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Investigation on the Excitation Function of Alpha-Induced Reaction on 116-Cd in the Energy Range between 15 and 40 Mev

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Abstract

In this work, the alpha particle-induced reaction on Cadmium-116 in the energy range 20-40 MeV has been studied. The excitation function for the following reaction channels of this type have been studied in the energy range of 15 MeV-40 MeV are; 48-Cd-116(α, n) 50-Sn-119. This reaction has a total number of exciton six, number of neutron one and number of holes also one. 48-Cd-116(α, 2n + p) 49-In-117. In this reaction (TD = 10, Ex1 = 3 and Ex2 = 3). 48-Cd-116(α, 3n) 50-Sn-117. The exciton number of this reaction is (TD = 10, Ex1 = 3 and Ex2 = 3) 48-Cd-116(α, 3n + p) 49-In-116. It has an exciton number of (TD = 12 Ex1 = 4 and Ex2 = 4) 48-Cd-116(α, n + α) 48-Cd-115. This reaction has (TD = 14, Ex1 = 1, Ex2 = 5 and Ex3 = 4) were studied and comparative analysis was performed for reaction channels of 116-Cd target nuclei. The experimentally measured excitation functions obtained from the EXFOR data source, IAEA, were compared with the theoretical calculations with and without the inclusion of pre-equilibrium emission of particles, made by the COMPLET code. The level density parameter is varied to obtain good agreement between the calculated and measured data with minimum effort on the fitting parameter.

Keywords

Pre-equilibrium, Exfor, Density parameter, Complet code

Introduction

Naturally occurring cadmium is composed of 8 isotopes. Two of them are radioactive, and three are expected to decay but have not decayed under laboratory conditions. The two natural radioactive isotopes are ^{113}Cd (beta decay, half-life is 7.7×10^{15} years) and ^{116}Cd (two-neutrino double beta decay, half-life is 2.9×10^{19} years). The other three, ^{106}Cd, ^{108}Cd (both double electron capture), and ^{114}Cd (double beta decay), were predicted to be radioactive, but their decays were never observed [1].

Cadmium occurs as a minor component in most zinc ores and is a byproduct of zinc production. Cadmium was used for a long time as a corrosion-resistant plating material on steel, and cadmium compounds are used as red, orange, and yellow pigments, to color glass, and to stabilize plastic. 116-Cd is used as a thermal neutron shield. It captures all thermal neutrons that are focused on it. However, 116-Cd may not be used as a shield against other radiations such as alpha-particle flux [2].

Therefore, in the nuclear industry, cadmium is commonly used as a thermal neutron absorber because of its very high neutron absorption. Neutrons are particles that have neither a positive nor a negative charge, and thus provide a wide range of energy and mass levels that must be blocked. Alpha particles are positively charged helium nuclei, and are relatively easy to block, whereas beta particles are negatively charged electrons that are more difficult to shield against. Generally, the 116-Cd isotope is used for ^{115}In radionuclides and is used for studies of double beta -decay [3]. Some possible reactions alpha induced on $^{116-}$Cd are as follows:- 48-Cd-116 (α, 3n + 2p) 48-Cd-115. In this reaction, alpha is a projectile particle and 3n+2p are out going particles [4-14], 48-Cd-116 (α, 3n + p) 49-In-116. In this reaction, 3n+p are out going particle [14], 48-Cd-116 (α, n) 50-Sn-119. In this reaction, the neutron is an outgoing particle [15], 48-Cd-116 (α, n + α) 48-Cd-115. In this reaction, neutron plus alpha is the outgoing particle [16], 48-Cd-116 (α, 2n + p) 49-In-117. In the reaction, 2n+p are out going particle, 48-Cd-116 (α, 3n)

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50-Sn-117. In this reaction, 3n is the outgoing particle [17], and 48-Cd-116 (α, 4n) 50-Sn-116. In this reaction, 4n is the outgoing particle.

General objectives

The general objective of this study was to theoretically calculate the excitation function of the alpha-induced reaction on ^{116}Cd.

Methods

Analytical method

In this research, analytically, the equation of the reaction cross section of different channels of 116-Cd (α, x) in different energy ranges derived based on the compound nucleus and pre-equilibrium reaction have been performed.

