وقائع المؤتمر العلمي الثالث لكلية العلوم جامعة ديالى ٦-٧/٥/٢٠١٢

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Calculation the Cross Sections and Neutron Yield for $^{59}Co(p,n)^{59}Ni$ Reaction

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Abstract:

In this study intermediate elements ^{59}**Co** , ^{59}**Ni** for ^{59}**Co(p,n)** ^{59}**Ni** reaction with proton energy from (2.2) MeV to (4.8) MeV with threshold energy (1.886709) MeV are used according to the available data of reaction cross sections. The more recent cross sections data of ^{59}**Co(p,n)**^{59}**Ni** reaction is reproduced in fine steps and by using (Matlab-7.6) program and get the equation from 2-degree for plotted. We deduced that the high probability to produced ^{59}**Ni** by bombard ^{59}**Co** by proton. These cross sections together with the stopping powers calculated from the Zeigler formula have been used to calculate the n-yield for reaction.

حساب المقاطع العرضية والحصيلة النيوترونية لتفاعل $^{59}Co(p,n)^{59}Ni$

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الخلاصة

في هذه الدراسة تم حساب المقاطع العرضية للنوى المتوسطة ^{59}**Co** , ^{59}**Ni** للتفاعل ^{59}**Co(p,n)**^{59}**Ni** للبيانات المتوفرة في الادبيات العالمية وللمدى الطاقي من MeV (2.2) الى MeV (4.8) وبطاقة عتبه مقدارها MeV(1.886709) وذلك بأستخدام ال(في برنامج الماتلاب) ومن خلاله تم الحصول على معادلة من الدرجه الثانية fitting كدالة للمقاطع العرضية تم عرضها في الرسم وفي فقرة مناقشة النتائج. تم رسم وجدولة النتائج بالاضافة الى مناقشة النتائج وتحديد الحصيلة النيوترونية من قصف ^{59}**Co** بالبروتون.أستخدمت هذه المقاطع العرضيه المستحدثة مع قدرة الايقاف المحسوبة من معادلات Zeigler والتي تم معالجتها ورسمها لحساب الحصيلة النيوترونية للتفاعل المذكور.

1.Introduction

When two charged nuclei, overcoming their Coulomb repulsion, a rearrangement of the constituents of the nucleus may occur. Similar to the rearrangement of atoms in reacting molecules during a chemical reaction this may result as a nuclear reaction. Nuclear reactions

are usually produced by bombarding a target nucleus with a nuclear projectile , in most cases a nucleon (neutron or proton) or a light nucleus such as a deuteron or an α-particle **[1]**.

At low excitation energies (< 10 MeV), the majority of nuclear reactions involve the formation of two nuclei, one nearly equal in charge and mass number to the target nucleus. Such reactions are represented by an equation of the type :

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

Or $X(a,b)Y$

Where (a) is the light projectile nucleus (proton , neutron, deuteron, ^{3}H, ^{3}He, or ^{4}He) and (X) is the target nucleus at rest in the laboratory system. (Y) is the produced nucleus and (b) is a light nuclear particle which carries away the major share of the kinetic energy. If the product nucleus (Y) is left in an excited state after the emission of the light particle (b), it usually subsequently decays by radiating one or more gamma rays. Alternatively if (Y) is beta unstable, it decays at some later date by electron or positron emission followed by gamma emission **[2]**.

Nuclear reactions of low excitation energies include the following types : (n,γ) , (n,p) , (n,α) , (α,n) , (p,γ) , (p,n) , (d,n) , (d,p) , ...etc.

$$X + a \longrightarrow \begin{cases} X + a, \\ X^{*} + a, \\ Y + b, \quad \text{------ (2)} \\ Y^{*} + b, \end{cases}$$

In the first two reactions of the set (2) the outgoing particle is of the same kind as the incident particle, and the process is called scattering. The first reaction represents elastic scattering and the second reaction represents inelastic scattering in which the target nucleus (X) is raised into an excited state (X*). The other reactions of the set represent different possible nuclear transmutations in which the product nuclei may be found in their ground states or, more often, in excited states. The excited product nucleus usually decays very quickly to the ground state with the emission of γ-rays.

