Calculation the Cross Sections and Neutron Yield for ^{50}Cr(p,n)^{50}0Mn Reaction

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Abstract

In this study intermediate elements ^{50}***Cr*** , ***50Mn*** for ^{50}***Cr(p,n)***^{50}***Mn*** reaction as well as proton energy from (3.4576) MeV to (148.0) MeV with threshold energy (8.8179)MeV are used according to the available data of reaction cross sections. The more recent cross sections data of ^{50}***Cr(p,n)***^{50}***Mn*** reaction is reproduced in fine steps and by using (Matlab-7.6)program and get the equation from 10-degree for plotted .By using inverse reaction principle also get mathematical equation to calculate the cross section of ^{50}***Mn(n,p)***^{50}***Cr*** . We deduced that the high probability to produced ^{50}***Cr*** by bombard ^{50}***Mn*** by neutron. These cross sections together with the stopping powers calculated from the Zeigler formula have been used to calculate the n-yield for reaction.

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.

Cross Sections Of Nuclear Reactions

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 ***[1]***. The reaction cross section data provides information of fundamental importance in the study of nuclear systems. The cross section is defined by ***[3]***:

$$\sigma = R / I \text{ ------ } (3)$$

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:

$$1 \text{ barn} = 10^{-24} \text{ cm}^2$$

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]***

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

Where σ_i is the partial cross section for the process.

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]***.

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]***

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

Where S_{Low} (Low energy stopping) is

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

And S_{High} (High energy stopping) is

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

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 .

Neutron Yields

For an accelerating beam traversing a target, the occurred nuclear reactions produce (N) light product particles per unit time. Referring to Fig. (1) the yield is given by

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

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

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

where (N_d x) is the a real number density of target atoms, and (η)is the neutrondetection efficiency.

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]***

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

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 η(E`) = 1, then the resulting yield is called the thick-target yield which is given by

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

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]***:

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

Where (E_b) is the average of (E_1) and (E_2). If σ(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 σ(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]***

$$Y_0 = Y(E) \text{ ------ } (14)$$

where (Y_0) is the neutron yield per 10^6 bombarding particle for the natural element.

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

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

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]***.

$$Y_o = \frac{a_1}{c_1} Y_1(E) + \frac{a_2}{c_2} Y_2(E) + ... \quad \text{---- } (16)$$

Results and Discussion

These data have been plotted, spline interpolated and recalculated in fine steps for proton energy from (3.4576) MeV to (148) MeV ***[11]*** by using Matlab program as shown in table (1). The reproduced cross sections by authors Chiba S., Chadwick M., Young P. ***[11]*** and declared by EXFOR-Library, we get the equation from 10-degree for plotted shown in Fig.(2) as fallows:

Y = - 4.3*10^{6}*x^{7} + 2.6*10^{6}*x^{6}- 6.5*10^{5}x^{5} + 8.6* 10^{4} * x^{4} - 6.1*10^{3}*x^{3} + 1.9*10^{2}*x^{2} + 2.6*x + 0.1 By using the compound theory we derive the mathematical formula for $^{50}Mn(n,p)^{50}Cr$ reaction for first exited state :

$$\sigma_{n,p} = 0.45417\frac{T_p}{T_n}\sigma_{p,n} \quad \text{----- (17)}$$

Using semi empirical formula the evaluated cross sections as a function of neutron energy from (0.1821)MeV to (113.184)MeV of present work are listed in table (2). From these data which were plotted and we get the mathematical equation representing the cross sections distribution in the indicated range of neutron energy Fig.(3) as follows :

$$y = -4.1*10^{-19}*x^{10} + 3*10^{-16}*x^{9} - 9.5*10^{-14}*x^{8} + 1.7*10^{-11}*x^{7} - 1.9*10^{-9}*x^{6} + 1.4*10^{-7}*x^{5} - 6.7*10^{-6}*x^{4} + 0.00021*x^{3} - 0.0039*x^{2} + 0.038*x + 0.36 \quad \text{----- (18)}$$

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).