Computational method

In this research, using computational methods, the following procedures were performed:

a. Using Alice-91-based computer code, a theoretical calculation of the reaction was made and

b. The theoretical calculations have been validated by comparison with accepted data in the literature.

Results and Discussion

Reaction channels

Reaction channels of 48-Cd-116

This study was based on five selected 116-Cd possible reaction channels in the energy range of 15-40 MeV, where alpha is the projectile particle for all reactions and 116-Cd is the target nucleus for all of them. The possible reaction channels studied are: 48-Cd-116(α, n) 50-Sn-119, 48-Cd-116(α, 2n + p) 49-In-117, 48-Cd-116(α, 3n) 50-Sn-117, 48-Cd-116(α, 3n + p) 49-In-116, and 48-Cd-116(α, n + α) 48-Cd-115.

Analysis and discussion

This chapter presents sample description and characterization and describes and summarizes the main results, which are discussions of the main trends, patterns, and connections that have emerged, which are preceded by tables and plots. The excitation function of the alpha-particle- induced reaction on the isotopes of 116-Cd was theoretically evaluated using the computer code Complet. The experimental cross-section was obtained from the IAEA data source, Exfor library. The theoretical and experimental cross-sections are plotted against the projectile energy and are shown in Figure 1, Figure 2, Figure 3, Figure 4 and Figure 5. Theoretical calculations are performed for two cases. These are for the pre-equilibrium plus compound nucleus decay excitation function and for only the compound nucleus decay excitation function. The excitation function for the pre-equilibrium plus compound reaction is shown in olive green, the compound reaction is shown in red, and the excitation functions for the experimental results are shown in blue.

The excitation function produced by the target of the heavy nucleus 116-Cd reaction channel is explained. The energy range selected from the experimental data from EXFORE is 15-40 MeV. The cross sections of theoretical and experimental data with the selected energy range are given in Table 1, Table 2, Table 3, Table 4 and Table 5. Various parameters are used for the calculations of excitation