2. Cross Sections Of Nuclear Reactions:

To characterize the probability that a certain nuclear reaction will take place, it is customary to define an effective area of the nucleus for that reaction, called a cross section **[1]**. The reaction cross section data provides information of fundamental importance in the study of nuclear systems. The cross section is defined by **[3]**:

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$\sigma = R / I$ ------ (3)

where (σ) is the cross section,

(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 and 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 **[4]**:

$$\sigma_{tot} = \sum_i \sigma_i \quad \text{------- (4)}$$

Where σ_i is the partial cross section for the process.

3. Stopping Power:

The stopping power is define a measure of the effect of a substance on the kinetic of a charged particle passing through it. Stopping power is often quoted relative to that of a standard substance, usually air or aluminum **[5]**.

4. Proton Stopping Power :

For hydrogen projectiles, the nuclear stopping power is very small for all energies of interest **[6]**. The electronic stopping power is found to be proportional to projectile velocity, the specific dependence **[7]** being given by:

$$S_e = Z_1^{1/6} \times 8\pi e^2 a_o \frac{Z_1 Z_2}{(Z_1^{2/3} + Z_2^{2/3})^{3/2}} \times \frac{\upsilon}{\upsilon_o}, \quad \text{------- (5)}$$

where $\upsilon \langle \upsilon_o Z_1^{2/3}$ and (Z_1), (Z_2) are the atomic numbers of projectile and target respectively .

(υ)is the projectile velocity,

(a_o), (υ_o) are the Bohr radius of the hydrogen atom and the Bohr velocity.

In the present work ,by using the formulas proposed by Varelas and Biersack sited in Ziegler **[6]**

$$S_e = \frac{S_{Low}\, S_{High}}{(S_{Low} + S_{High})} \quad ------ (6)$$

Where S_{Low} (Low energy stopping) is

$$S_{Low} = B_1 E^{1/2} \quad ------ (7)$$

And S_{High} (High energy stopping) is

$$S_{High} = \frac{B_2}{E}\ln(1+\frac{B_3}{E}+EB_4) \quad ----- (8)$$

where B_1, B_2, and B_3 are fitting constants

$$B_4 = 4\, m / I\, M$$

where (m) is the electron mass,

(I) is the mean ionization potential,

(M) is the projectile mass

Eq.(6) asymptotically agree with eq.(5) at low energy , and with Bethe formula [6] at high energy .

5. Neutron Yields :

For an accelerating beam traversing a target, the occurred nuclear reactions produce (N) light product particles per unit time. Referring to Fig. (١) the yield is given by

$$Y(x) = I_o N_d \sigma x \quad ------ (9)$$

where (N_d x) is the a real number density of target atoms . Experimentally, the yield of neutrons detected per incident particle Y_n , for an ideal, thin and uniform target and mono-energetic beam of energy (E) is given by

$$Y_n = (N_d x)\, \sigma(E_b)\, \eta(E_b) \quad ----- (10)$$

($\eta(E_b)$)is the neutron-detection efficiency as a function of energy .

For a target which is not infinitesimally thin, the beam loses energy as it passes through the target, and the yield is then given by **[8]**

$$Y_n = \int_{E_t}^{E_b} \frac{\sigma(E`)\eta(E`) f dE`}{\frac{dE}{dx}(E`)} \quad --- (11)$$

in which $E_t = E_b - \Delta E$, where (ΔE) is the energy loss of the beam in the target, f is the number of target atoms in each target molecule, and $\frac{dE}{dx}(E')$ is the stopping power per target molecule, If the target is sufficiently thick, and there exist one atom per each molecule (i.e., f = 1) and taking $\eta(E') = 1$, then the resulting yield is called the thick-target yield which is given by

$$Y(E_b) = \int_{E_{thr}}^{E_b} \frac{\sigma(E)dE}{dE/dx} \text{ ------ (12)}$$

where E_{thr} is the reaction threshold energy.