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حساب المقاطع العرضية والحصيلة النيوترونية لتفاعل $^{50}Cr(p,n)^{50}Mn$

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الخلاصة

في هذه الدراسة اعيد حساب المقاطع العرضية للنوى المتوسطة ^{50}Mn , ^{50}Cr لتفاعل $^{50}Cr(p,n)^{50}Mn$ للبيانات المتوفرة في الأدبيات العالمية وللمدى الطاقي من MeV (3.4576) الى MeV (148.0) وبطاقة عتبه مقدارها (8.8179)MeV كدالة للمقاطع العرضية باستخدام نظرية التعاكس تم اشتقاق معادلة لحساب المقاطع العرضية لتفاعل $^{50}Mn(n,p)^{50}Cr$ وذلك بالاعتماد على المقاطع العرضية لتفاعل $^{50}Cr(p,n)^{50}Mn$. تم رسم وجدولة النتائج بالإضافة الى مناقشة النتائج وتحديد نوع النيوترون لأنتاج ^{50}Cr. أستخدمت هده المقاطع العرضية المستحدثة مع قدرة الأيقاف المحسوبة من معادلات Zeigler لحساب الحصيلة النيوترونية للتفاعل المذكور.

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Table (l):The cross sections of $^{50}Cr(p,n)^{50}Mn$ reaction as a function of proton energy with threshold energy (8.81 79)M eV

p -energy (MeV)	Cross sections (mbarn)	p -energy (MeV)	Cross sections (mbarn)	p -energy (MeV)	Cross sections (mbarn)
3.4576	0.0554	30.1084	0.9495	73.0000	0.7698
4.0000	0.1189	30.2599	0.9484	74.0000	0.7667
5.0000	0.2638	31.0000	0.9423	75.0000	0.7637
6.0000	0.4073	29.0000	0.9570	76.0000	0.7608
7.0000	0.5375	30.0000	0.9503	77.0000	0.7578
8.0000	0.6597	32.0000	0.9328	78.0000	0.7550
8.5842	0.7201	32.0715	0.9321	79.0000	0.7521
8.7296	0.7331	33.085	0.9224	80.0000	0.7493
9.0000	0.7553	34.0000	0.9144	81.0000	0.7465
9.7838	0.8082	35.0000	0.9078	82.0000	0.7438
10.0000	0.8197	35.3458	0.9060	83.0000	0.7411
10.9934	0.8627	35.3992	0.9058	84.0000	0.7384
11.0000	0.8629	35.4093	0.9057	85.0000	0.7358
11.8652	0.8881	35.6683	0.9045	86.0000	0.7332
12.0000	0.8916	36.0000	0.9029	104.0000	0.6941
13.0000	0.9156	36.0311	0.9027	106.0000	0.6908
14.0000	0.9356	36.9437	0.8986	108.0000	0.6875

15.0000	0.9520	37.0000	0.8984	110.0000	0.6845
15.4051	0.9577	37.0052	0.8983	112.0000	0.6816
16.0000	0.9652	38.0000	0.8942	114.0000	0.679
16.6785	0.9722	38.7228	0.8913	116.0000	0.6765
16.7206	0.9726	39.0000	0.8903	118.0000	0.6743
16.7686	0.9730	39.8840	0.8869	120.0000	0.6723
16.8945	0.9741	40.0000	0.8865	122.0000	0.6705
17.0000	0.9750	41.0000	0.8828	124.0000	0.6689
18.0000	0.9814	42.0000	0.8791	126.0000	0.6675
19.0000	0.9849	42.4270	0.8776	128.0000	0.6664
19.2834	0.9855	43.0000	0.8755	130.0000	0.6654
19.9169	0.9863	43.1451	0.8749	132.0000	0.6646
20.0000	0.9864	44.0000	0.8718	134.0000	0.664
21.0000	0.9862	44.4436	0.8701	136.0000	0.6637
21.9342	0.9852	45.0000	0.8680	138.0000	0.6636
22.0000	0.9851	45.3450	0.8667	140.0000	0.6638
23.0000	0.9831	46.0000	0.8641	142.0000	0.6643
23.2553	0.9825	46.2916	0.8630	144.0000	0.665
23.2777	0.9825	48.0000	0.8564	146.0000	0.6661
24.0000	0.9805	48.3759	0.855	148.0000	0.6675
24.2476	0.9798	49.0000	0.8526	----	----
25.0000	0.9773	50.0000	0.8488	----	----
26.0000	0.9733	51.0000	0.8450	----	----
26.2704	0.9721	51.2295	0.8441	----	----
26.3120	0.9719	52.0000	0.8412	----	----

