162) \quad \dots\dots(12)$$

$$^{12}\text{C}(\text{d},\text{n})^{13}\text{N}: Y_5 = 0.0197E^5 - 0.6247E^4 + 7.415E^3 - 39.982E^2 + 123.04E - 127.63 \quad (\chi^2=0.098) \quad \dots\dots(13)$$

$$^{14}\text{N}(\text{d},\text{n})^{15}\text{O}: Y_4 = 0.2427E^4 - 6.5229E^3 + 62.297E^2 - 174.26E + 128.85 \quad (\chi^2=0.126) \quad \dots\dots(14)$$

- At a fixed values of deuteron energy in lab. system (E_d), the variation of the neutron yields with the physical parameters (atomic number Z) has been fitted to the polynomial expression using eq.(6). he obtained results are taken into consideration to determine the free parameters (C_i).
- The free parameters C_i are plotted against the prefixed values of deuteron energy in lab. system and fitted to adequate the polynomial expression where presented in eq. (9) .
- The final formula of a set of (d,n) reactions have been determined by using the combination of the two polynomials to show the systematic behavior of the reactions.

B. The Empirical Formulae Relating the neutron yields to deuteron Energies in lab .system (E_d) and the Atomic Number (Z) of the Target Nucleus:

The empirical formulae relating the neutron yields with both of the deuteron energies in lab. system E_{lab} and the target atomic number (Z) were performed as follows:

- 1- At a fixed value of deuteron energy in lab. system (3,4,5,6,7,8,9 and 10 MeV), the variation of neutron yields ($n/10^6 d$) with the atomic number (Z) for $^{10}B(d,n)^{11}C$, $^{12}C(d,n)^{13}N$ and $^{14}N(d,n)^{15}O$ reactions have been plotted as shown in Fig.(V), and the data have been fitted to the following polynomial expression:

$$Y = \sum_{i=0}^2 C_i X^i \quad \dots\dots\dots(15)$$

Where, Y=Neutron yields and $X=Z$, with free parameters C_i (C_0, C_1 and C_2)

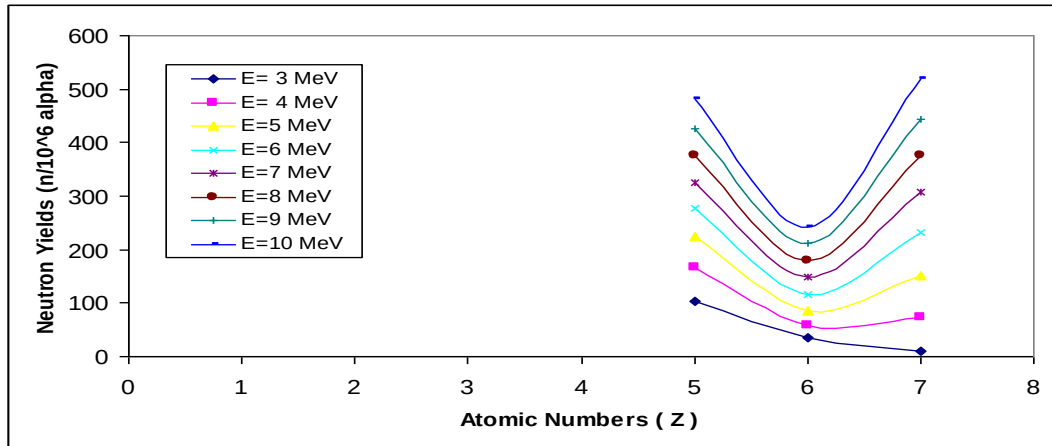


Fig.(V): The variation of neutron yields with the atomic number (Z) for $^{10}B(d,n)^{11}C$, $^{12}C(d,n)^{13}N$ and $^{14}N(d,n)^{15}O$ reactions at a fixed values of deuteron energies

- 2- The adopted neutron yields have been used as the input data as a function of target atomic number at a fixed deuteron energy in lab. system using Excel computer program to obtain the fitting expressions and then used to calculate the fitting parameters. The obtained results are presented in Table(III).

