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Investigation of α-induced Reaction on Copper Isotopes for Energy Range of 15-50 Mev

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Abstract: The present work was done on alpha induced reaction mechanics on two natural coppers isotopes for the energy range of 15 to 30 Mev were investigated. The reaction channels for the total cross section ^{63}Cu (α, n) ^{66}Ga, ^{65}Cu (α, 2n)^{67}Ga, ^{63}Cu(α, pn) ^{65}Cu and ^{65}Cu(α, n)^{68}Ga were studied. The experimental data of reaction cross section COMPLETE code have been used. The aim study was compared experimental and theoretical reaction cross section both compound and pre-compound reaction and know the property, the reaction mechanism of the projectile particle reacts with target nuclei. The theoretical result was obtained from international atomic energy agency, exchange format data source. We understood the reaction mechanisms and the property of fragment particles during the reaction. Level density parameter and exaction number were varied to become good agreement between the calculated and measured data. In this study different dependency reaction cross section, the projectile energy was observed between the production of ^{67}Ga and ^{65}Zn. In alpha induced reaction with copper isotopes ^{66}Ga, ^{67}Ga, ^{68}Ga and ^{65}Zn are produced. Normally the calculation using a COMPLET code provides good outcome for the reaction cross-section of alpha induced reaction on low projectile energy. During the study of the reaction compound and pre-equilibrium reaction are occurred but direct reaction was almost not expected. Direct reaction is required to very large amount of energy.

Keywords: Compound, Pre-Compound, Induced, Cross Section, and Isotopes

1. Introduction

The study of nuclear reaction induced by alpha particle has been got significance result for reaction cross section [1]. The investigation of characters of atomic nuclei and the fundamental physical relationships governing their interactions is the basis for all nuclear technologies [2]. Nuclear reaction refers to the process of producing new nuclei and elementary particles as particles and nuclei interact [3]. This is why accurate measurement and calculation of the cross section of nuclear reactions, and understanding of nuclear reaction mechanisms, is important. The reaction mechanisms are seen from the shape of the difference in reaction cross-section or excitation energy [4]. Copper is a transition metal with atomic number 29 and is an important trace element for such number of life forms in all kingdoms [10]. One important part of studying such reactions is to enhance basic understanding of the reaction mechanism. The mechanism of nucleon-induced reactions, particularly proton-induced reactions, is still unclear. At moderate excitation energies, there are indications that compound and pre-compound reaction processes play an important role [9]. Nuclear data for accelerator-driven technologies is required for a large number of target elements covering almost the entire periodic table and covering a wide range of energies. As a well, more detailed and accurate measurements are needed to achieve this data requirement. The nuclear data required for these applications is primarily obtained by nuclear scattering and reaction forecasting The nuclear data required for these applications are mainly obtained from nuclear scattering and reaction model calculations, which are depending on optical models, the parameters of which are determined by elastic scattering and total cross-section data [11]. The process of pre-equilibrium emission in light-ion induced reactions is a subject extensively studied in the last few years. Although there have been many theoretical and experimental works on this subject, the process is still not fully understood, particularly where competition between the equilibrium and pre-equilibrium emission of light particles is high [12]. Accelerators are used to produce isotopes by bombarding appropriate targets with beams of charged nuclei, so impinge on the targets to produce the required isotope [13]. The main goal of this work was to have a unitary analysis of the nuclear reaction mechanisms causing alpha interactions with 63,65Cu target nuclei [14]. The compound nucleus wave function is also somewhat complicated, involving a large number of particle-hole excitations that can be presented scientifically [15]. The alpha particle was found by accident during the natural radioactive decay of heavy mass nuclei. Even after that, a large number of heavy mass-particle emitting radionuclides that were synthesized artificially were characterized. Their half-lives vary widely, but the-particle energies are usually between 4 and 7 MeV [16]. For all investigated, thick target production yields were calculated using the new cross sections [17]. From which exchange format database were all available data for charged particle induced reactions, up to incident particle energy of 15Mev to 30Mev, used in the production of gallium isotopes collected [18]. The energy of alpha particles obtained from natural radioactive nuclei is dispersed to all parts and discrete in nature, and it is significantly smaller than the coulomb barrier, making it unfit for nuclear reactions [19]. Alpha particles are made up of two protons and two neutrons, so they have the structure of helium nuclei [20]. The shape of the difference of reaction cross-section vs excitation energy reveals the reaction mechanisms [21].