26.3378	0.9718	53.0000	0.8375	----	----
27.0000	0.9686	54.0000	0.8338	----	----
27.3797	0.9666	55.0000	0.8301	----	----
28.0000	0.9631	55.7216	0.8275	----	----
28.3553	0.9611	56.0000	0.8265	----	----
28.4858	0.9603	57.0000	0.8229	----	----
1 28.5676	0.9598	57.8851	0.8197	....	

Table (2): The cross sections of $^{50}Mn\ (n,p)\ ^{50}Cr$ reaction as a function of neutron energy.

n -energy (MeV)	Cross sections (mbarn)	n -energy (MeV)	Cross sections (mbarn)	n -energy (MeV)	Cross sections (mbarn)
0.1821	0.3822	24.1824	0.4671	54.1828	0.4058
0.9659	0.4089	24.2675	0.4667	55.1828	0.4041
1.1821	0.4148	25.1824	0.4627	56.1828	0.4024
2.1755	0.4365	26.1824	0.4594	57.1829	0.4007
2.1821	0.4366	26.5282	0.4585	58.1829	0.3991
3.0473	0.4494	26.5817	0.4583	59.1829	0.3975
3.1821	0.4511	26.5918	0.4583	60.1829	0.3958
4.1822	0.4633	26.8507	0.4577	61.1829	0.3942
5.1822	0.4734	27.1825	0.4569	62.1829	0.3926
6.1822	0.4817	27.2136	0.4568	63.1829	0.3911
6.5873	0.4846	28.1262	0.4547	64.1829	0.3895
7.1822	0.4884	28.1825	0.4546	65.183	0.388
7.8607	0.4919	28.1877	0.4546	66.183	0.3865

7.9028	0.4921	29.1825	0.4525	67.183	0.385
7.9508	0.4924	29.9053	0.451	68.183	0.3835
8.0767	0.4929	30.1825	0.4505	69.183	0.382
8.1822	0.4933	31.0665	0.4488	70.183	0.3806
9.1822	0.4966	31.1825	0.4486	71.183	0.3791
10.1822	0.4984	32.1825	0.4467	72.1831	0.3777
10.4657	0.4987	33.1825	0.4448	73.1831	0.3763
10.4827	0.4987	33.6095	0.4441	74.1831	0.375
11.0991	0.4991	34.1826	0.443	75.1831	0.3736
11.1822	0.4991	34.3276	0.4427	76.1831	0.3723
12.1823	0.499	35.1826	0.4411	77.1831	0.371
13.1165	0.4985	35.6261	0.4403	78.1831	0.3697
13.1823	0.4985	36.1826	0.4392	79.1831	0.3685
14.1823	0.4975	36.5276	0.4385	80.1832	0.3672
14.4375	0.4972	37.1826	0.4373	81.1832	0.366
14.46	0.4971	37.4742	0.4367	82.1832	0.3648
15.1823	0.4962	38.1826	0.4353	83.1832	0.3636
15.4299	0.4958	39.1826	0.4334	84.1832	0.3625
16.1823	0.4945	39.5585	0.4326	85.1832	0.3613
17.1823	0.4925	40.1826	0.4314	86.1832	0.3602
17.4528	0.4919	41.1826	0.4295	87.1833	0.3591
17.4943	0.4918	42.1827	0.4276	88.1833	0.3580
17.5201	0.4917	42.4122	0.4271	89.1833	0.3570
18.1823	0.4901	43.1827	0.4257	90.1833	0.3560
18.5620	0.4891	44.1827	0.4238	91.1833	0.3550