Table(III):Free parameters C_i (C_0, C_1 and C_2) as a function of deuteron energy in lab. system E_d

E_d (MeV)	C_0 (coefficient)	C_1 (coefficient)	C_2 (coefficient)
3	1086	-302.91	21.32
3.5	1763.9	-523.55	39.587
4	2511.4	-770.55	60.319
4.5	3262.5	-1020.9	81.532
5	3975.1	-1259.7	101.92
5.5	4627.5	-1479.1	120.77
6	5214.9	-1676.7	137.83
6.5	5744.7	-1854.8	153.25
7	6233.6	-2018.6	167.42
7.5	6703.4	-2175.3	180.94
8	7177.3	-2332.7	194.44
8.5	7676.1	-2497.9	208.55
9	8214.3	-2676.3	223.75
9.5	8796.5	-2869.9	240.26
10	9413.5	-3076.5	258

- 3- The obtained free parameters C_i (C_0, C_1 and C_2), as shown in Table (III) are plotted against with the prefixed values of deuteron energy in lab. system (3,4,5,6,7,8,9 and 10 MeV) as shown in Fig.(VI) and then the obtained free parameters C_i have been fitted to the following polynomial expression:

$$C_i = \sum_{ij}^N C_{ij} E^j \quad (16)$$

with the free parameters C_{ij} ($i=0, 1, 2$), ($j=0, 1, 2, 3, 4$), as shown in Fig.(VI):

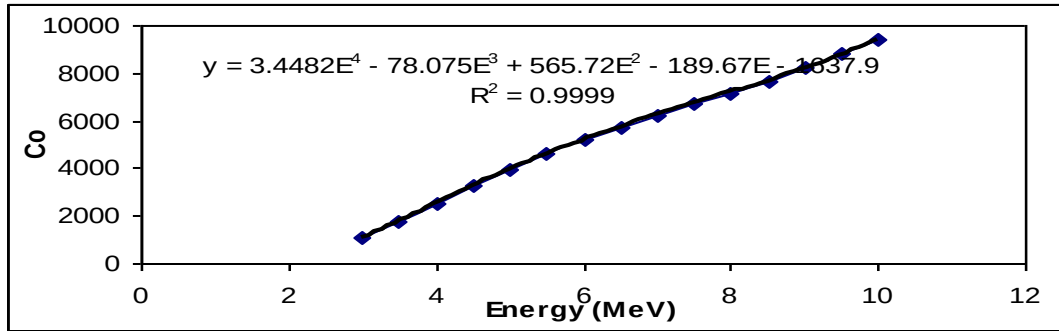


Fig.(VI) (a):Plots of (C_0) coefficients against deuteron energy in lab.system. The solid line represent the fitted curve through the data. The fitted expressions for each coefficient are also presented.

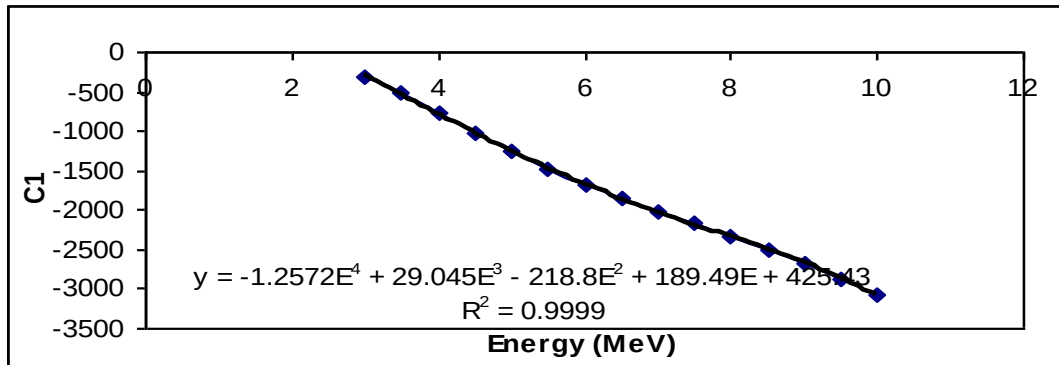


Fig.(VI) (b) :Plots of (C_1) coefficients against deuteron energy in lab.system. The solid line represent the fitted curve through the data. The fitted expressions for each coefficient are also presented.