2. Methodology

The study of this research was conducted mixed methods that mean quantitative with qualitative approach using computer base COMPLETE code software. The data was gathered from IAEA data source in the searching google engine. The experimental data information was generated by bombarded projectile as alpha particle with target nuclide different copper isotopes using this computer based software package.

2.1. COMPLETE Code

COMPLETE code was a nuclear reaction code which was designed for versatility and easy use in the incident energy range of a few Mev to several hundred Mev [6]. The code COMPLETE generate yield and spectra for all reactions populated by all combination of n,p,d,T,α and can provides all input parameters. There running time of COMPLETE code was very short time [8]. Its version needed about 2-megabyte memory. It also used determined p – spectra, n-spectra, pre-equilibrium, neutron proton alpha emission up to two particles, evaporation of deuterium and tritium [7].

2.2. Experimental Calculation Using Computer Code

The software program run the impute and output directory were defined. Alpha particle was preferable as incident particle followed by selecting target nuclide. The number of incident energy was specified followed by the first incident energy, then the incident energy step is avelaiabled. For practical applications of the statically model was important to obtain parameters of the level density description from reliable experiment [5]. In compound and pre-equilibrium emission calculations, the level density parameter and initial excitation configurations were essentials quantity. The reaction cross section both compound and pre-compound reaction was measured by mill barn (mb). The nuclear level density effects the height and the shape of calculated cross section. The levels density of the nucleus included in the evaporation chain calculated from fermi density distribution.

$$\rho\ (\mathrm{E}) = \frac{\pi^{\frac{1}{2}}}{12E^{\frac{5}{4}}\alpha^{\frac{1}{4}}} e2\sqrt{\alpha E} \quad (1)$$

Where:

E – is the excitation energy

α - The level density parameter

The mean free path parameter calculation in pre-equilibrium was given

$$L = \frac{1}{\rho \bar{\sigma}_0} \quad (2)$$

ρ - is the level density of nuclear matter

$\bar{\sigma}_0$ - is Pauli corrected nucleon – nucleon (N-N) interaction the scattering cross section, appropriated weighted for target neutron and proton number.

The level density parameter obtained by experiment shown that a linear dependent with the mass number of nucleus was given by

$$\alpha = \frac{ACN}{K} \quad (3)$$

Where: ACN is the mass of the compound nucleus an K is the free constant. We have used the level density parameters

$$\alpha = \frac{ACN}{8}, \frac{ACN}{10}, \frac{ACN}{12} \quad (4)$$

$$\sigma\ \mathrm{t} = 2\pi\lambda'^{2} \sum_{l=0}^{l\max} (2l+1)[1-\mathrm{Re}\,\eta l] \quad (5)$$

Where:

λ'^{2-} is reduced de Broglie wave length

L – is angular momentum

$\mathrm{Re}\,\eta l$ - is real part of complex constant which contains the effect of the scattering center.

3. Result and Discussion

3.1. Result

When the alpha particle strick target copper the gave as ^{67}Ga at excitaed states. During the reaction emitted two neutron as ejectile particles.

Here the experimental and theoretical result maximum cross section is occurred at initial energy range 16.3Mev. Contrary the projectile energy increasing strictly the minimum cross section is dominated. This show that the cross section reaction depends on the incident energy.

When the alpha particle strick target copper the gave as ^{67}Ga at excitaed states. During the reaction emitted two neutron as ejectile particles.

Table 1. *Experimental and theoretical value of reaction cross section of* $^{65}Cu(\alpha,2n)^{67}Ga$.