Thus, by measuring the yield at two closely spaced energies (E_1) and (E_2), one can determine the average value of the integrand over this energy interval as follows **[9]**:

$$[\frac{\sigma(E)}{dE/dx}]_{E_b} = \frac{Y(E_2) - Y(E_1)}{E_2 - E_1} \text{ ---- (13)}$$

Where (E_b) is the average of (E_1) and (E_2). If $\sigma(E)$ are available in the literature as a function of projectile energy (E_b) for natural elements, then the neutron yield can be calculated using eq.(13). If neutron yield is available as a function of projectile energy (E_b), then eq. (13) can be used to calculate $\sigma(E)$ as a function of (E_b). Thus, consequently one can calculated the neutron yield by using eq. (13).

For natural elements and if only one stable isotope is available in nature, then **[10]**

$$Y_o = Y(E) \text{ ------ (14)}$$

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

If $\sigma(E)$ is calculated for a certain isotope whose concentration (enrichment) is C %, then **[10]**

$$Y_o = \frac{a}{c} Y(E) \text{ ------ (15)}$$

where (a)is the abundance of the isotope in the natural element. If there exist more than one isotope that can be involved in the nuclear reaction and the cross sections are calculated as a function of incident energy for each isotope, then **[10]**.

$$Y_o = \frac{a_1}{c_1} Y_1(E) + \frac{a_2}{c_2} Y_2(E) + ... \text{ ---- (1 6)}$$

6. Results and Discussion

The evaluated cross sections by authors Chiba S., Chadwick M., Young P. **[11]** and declared by EXFOR-Library we reproduced by fitting and we get the equation from 2-degree for plotted shown in Fig.(2) as fallows:

$$Y= 25*X^2-1.1*10^2X + 1.3*10^2$$

These data have been plotted, spline interpolated and recalculated in fine steps (0.02MeV) for proton energy from (2.2) MeV to (4.8) MeV **[11]** by using Matlab(7.6) program as shown in table (1). We calculated the stopping power from (srim-2008) program by summing electric stopping power and nuclear stopping power as shown in figure (3) and by using computer program we get the equation from 4-degree of stopping power for proton energy of cobalt as fallows:

$$S = -1.7*10^3X^4+6.9*10^2X^3-1.1*10^2X^2+7.6X+0.06$$

These cross sections together with the stopping powers calculated from the Zeigler formula (12) have been used to measure the n-yield for reaction as shown in Fig.(4).

$$Y(E_b) = \int_{E_{thr}}^{E_b} \frac{\sigma(E)dE}{dE/dx}$$

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Table (1):The cross sections of ^{59}**Co(p,n)**^{59}**Ni** reaction as a function of proton energy with interval 0.02 MeV

p -energy (MeV)	Cross sections (mbarn)	p -energy (MeV)	Cross sections (mbarn)	p -energy (MeV)	Cross sections (mbarn)
2.2	2.6107	3.18	24.605	4.16	99.1343
2.22	2.7443	3.2	25.4277	4.18	100.5169
2.24	2.8779	3.22	26.8159	4.2	102.1568
2.26	3.0114	3.24	28.2669	4.22	104.5291
2.28	3.145	3.26	29.7178	4.24	106.9014
2.3	3.2786	3.28	31.1688	4.26	109.2738
2.32	3.6054	3.3	32.6029	4.28	111.6461
2.34	3.9915	3.32	33.7466	4.3	114.0045
2.36	4.3776	3.34	34.8904	4.32	116.27
2.38	4.7637	3.36	36.0341	4.34	118.5354
2.4	5.1498	3.38	37.1778	4.36	120.8009
2.42	5.2879	3.4	38.3253	4.38	123.0663
2.44	5.389	3.42	39.5015	4.4	125.3834
2.46	5.4901	3.44	40.6778	4.42	127.9136
2.48	5.5911	3.46	41.854	4.44	130.4438
2.5	5.6922	3.48	43.0302	4.46	132.974
2.52	6.0729	3.5	44.2065	4.48	135.5042
2.54	6.5596	3.52	45.5326	4.5	138.0612
2.56	7.0463	3.54	46.8618	4.52	140.6782