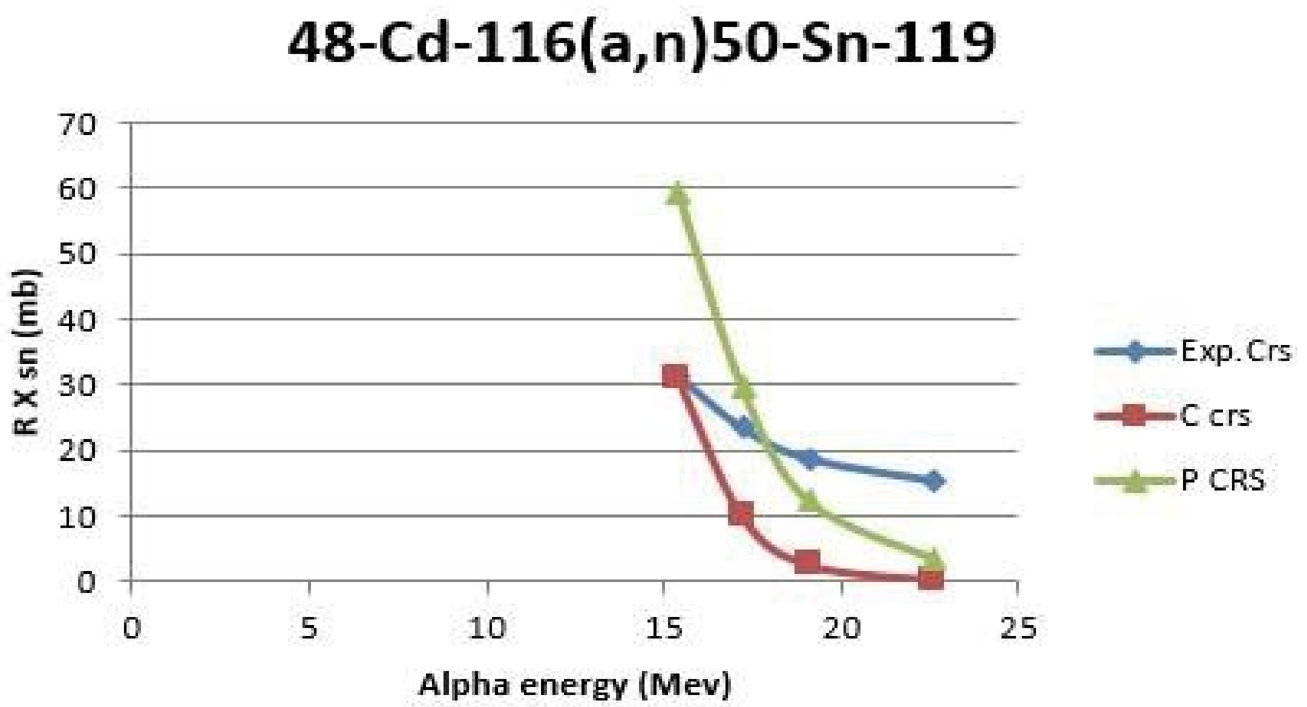

Figure 1: Experimental and theoretical excitation functions for the reaction of 48-Cd-116 (α, n) 50-Sn-119.

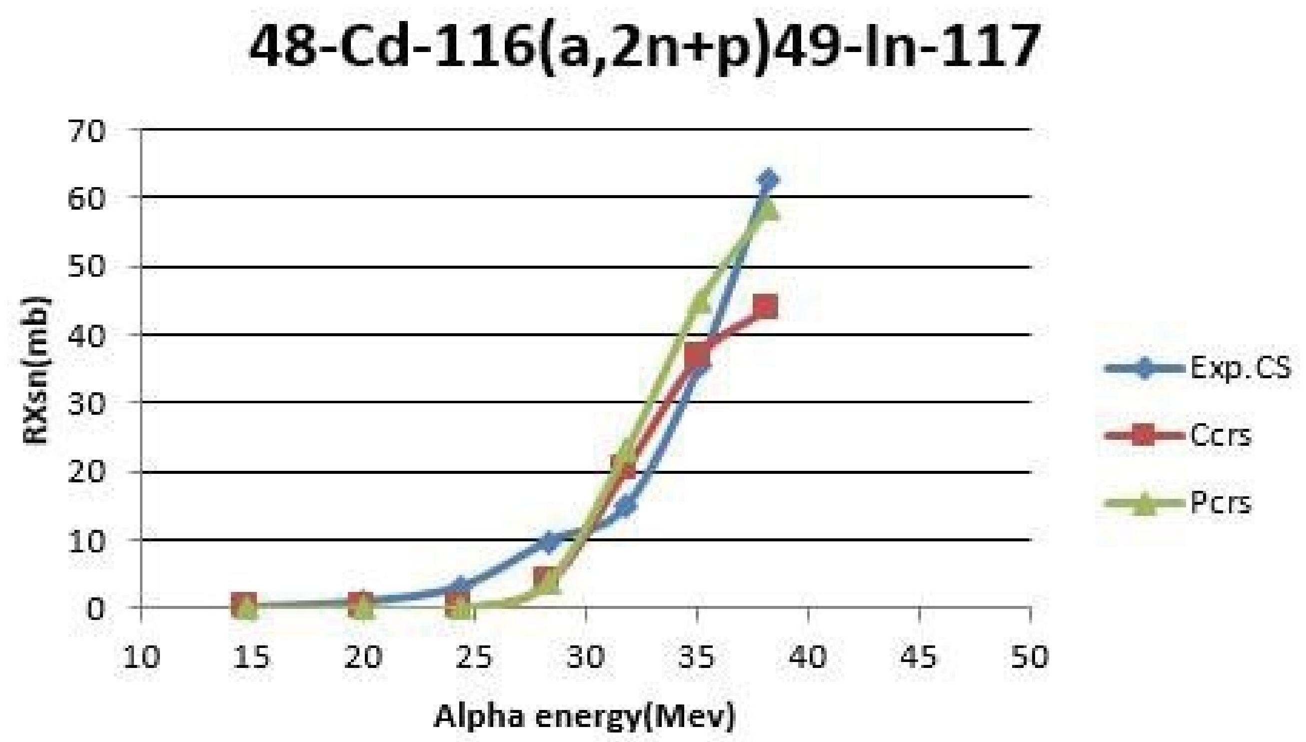

Figure 2: Experimental and theoretical excitation functions for the reaction of 48-Cd-116 (α, 2n + p) 49-In-117.