E_α Mev	$\sigma_{Exp(mb)}$	$\sigma_{Pre-compound(mb)}$	$\sigma_{Compund(mb)}$
15	1.1	-	-
18	68.5	167.8	185.6
20	151.9	398.6	453.4
23	257.5	478.3	555.6
26	299.5	383	465.8
29	293	309.3	341.8
33	220.9	207.7	142
39	86.8	122.4	24.26
43	46.4	106.9	10.50
45	35.9	91.86	5.799
45	24.4	76.68	1.240

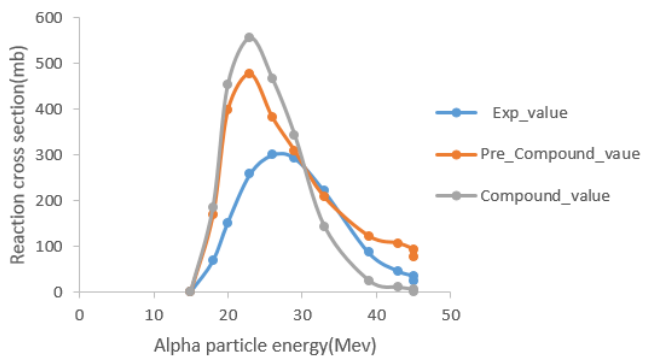

Figure 1. *When compare Experimental and theoretical value of reaction cross section of* $^{65}Cu(\alpha, 2n)^{67}Ga$.

From this figure it seen that compound nucleus was dominated than pre-compound reaction. This show that compound nucleus occurs at low energy levels from energy range 15Mev to 30Mev. When the energy rage extended from 30 Mev it was existed pre-compound nucleus reaction. This lead to emission of some of the excited nucleons before compound nucleus statically reached at equilibrium. When it seen that Production of ^{68}Ga which emitted one alpha and one neutron particles.

In this work at the energy range between 15Mev to 30Mev both compound and pre-compound nucleus far apart with experimental result. But the energy range above 30Mev pre-compound nucleus slightly comparable with experimental result than compound nucleus reaction. The projectile energy beyond 35 Mev both theoretical and experimental result was gained overlap which show that at high energy it likely move to direct reaction.

Similarly, in table 1 when it seen that Production of ^{66}Ga which emitted one alpha and one neutron particles.

Table 2. *Experimental and theoretical value of reaction cross section of* $^{65}Cu(\alpha,n)^{68}Ga$.

E_α Mev	$\sigma_{Exp(mb)}$	$\sigma_{Pre-compound(mb)}$	$\sigma_{Compund(mb)}$
16.3	760	657.4	664
17.3	790	331.2	306.9
20.2	580	154.2	137.4
25.1	206	36.16	15.67
28.4	60	23.57	4.534
34.5	18.0	12.82	0.4127
39.6	6.2	8.455	0.05953
42.1	4.8	8.451	0.03260
44.5	3.2	8.203	0.01708
46.7	2.4	7.444	0.008913
49	2.0	6.915	0.004817

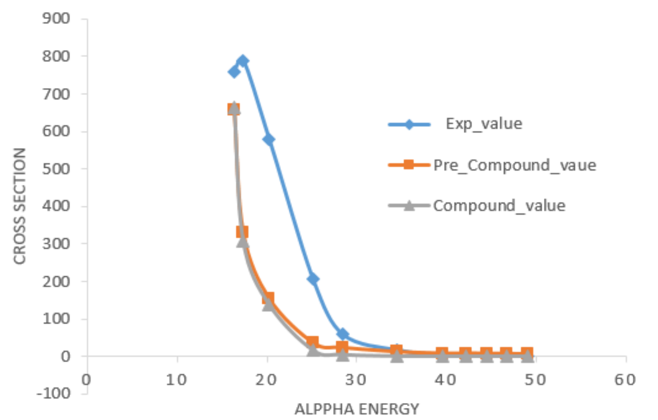

Figure 2. *Compare experimental and theoretical value of reaction cross section of* $^{65}Cu(\alpha,n)^{68}Ga$.

Table 3. *Experimental and theoretical value of reaction cross section of* $^{63}Cu(\alpha,n)^{66}Ga$.