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2.58	7.533	3.56	48.191	4.54	143.2951
2.6	8.0128	3.58	49.5202	4.56	145.912
2.62	8.1521	3.6	50.8848	4.58	148.5289
2.64	8.2915	3.62	52.4761	4.6	151.1089
2.66	8.4308	3.64	54.0674	4.62	153.5962
2.68	8.5702	3.66	55.6586	4.64	156.0835
2.7	8.7095	3.68	57.2499	4.66	158.5709
2.72	9.3274	3.7	58.861	4.68	161.0582
2.74	9.9841	3.72	60.6606	4.7	163.4555
2.76	10.6407	3.74	62.4601	4.72	165.3622
2.78	11.2974	3.76	64.2597	4.74	167.2688
2.8	11.954	3.78	66.0593	4.76	169.1755
2.82	12.4346	3.8	67.8976	4.78	171.0821
2.84	12.902	3.82	69.8856	4.8	172.9197
2.86	13.3693	3.84	71.8737	----	----
2.88	13.8367	3.86	73.8618	----	----
2.9	14.3109	3.88	75.8498	----	----
2.92	15.0076	3.9	77.7296	----	----
2.94	15.7043	3.92	79.0986	----	----
2.96	16.401	3.94	80.4677	----	----
2.98	17.0977	3.96	81.8367	----	----
3	17.7946	3.98	83.2057	----	----
3.02	18.4963	4	84.6042	----	----
3.04	19.198	4.02	86.7096	----	----
3.06	19.8997	4.04	88.815	----	----

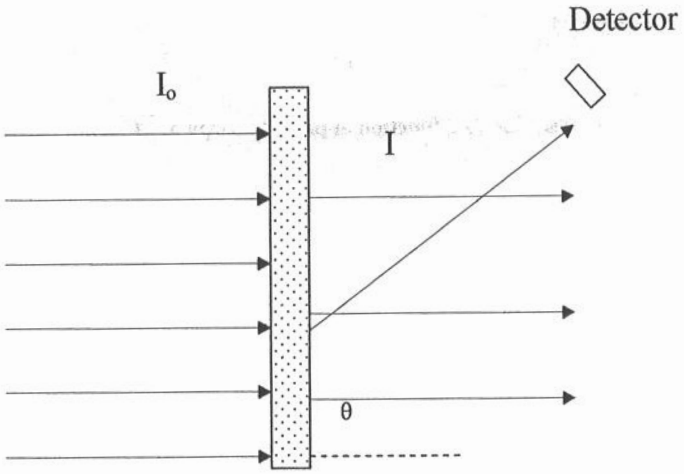
3.08	20.6014	4.06	90.9203	----	----
3.1	21.314	4.08	93.0257	----	----
3.12	22.1368	4.1	94.9865	----	----
3.14	22.9595	4.12	96.3691	----	----
3.16	23.7823	4.14	97.7517	----	----

Table (2): The Stopping Power for proton energy of Cobalt and neutron yield

Energy (MeV)	Stopping Power (MeV/(mg/cm^2)	Energy (MeV)	Stopping Power (MeV/(mg/cm^2)
0.01	0.1247	0.106	0.2785
0.012	0.1365	0.108	0.2787
0.014	0.1473	0.11	0.2789
0.016	0.1574	0.112	0.2789
0.018	0.1668	0.114	0.2789
0.02	0.1754	0.116	0.279
0.022	0.1835	0.118	0.279
0.024	0.1911	0.12	0.279
0.026	0.1981	0.122	0.2789
0.028	0.2047	0.124	0.2789
0.03	0.2108	0.126	0.2788
0.032	0.2163	0.128	0.2787

0.034	0.2215	0.13	0.2786
0.036	0.2262	0.132	0.2784
0.038	0.2306	0.134	0.2782
0.04	0.2346	0.136	0.2779
0.042	0.2381	0.138	0.2777
0.044	0.2416	0.14	0.2775
0.046	0.2448	----	----
0.048	0.2476	----	----
0.05	0.2504	----	----
0.052	0.2527	----	----
0.054	0.255	----	----
0.056	0.2571	----	----
0.058	0.2589	----	----
0.06	0.2608	----	----
0.062	0.2623	----	----
0.064	0.2639	----	----
0.066	0.2653	----	----
0.068	0.2665	----	----
0.07	0.2678	----	----
0.072	0.2688	----	----
0.074	0.2697	----	----
0.076	0.2707	----	----
0.078	0.2716	----	----
0.08	0.2726	----	----
0.082	0.2733	----	----