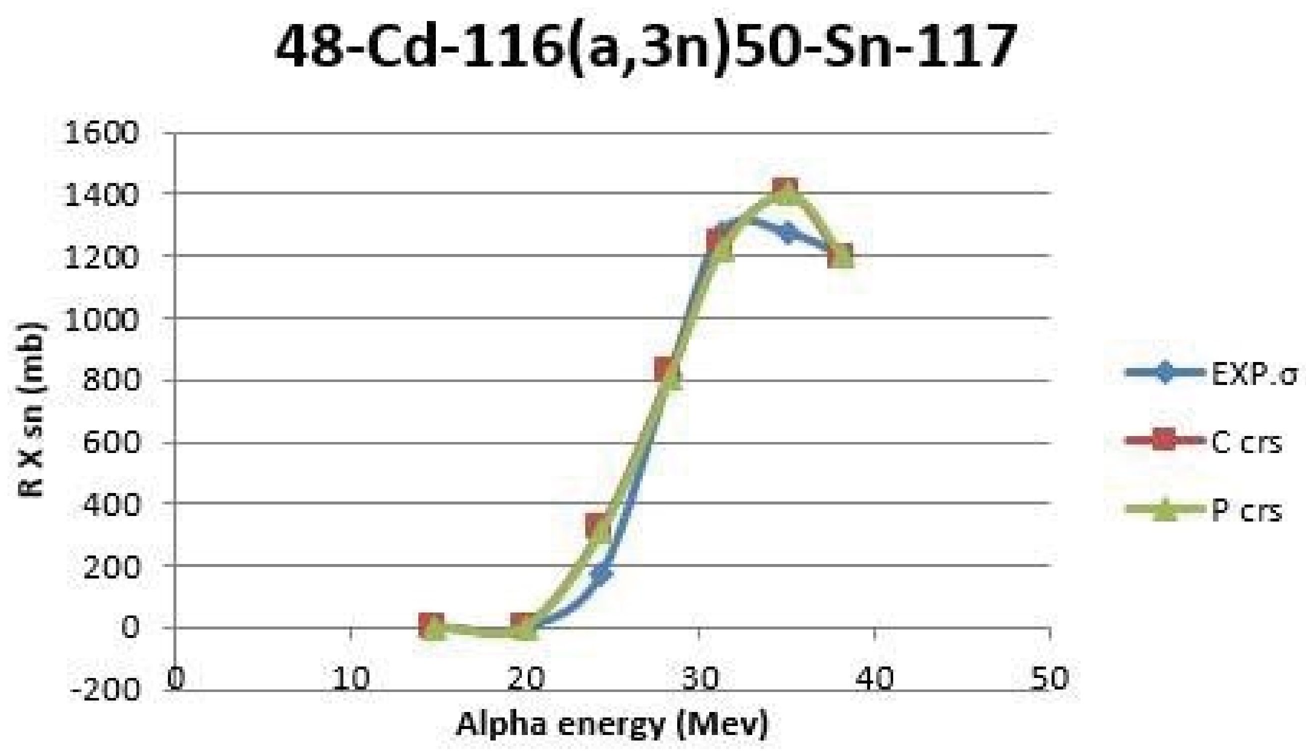

Figure 3: Experimental and theoretical excitation function for the reaction of 48-Cd-116 (α, 3n) 50-Sn-117.

functions. However, the initial exciton number is found to play an important role in the theoretical predictions of pre-equilibrium reactions. In this research, the initial exciton number (n0 = 4) with configurations (2p+2n+0h) has been mainly taken for projectiles, which interact independently with particles below the Fermi level, creating either a new particle-hole configuration in the second stage or being emitted into the continuum. However, the initial exciton