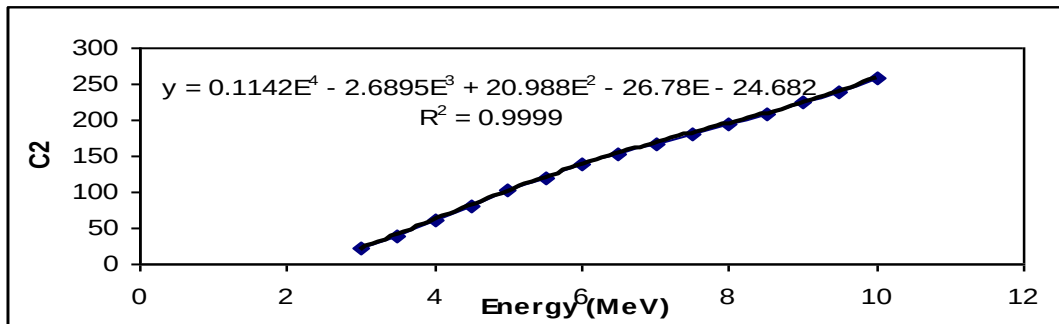


Fig.(VI) (c) : Plots of (C_2) coefficients against deuteron energy in lab.system . The solid line represent the fitted curve through the data. The fitted expressions for each coefficient are also presented.

The combination of the two polynomials takes the form of the following formula from energy range (3 to 10 MeV) in lab. system:

$$Y = \sum_{i=0}^2 \left(\sum_{j=0}^4 C_{ij} E^j \right) X^i \quad (18)$$

$$Y = \sum_{i=0}^2 (C_{i0} E^0 + C_{i1} E^1 + C_{i2} E^2 + C_{i3} E^3 + C_{i4} E^4) X^i \quad (19)$$

$$Y = C_{00} E^0 X^0 + C_{01} E^1 X^0 + C_{02} E^2 X^0 + C_{03} E^3 X^0 + C_{04} E^4 X^0 + C_{10} E^0 X^1 + C_{11} E^1 X^1 + C_{12} E^2 X^1 + C_{13} E^3 X^1 + C_{14} E^4 X^1 + C_{20} E^0 X^2 + C_{21} E^1 X^2 + C_{22} E^2 X^2 + C_{23} E^3 X^2 + C_{24} E^4 X^2 \quad (20)$$

where Y =neutron yields, $X=Z$ and $(C_{00}, C_{01}, C_{02}$ and $C_{01}, \dots)$ are free parameters as follows :

C_{00}	C_{01}	C_{02}	C_{03}	C_{04}	-1637.9	-189.67	565.72	-78.075	3.4482
C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	425.43	189.49	-218.8	29.045	-1.2572
C_{20}	C_{21}	C_{22}	C_{23}	C_{24}	-24.682	-26.78	20.988	-2.6895	0.1142

The obtained formula of a set of reactions such as $^{10}\text{B}(\text{d},\text{n})^{11}\text{C}$, $^{12}\text{C}(\text{d},\text{n})^{13}\text{N}$ and $^{14}\text{N}(\text{d},\text{n})^{15}\text{O}$ reactions has been used to calculate the neutron yields for each of the above (d,n) reactions and compared with the adopted neutron yields calculated from the fitting expressions and shown to be in a good agreement and the comparison of the two results are shown in Table (IV).