0.084	0.2739	----	----
0.086	0.2746	----	----
0.088	0.2752	----	----
0.09	0.2759	----	----
0.092	0.2763	----	----
0.094	0.2767	----	----
0.096	0.2771	----	----
0.098	0.2775	----	----
0.1	0.2779	----	----
0.102	0.2781	----	----
0.104	0.2783	----	----



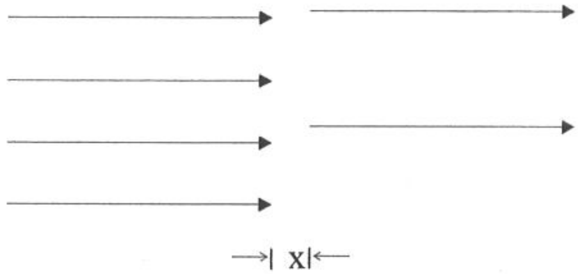
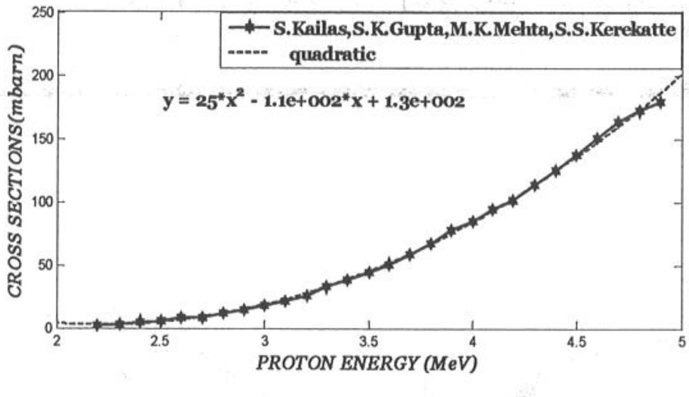


Figure (1): A schematic diagram illustrating the definition of total cross section in terms of the reduction of intensity[8]



Figure(2): Cross section as a function of proton energy of $^{59}Co(p,n)^{59}Ni$ Reaction

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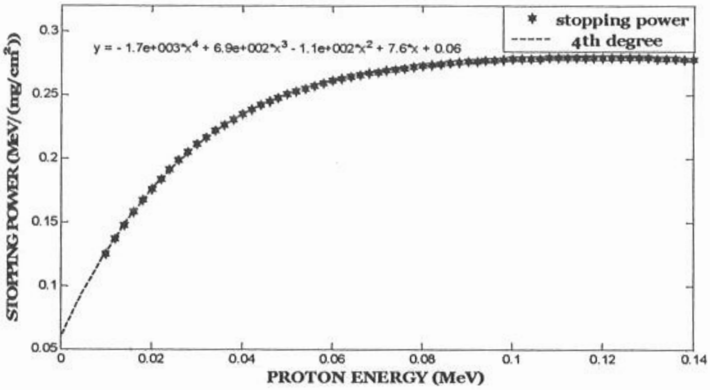
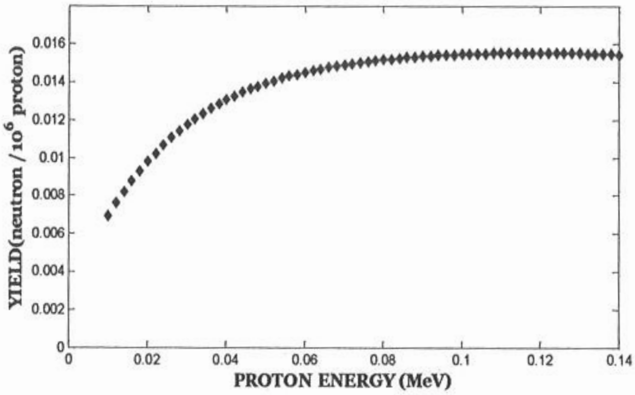


Figure(3):Stopping power of Cobalt as a function of the proton energy



Figure(4): Neutron Yield for $^{59}Co(p,n)^{59}Ni$ Reaction