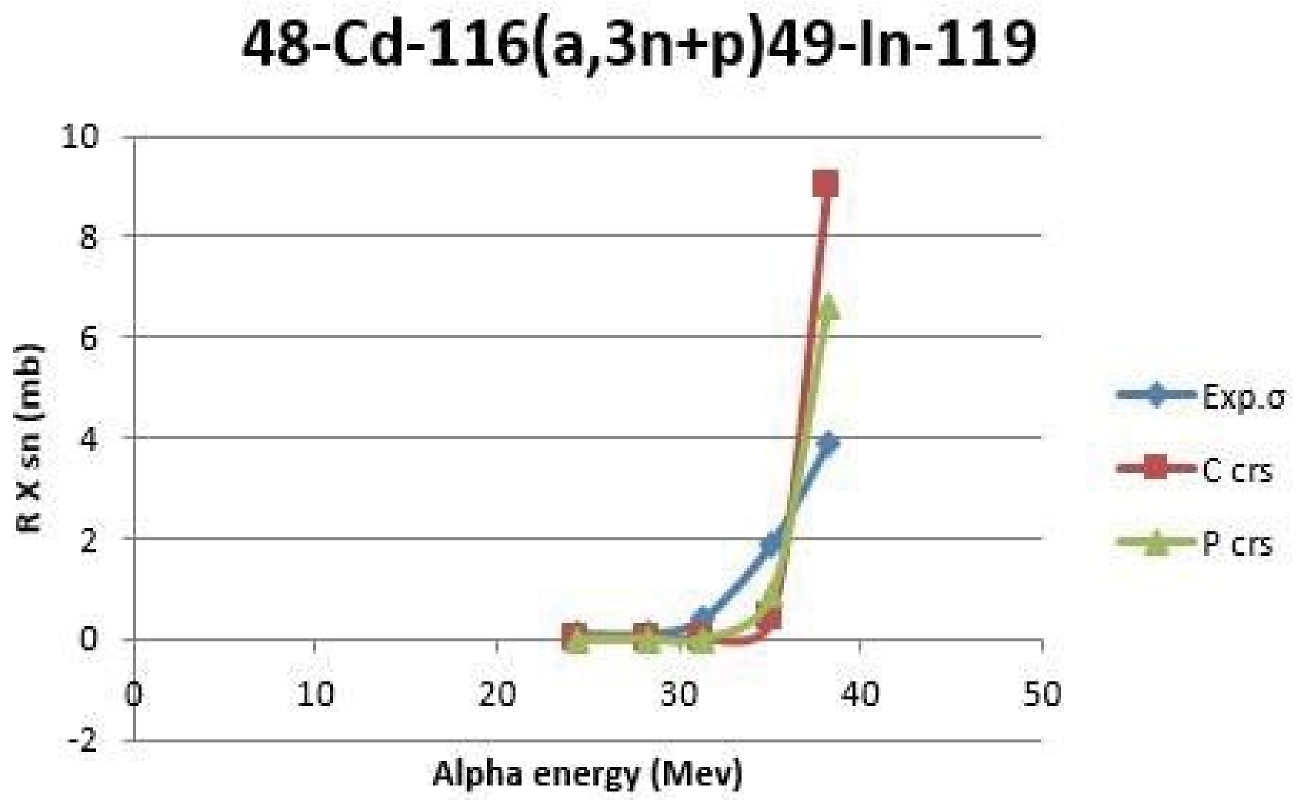

Figure 4: Experimental and theoretical excitation functions for the reaction of 48-Cd-116 (α, 3n + p) 49-In-116.