Table (IV) : The Comparison between the polynomial fitting expression (best fitting) of the adopted neutron yields of (d,n) reactions with those calculated from eq. (20)(the new formula).

Energy (MeV)	$^{10}\text{B}(\text{d},\text{n})^{11}\text{C}$		$^{12}\text{C}(\text{d},\text{n})^{13}\text{N}$		$^{14}\text{N}(\text{d},\text{n})^{15}\text{O}$	
	5 th degree polyn. Best Fit.	4 th degree (Formula) Set(3) Best Fit	5 th degree polyn. Best Fit.	4 th degree (Formula Set(3) Best Fit	4 th degree polyn. Best Fit.	4 th degree (Formula) Set(3) Best Fit
3	104.4425	103.8507	36.0434	36.4732	10.2834	10.1031
3.25	120.1688	120.2115	41.93068	41.43364	23.675303	23.424084
3.5	135.8474	136.1545	47.75139	46.81939	38.829081	38.515913
3.75	151.3737	151.6934	53.62072	52.59216	55.440381	55.07325
4	166.6666	166.8432	59.6276	58.7152	73.2276	72.8136
4.25	181.6659	181.6208	65.83703	65.15327	91.93189	91.477303
4.5	196.331	196.0446	72.29237	71.87264	111.31716	110.82754
4.75	210.6392	210.1347	79.01768	78.84111	131.17006	130.65032
5	224.5835	223.9125	86.02	86.028	151.3	150.7545
5.25	238.171	237.4014	93.29166	93.40414	171.53915	170.97177
5.5	251.4214	250.6263	100.8126	100.9419	191.74243	191.15666
5.75	264.3646	263.6135	108.5527	108.6151	211.78751	211.18654
6	277.0394	276.3912	116.474	116.3992	231.5748	230.9616
6.25	289.4916	288.9891	124.5331	124.2711	251.02749	250.40489
6.5	301.7721	301.4384	132.6836	132.2091	270.09151	269.46229
6.75	313.9351	313.7721	140.8779	140.1934	288.73553	288.10251
7	326.0365	326.0247	149.0702	148.2052	306.951	306.3171
7.25	338.1319	338.2324	157.2183	156.2276	324.7521	324.12046
7.5	350.2748	350.4328	165.286	164.2452	342.17578	341.54981
7.75	362.5151	362.6654	173.2457	172.2439	359.28173	358.66523
8	374.897	374.9712	181.0804	180.2112	376.1524	375.5496
8.25	387.4572	387.3927	188.786	188.1363	392.89299	392.30868
8.5	400.2233	399.9741	196.3738	196.0096	409.63146	409.07104
8.75	413.212	412.7613	203.8727	203.8234	426.51851	425.98809
9	426.4271	425.8017	211.3316	211.5712	443.7276	443.2341
9.25	439.8579	439.1443	218.8215	219.2481	461.45495	461.00615
9.5	453.4773	452.8398	226.438	226.8509	479.91953	479.52416
9.75	467.24	466.9404	234.3037	234.3776	499.36306	499.03091
10	481.081	481.5	242.57	241.828	520.05	519.792

V. Conclusion

- (1) The neutron yields ($n/10^6\alpha$) calculated in the present work, in general, are in good agreement or consistent with those measured previously by other authors
- (2) The results of the present work indicates that the integration law (eqn.3) has been applied on (d,n) reaction successfully
- (3) The studied (d,n) reactions may be arranged in a descending order with respect to the value of neutron yields ($n/10^6\text{d}$) for ($^{14}\text{N}(\text{d},\text{n})^{15}\text{O}$, $^{10}\text{B}(\text{d},\text{n})^{11}\text{C}$ and $^{12}\text{C}(\text{d},\text{n})^{13}\text{N}$) reaction at (10 MeV).
- (4) The calculated neutron yields ($n/10^6\text{d}$) by using the polynomial expressions, in general, are in good agreement with those calculated by using the set of empirical formulae (equation 20).