19.1824	0.4874	45.1827	0.4219	93.1833	0.3531
19.5377	0.4863	46.1827	0.4200	95.1834	0.3512
19.6682	0.4859	46.9044	0.4187	97.1834	0.3495
19.7500	0.4857	47.1827	0.4182	99.1834	0.3479
20.1824	0.4843	48.1827	0.4164	101.183	0.3463
21.1824	0.4808	49.0678	0.4148	103.184	0.3449
21.2908	0.4805	49.1828	0.4146	105.184	0.3436
21.4423	0.4799	50.1828	0.4128	107.184	0.3423
22.1824	0.4768	51.1828	0.4110	109.184	0.3412
23.1824	0.4720	52.1828	0.4093	111.184	0.3402
23.2539	0.4717	53.1828	0.4075	113.184	0.3393

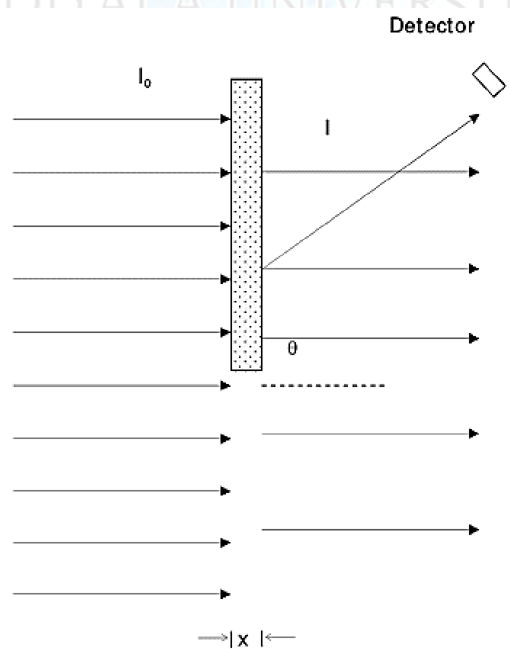


Figure (1): A schematic diagram illustrating the definition of total cross section in terms of the reduction of intensity*[8]*