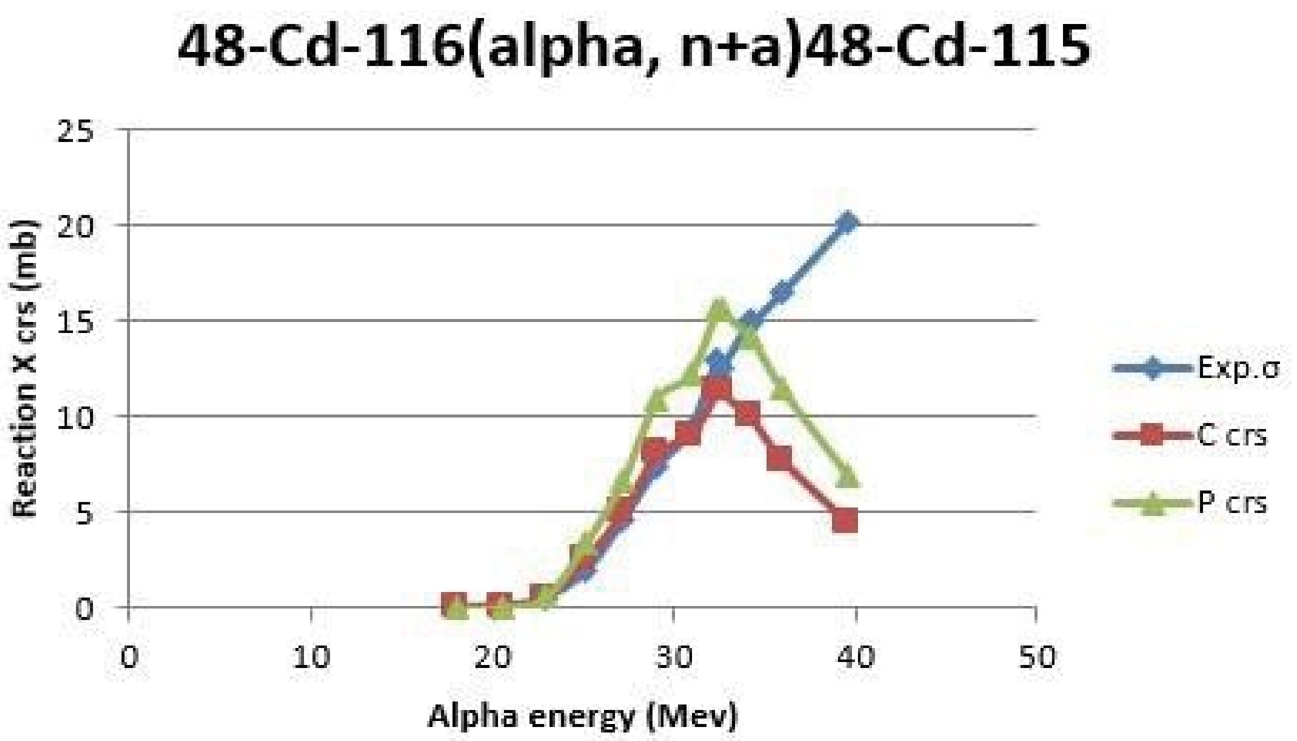

Figure 5: Experimental and theoretical excitation functions for the reaction of 48-Cd-116 (α, n + α) 48-Cd-115.

number (n0 = 6) with configurations (TD = 6, EX1 = 1, EX2 = 2) has been taken for the projectile in the reaction channels of 48-Cd-116(α, n) 50-Sn-119.

The next exciton number is (no = 10) with configurations of (TD = 10, EX1 = 3, EX2 = 3) has been taken for the projectile in the reaction channels of 48-Cd-116 (α, 2n+p) 49-In-117. Also, the next reaction channel has an exciton number (no = 10) with a configuration of (TD = 10, EX1 = 3 and EX2 = 3) in the reaction of 48-Cd-116 (α, 3n) 50-Sn-117. The reaction of 48-Cd-116 (α, 3n + p) 49-In-116, has number of (TD = 12, EX1 = 4, and EX2 = 4). The last reaction has an exciton number of (TD = 14, EX1 = 1, EX2 = 5 and EX3 = 4) in the reaction of 48 = Cd-116 (α, n + α) 48-Cd-115.

The level density parameter also plays an important role in statistically calculating the nuclear reaction model, such as in calculating the evaporation model of nuclear reaction and in studies of intermediate-energy. The level density parameter obtained experimentally shows a linear dependence on the mass number of the compound nucleus. In general, it is given by the expression a = ACN/K, where ACN is the mass of the compound nucleus and K is the free constant. In this research, the level density parameter k = 9, 10, 28, 12, 4, and 18 were employed for the respective reactions, which gave the best fit to the experimental results.

The variation in the value of K is due to the search for the best fit to the experimentally measured excitation function, where the parameter a is known as the level density parameter.