REFERENCES

- [1] K.Wohlleben and E.Schuster, ((Radiochimica Acta)), Vol.12, Issue.2, p.75,(1969).
- [2] B.Ja.Guzhovskij, S.N.Abramovich and V.A.Pereshivkin., ((Vop. At.Nauki Tekhn .,Ser.Yadernye constanty)) , Issue.2, p.55,(1984)
- [3] R.W.Michelmann, J.Krauskopf, J.D.Meyer and K.Bethge, ((Nucl. Instrum Methods in Physics Res.,)), Sect.B , Vol.51, Issue.1, p.1, (1990).
- [4] O.D.Brill and L.V.Sumin, ((Atomnaya Energiy)), Vol.7, p.377, (1959).
- [5] R.W.Michelmann, J.Krauskopf, J.D.Meyer and K.Bethge,((Nucl. Instrum. Methods in Physics Res.,)), Sect.B , Vol.51, Issue.1, p.1, (1990)
- [6] M.L.Firouzbakht, D.J.Scholyer and A.P.Wolf,((Radiochimica Acta)), Vol.55, p.1,(1991) .
- [7]H.VeraRuiz and A.P.Walf. ((Radiochimica Acta)), Vol.24,P.65(1977)
- [8] M.Sajjad,R.M.Lamb and A.P.Wolf.((Radiochemica Acta)),Vol.38,P.57(1985)
- [9] F.Koehl, J.Krauskopf, P.Misaelide, R.Michelmann, G.Wolf and K.Behge. ((Nucl.Instrum. Methods in Physics Res.)) , Section.B, Vol.50, P.19(1990)
- [10] S.Takacs, F.Tarkany, A.Hermanne and R.Paviotti Decorcuera.((Nucl.Instrum. Methods in Physics Res.)) Section.B, Vol.211, P.169(2003)
- [11] J.H.Gibbons, (Physical.Rev.), Vol.137,p.B1508(1965)
- [12] Heaton R., Lee H., Skensved P. and Robertson B.C., "Nuclear InstrumentsAnd Methods" vol A276, 529(1989).
- [13]Meyerhof W. E., Elements of Nuclear Physics, McGraw-Hill Book Co., 1967
- [14] Norman E.B., Chupp T.E., Lesko K.T., Grant P.J., and Woodruff G.L., Phys.Rev.C30, 339 (1984) .
- [15] Berington P.R., " Data Reduction and Error Analysis for the Physical Science", Mc-Graw-Hill, (1969).
- [16] Belgaid M., Tassadit A., Kadem F., and Amokrane A., "Semi-empirical Systematics of (n,p) Reaction Cross Sections. at 14.5 MeV Neutron Energy ", Web Page (www.elsevier.com/locate/nimb), (2005), Published in " Nuclear Instruments. and Method in Physics Research "vol.xxx, xxx(2005).[17] Tuli J.K., Nuclear Wallet Cards for Radioactive Nuclides, National Nuclear Data Center NNDC, (2005).
- [18] Ziegler J.F., " Helium: Stopping Powers and Ranges is all Elemental Matter ", Pergamon Press, Oxford (1977).
- [19] Nakasima R., Matsunobu H., Oku T., Iijima S., Natto Y., and Masukawa F., "Data Book for Calculating Neutron Yields from (α ,n) Reaction and Spontaneous Fission", (JAERI) 1324(1992) (in Japanese).
- [20] Murata. T., shibata.k., Nucl. Sci. and Tech, 2, 76-79 (2002).
- [21] Ahmed A.H., Ph.D.thesis, University of Salahaddin, Kurdistan region, Iraq, (2006).
- [22] Abdullrahman L.R, M.Sc. Thesis, University of Salahaddin ,Kurdistan Region,Iraq,(2007)
- [23] Abdullah R.H., " Journal of Zanko" vol.19, No. 2, 20, (2007).
- [24] Abdullah R.H., Ph.D.thesis, University of Baghdad, Iraq, (1999).