E_α Mev	$\sigma_{Exp(mb)}$	$\sigma_{Pre-compound(mb)}$	$\sigma_{Compund(mb)}$
15	414.8	490.25	500.2
20	325.4	168.6	166.2
23	171	56.25	42.07
25	97.5	33.58	17.65
30	32.1	14.75	1.99
35	75.4	13.53	0.4907
39	135.1	9.0	0.0100
41	139.3	7.767	0.04655
45	121.1	5.483	0.01069
47	114.6	5.609	0.005933

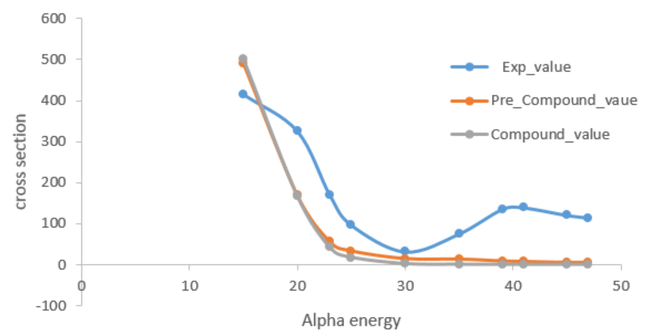

Figure 3. *Compare Experimental and theoretical value of reaction cross section of* $^{63}Cu(\alpha,n)^{66}Ga$.

From the figure shown that both theoretical cross section slightly approached to experimental cross section data. It could have seen that the cross section for the calculated value was high at low energy whereas the projectile energy around 23-35 Mev was decreased. After 39 Mev the value of cross section goes up and down which enables to made peak at medium energy.

When it seen that the production of ^{65}Zn with the given reaction channels which released one alpha, proton and neutron particles.

Table 4. *Experimental and theoretical value of reaction cross section of* $^{63}Cu(\alpha,pn)^{65}Zn$.

E_{α} Mev	$\sigma_{Exp(mb)}$	$\sigma_{Pre-compound(mb)}$	$\sigma_{Compund(mb)}$
15	0.99	-	-
19	205	303.7	332.4
22	468	473.8	506.7
26	498	457.5	419.8
30	746	395.4	274.4
35	592	390.1	89.21
40	385	220.7	31.21
45	225	167.3	7.221
48	155	142.2	2.898
50	117	134.2	1.61

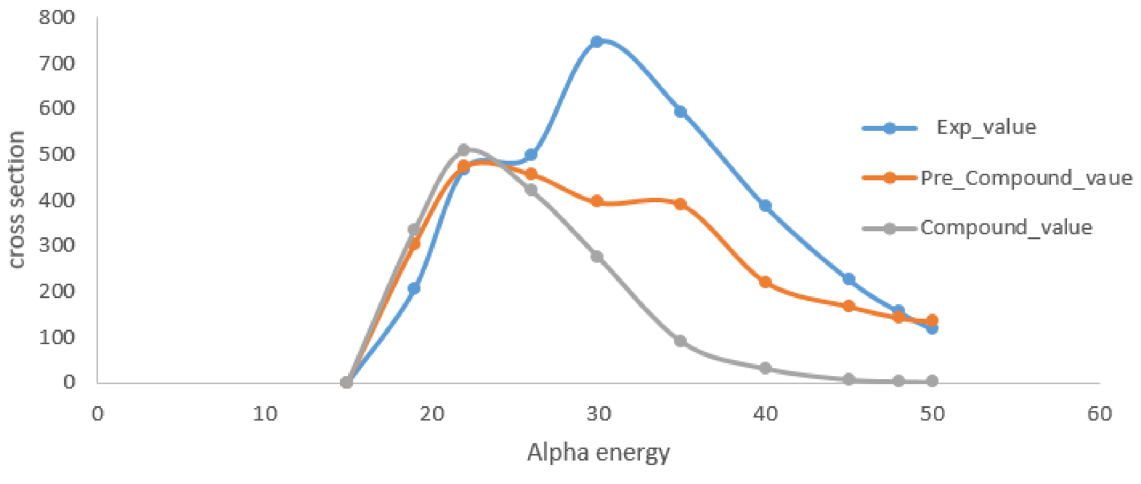

Figure 4. *Compare Experimental and theoretical value of reaction cross section of* $^{63}Cu(\alpha,pn)^{65}Zn$.

At low energy both theoretical value was not occurred, because of penetration of the barrier potential for less energy of incident particle. The cross section for calculated result reduced rapidly at very high energy which goes to direct reaction.