48-Cd-116(α, n) 50-Sn-119: This reaction was obtained by the evaporation of one neutron from the composite nucleus. The residue is 119-Sn and is stable. For the following reaction, the exciton number is given as (TD = 6, Ex1 = 1 and Ex2 = 1).

The results presented in Table 1 and Figure 1 show that the experimental values of the excitation function in the reaction are around 15.42 MeV. The calculated values of the compound nucleus reaction were closer to the experimental data value and the pre-compound theory was far from it. From the energy 17.22 MeV to 22.65 MeV, the value of the compound nucleus theory was far away from the experimental value, but the pre-compound theory was closer to the experimental value when compared to the compound nucleus theory. Therefore, as the value of energy increases,

Table 1: Theoretical and measured cross sections for the reaction of 48-Cd-116(α, n) 50-Sn-119.

No	Alpha Energy (MeV)	EXPXS (mb)	CNXS (mb)	PERXS (mb)
1	15.42	31.19	30.87	59.18
2	17.22	23.48	10.10	29.73
3	19.09	18.84	2.639	12.3
4	22.65	15.53	0.3236	3.453

Table 2: Theoretical and measurement cross-section of 48-Cd-116 (α, 2n+p) 49-In-117.

No	Alpha's Energy (MeV)	EXPXN (mb)	CXSN (mb)	PERXSN (mb)
1	14.8	0.03	0	0
2	20	0.9	0	0
3	24.4	3.1	0.05382	0.05388
4	28.3	9.7	3.684	3.827
5	31.8	14.8	20.25	23
6	35.1	35.4	36.84	44.82
7	38.2	62.6	43.68	58.67

Table 3: Theoretical and measured cross sections for the reaction of 48-Cd-116 (α, 3n) 50-Sn-117.

No	Alpha Energy (MeV)	EXPXS (mb)	CNXS (mb)	PERXS (mb)
1	14.8	1.4	0	0
2	20	1.7	1.703	1.601
3	24.4	177	319.6	309.6
4	28.3	817	820.3	806.2
5	31.8	1279	1235	1223
6	35.1	1272	1400	1401
7	38.2	1199	1189	1201

Table 4: Theoretical and measured cross sections for the reaction of 48-Cd-116 (α, 3n+ p) 49-In-116.

No	Alpha Energy (MeV)	EXPXS (mb)	CNXS (mb)	PERXS (mb)
1	24.4	0.1	0	0
2	28.3	0.1	0	0
3	31.8	0.4	0.0003657	0.004134
4	35.1	1.9	0.3941	0.8832
5	38.2	3.9	9.012	6.608

Table 5: Theoretical and measured cross sections for the reaction of 48-Cd-116 (α, n+α) 48-Cd-115.

No	Alpha Energy (MeV)	EXPXS (mb)	CNXS (mb)	PERXS (mb)
1	18	0.036	0.001557	0.001843
2	20.6	0.096	0.05118	0.06408
3	22.9	0.54	0.4365	0.5757
4	25.1	1.9	2.477	3.368
5	27.2	4.6	4.971	6.71
6	29.1	7.4	8.127	10.98
7	30.9	9.3	8.994	12.22
8	32.4	13	11.34	15.59
9	32.6	12.5	11.34	15.59
10	34.2	15	9.989	14.22
11	34.3	14.9	9.989	14.22
12	36	16.5	7.745	11.47
13	39	20.2	4.449	7.013

pre-compound theory is closer to experimental data than compound nucleus theory.

48-Cd-116(α, 2n + p) 49-In-117: The residue nucleus 117-In is the result of the evaporation of three nucleons (two neutrons and 0ne proton) from the composite nucleus. The residue nucleus is unstable and decay having the half-life time T1/2 = 43.2 min. Undergoes the decay mode of beta minus emission. The exciton number of the following reaction is (TD = 10, Ex1 = 3, Ex2 = 3).