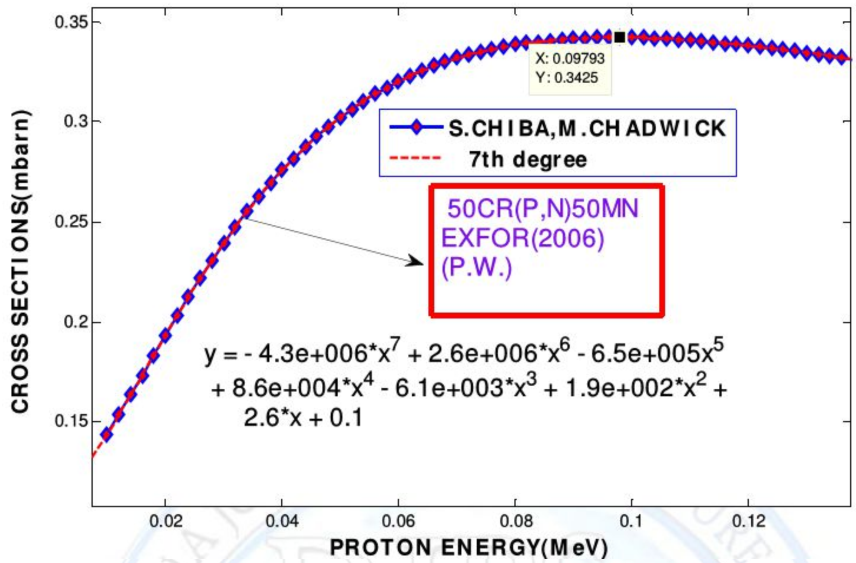
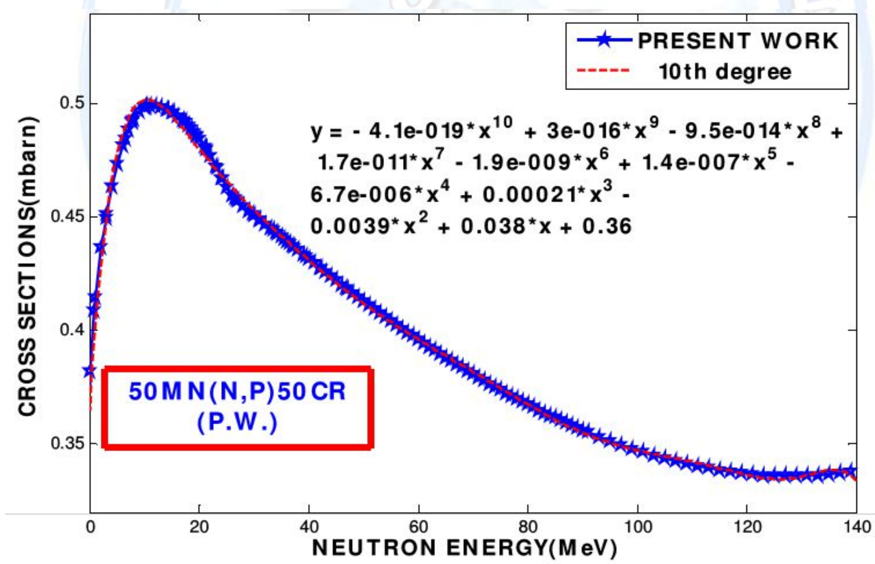


Figure (2):Cross Sections for 50Cr(p,n)50M n



Figure(3):Cross Sections of 50M n(n,p)50Cr

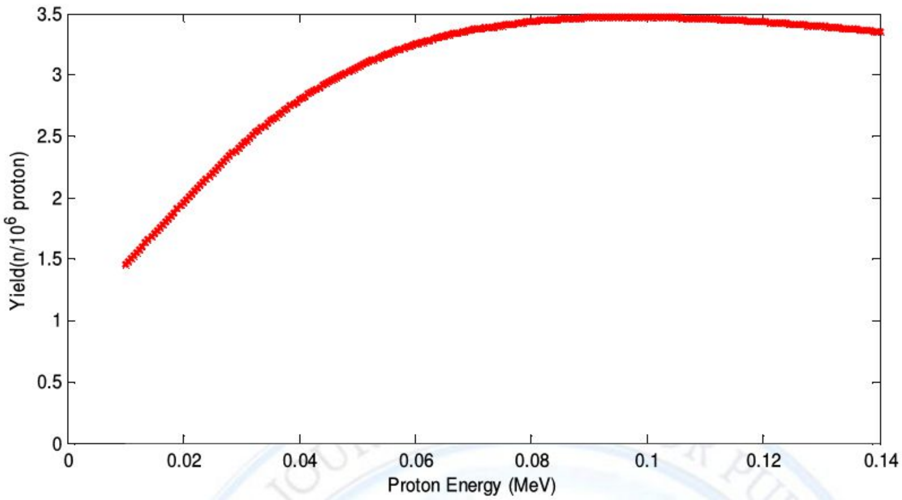


Fig.(4) : Neutron Yield for $^{50}Cr(p,n)^{50}Mn$ reaction