3.2. Discussion

The present work we discussed that alpha induced reaction on the natural coppers isotopes for the energy range of 15-50Mev.The quantitative earlier experimental cross section date were reported from IAEA, EXFOR data center. The exchange format data base center was the package of collected experimental reaction cross section data with projectile charged particles. The COMPLETE code software gave the result of both compound and pre-compound reaction or pre-equilibrium reaction. The pre-equilibrium reaction was depending on the incident energy and the target mass. It occurs before the reaction at spastically at equilibrium was reached in the system. Compound nuclear reaction occur the system at equilibrium. The various parameter was used to calculate cross section which depending on the projectile of alpha particle bombarded with various nuclei with level density parameters also influenced. The projectile energy is measured in mega electron volt (Mev) whereas the cross section is measured in mill barn (mb). For pre-equilibrium emission initial conflagration could be neutron, proton and alpha particle. The mean free path (MFP) and level density parameter were essential for the reaction cross section. The level density parameter $\alpha = \frac{ACN}{8}$, $\alpha = \frac{ACN}{10}$ and $\alpha = \frac{ACN}{12}$ are taken for all reaction channels. Even though, all the mean free path parameter are used for each reaction channel the MFP at 2 fm with level density $\alpha = \frac{ACN}{8}$ got good agreement to fit with experimental result. When we see that at low energy for theoretical cross section initially was not observed which show that alpha induced reaction is required high amount of energy to overcome the coulomb potential barrier. At maximum cross section (low energy) compound nuclei is dominated, whereas at low cross section (high energy) pre-equilibrium reaction more significance.

The theoretically calculated cross-section values for the reaction $^{65}Cu(\alpha,2n)^{67}Ga$ starts from the minimum energy of 15 MeV with cross section of 11.1 mb and reaches its maximum peak at about 26 MeV with 383 mb and starts to fall down for increasing value of energy. Similarly, the experimental reaction cross-section starts to fall down at about the projectile energy of 24.4 MeV reaching its maximum cross-section 465.8 mb. The theoretically calculated and experimental reaction cross-section values in a given energy range are different at some energies but they both increases and decreases at the same time with the same projectile energy as in the figure 1. This shows that both the theoretical and experimental excitation functions follows the same pattern at the same projectile energy. It was observed that there was a gap in the energy between 19 MeV to 35 MeV, in the theoretically calculated and experimental reaction cross-section. Whereas, the theoretically calculated cross section approaches the experimental cross-section value best for the energy from 16.3 -20.2 MeV and 22- 26 MeV as in the figure 3. In general, both the theoretical and experimental reaction cross-section are agreed for the reaction ^{63}Cu (α, n)^{66}Ga which shows that COMPLET code calculation give good result for experimental work with theoretical when compared to other reaction channels.

4. Conclusion

The present work of investigation of α-induced reaction on copper isotopes for energy range of 15-50 Mev were studied by using excitation model with an improved computer COMPLETE code software. As the result of this, compound nucleus was occurred through the de- excitation of selected nuclei by emitted one alpha, one neutron, two neutrons using fitting level density parameter. In alpha induced reaction with copper isotopes ^{66}Ga, ^{67}Ga, ^{68}Ga and ^{65}Zn are produced. During the study of the reaction compound and pre-equilibrium reaction are occurred but direct reaction was almost not expected. Direct reaction is required to very large amount of energy. The level density parameter and initial excitation configuration were targeted quantity for the pre-equilibrium and compound reaction. The level density parameter ($\alpha = \frac{ACN}{12} Mev$) was good result with mean free path at 2fm. The pre-compound reaction was depended on the projectile energy and target mass. Thus reaction was occurred at high energy but at low energy rage not significance Even though projectile energy very low compound nucleus might have occurred.

List of Acronym

IAEA, EXFOR- International Atomic Energy Agency Exchange Format, COMPLETE code - projection angular momentum coupled evaporation Monte Carlo code.

Declarations

Availability of Data and Materials

The present work is totally my idea without considering citation of reference which mean that there was no conflict interest among the researchers. Theoretical data took from IAEA, EXFOR data and to generate experimental data COMPLETE code is used.

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Authors' Contributions

Research article conceived and designed the study. The Author done study validation, formal analysis, investigation resources, reaction mechanism and more gave attention research to the Nuclear science technology.

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