Table 2 and Figure 2 show when an alpha particle is bombarded on the target of a heavy nucleus (116-Cd). The nature of the reaction depends on the energy of the projectile. From the graph, we can see that for the lower energy (about 14.8 and 20 MeV) both the theoretically calculated pre-equilibrium and the compound nuclear reactions appear to be the same. However, in the higher energy region, the graph of the theoretically calculated pre-equilibrium excitation function approaches the result of the experimental value obtained from the data source.

48-Cd-116(α, 3n) 50-Sn-117: The emission of three nucleons (three neutrons) emerges from the composite nucleus by remaining in the residue stable nucleus 117-Sn. The stable has 7.86 percent natural abundance. This reaction has an exciton number of (TD = 10, Ex1 = 3 and Ex2 = 3).

According to the above Table 3 and Figure 3, when an alpha particle is bombarded on a target of 48-Cd-116. From the graph, we can see that for the lower energies of 14.8 MeV and 20 MeV, both the theoretically calculated pre-equilibrium and the compound nuclear reactions seem to overlap. However, the compound nuclear reaction dominates in such a lower energy range. In the higher energy region, the graph of the theoretically calculated pre-equilibrium excitation function approaches the result of the experimental value obtained from the data source.

48-Cd-116(α, 3n + p) 49-In-116: The emission of four nucleons (three neutrons and one protons) emerges from the composite nucleus by remaining in the residue metastable nucleus 116m-In. The metastable has a half-life of 54.29 min and undergoes the decay mode of beta-minus emission. The exciton number of the following reaction is (TD = 12, Ex1 = 4 and Ex2 = 4).

Table 4 and Figure 4 shows, when alpha particles are bombarded on a target of 116-Cd and 3n+p are particles that are outgoing. The nature of the reaction depends on the energy of the projectile. From the graph, we can see that for the lower energy of about 24.4 and 28.3 MeV, both the theoretically calculated pre-equilibrium and the compound nuclear reactions seem the same and more approach to the experimental value. However, in the higher energy region, the graph of the theoretically calculated pre-equilibrium excitation function approaches the result of the experimental value rather than the compound nucleus theory obtained from the data source. According to this graph, at higher energies, the pre-compound theory dominated.

48-Cd-116-(α, n + α) 48-Cd-115: This channel is characterized by the emission of five nucleons (a 4He nucleus and one neutron). The residual of the evaporation can be the radioactive 115Cd nucleus with a half-life time of T1/2 = 53.46hrs). The decay mode of 115Cd is beta-minus emission. The exciton number of this reaction is (TD = 14, Ex1 = 1, Ex2 = 5 and Ex3 = 4).

Table 5 and Figure 5 show the reaction channel under which the evaporation of five nucleons (one neutron and one helium) occurs with the residual nucleus of 115Cd. In the energy range from 18 MeV to about 22.9 MeV, both pre-compound and compound nucleus theory are not more approaching the experimental values, but from 25.1 MeV to 32.6 MeV, compound nucleus theory approaches the experimental values more. At the energies of (32.4 and 32.6) MeV, the compound nucleus reaction has the same value and the pre-equilibrium reaction has a similar value at these two different energies. Finally, according to this graph from the energy of 34.2 MeV to 39 MeV, the value of the pre-compound theory approaches the experimental data in the higher energy, the pre-compound was dominant.

Conclusion

Results of the present work are summarized in the plots of Figure 1, Figure 2, Figure 3, Figure 4 and Figure 5, where experimental and theoretical best excitation function graphs for; 116-48 Cd (_; n) 119 50 Sn, 116-48 Cd (_; 2n + p) 117-49-In, 116 48 Cd (_; 3n) 117 50 Sn, 116 48 Cd (_; 3n + p) 116 49 In and 116-48Cd (n+_) 115-48-Cd. Generally, for all these reactions channels, the theoretical values of the compound nucleus reaction and pre-equilibrium reaction have been calculated [18-20]. The theoretically calculated data and experimental values were validated. For only the first reaction (one neutron emitted), the alpha energy and reaction cross section were inversely proportional, but for the other reactions, the alpha energy and reaction cross-section were directly proportional together. Also, the compound nucleus reaction was dominant in the lower energy region, and the pre - equilibrium reaction was dominant in the higher energy region. Cadmium can never be used as a shielding material for alpha particles such as thermal nuclei.

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