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IJPRA INTERNATIONAL JOURNAL OF PHYSICS RESEARCH AND APPLICATIONS
ISSN 2766-2748

Thesis

Pre-equilibrium Effects on Alpha Particle Induced Reactions on Niobium Isotope from Threshold upto 100MeV using the Computer Code COMPLET

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Submitted: February 21, 2023
Approved: October 03, 2023
Published: October 04, 2023

How to cite this article: Mekonen CS, Mekonen TA. Pre-equilibrium Effects on Alpha Particle Induced Reactions on Niobium Isotope from Threshold upto 100mev using the Computer Code COMPLET. Int J Phys Res Appl. 2023; 6: 180-184.

DOI: 10.29328/journal.ijpra.1001069

Keywords: Alpha particles; Induced reactions; Niobium- 93 isotopes; COMPLET

Abstract

Excitation functions (EF) for four reactions of the type 93_{Nb} (α, xn); x = 1-4 were studied. This study provides current evidences about the dominance of pre-equilibrium processes at high energies followed by compound nucleus equilibration at low energies. The main objective of the work is to look pre-equilibrium emission induced by alpha particle energies up to 100 MeV on Niobium through describing, analyzing and interpreting the theoretical results of cross sections obtained from computer code COMPLET by comparing with experimental data obtained from EXFOR library. COMPLET code has been used for the analysis using the initial exciton number n_0 = 4(4p+oh) and level density parameter ACN/10. A general agreement was found for all reactions.

Introduction

Nuclear reactions induced by alpha particle in the energy region 20 MeV - 200 MeV are interesting since last few decades in view of the associated pre-equilibrium processes at high energies followed by compound nucleus at low energies. This smooth variations of cross sections as the equilibrating target-projectile system proceeds towards equilibration is an interesting study as the shape of excitation function reveals the reaction mechanisms [1-3]. In order to explain the nuclear equilibration several semi classical modals were proposed during the past decades [4-6]. This reaction modals were constantly revised and refined and very important when the experimental data are not available. The basic idea of these modals is that the projectile-target system is attributed by a very few degrees of freedom in the initial phase of interaction and successively passes through a series of stages of equilibration and eventually reaches the state of equilibrium which is characterized by a large number of degrees of freedom [7-10].

In this paper we have studied the excitation functions of four reactions of the type 93_{Nb} (α, xn); x = 1-4; bombard with alpha particle upto 100 MeV. The high energy tails of (α, xn) excitation functions provide a good basis to examine the pre-equilibrium modals in details. The experimental data is obtained from EXFOR library, IAEA [11,12].

Computer code COMPLET

The computer code COMPLET is a nuclear reaction code which was developed to generate theoretical data on nuclear reactions. Code COMPLET has been essentially developed to analyze the nuclear reaction mechanisms. The code COMPLET allows the evaporation of proton, neutron, deuterium and alpha particles, triton and Helium-3 [13-15]. This code is an improved version of earlier computer codes and is very important for several technical applications if the experimental data is not available or unable to measure the reaction cross-sections due to experimental difficulties. This code is a capable of calculating equilibrium and pre-equilibrium emission presses upto 300 MeV.

Comparison of theoretical result and experimental values

To compare the theoretical and experimental cross-section results, the researchers use Pearson's correlation coefficient (R).

$$R = \frac{\sum_{i=1}^{N} (X_{ti} - \langle X_t \rangle)(X_{ei} - \langle X_e \rangle)}{n-1\,(S_{Xt})(S_{Xe})} \quad (1)$$

Where, R-is correlation coefficient, $\langle X_t \rangle$ and $\langle X_e \rangle$ represent the mean theoretical and experimental cross-sections respectively, X_{ti} and X_{ei} are the theoretical and experimental cross-sections of the i^{th} value respectively, N is number of the theoretical and experimental data where as S_{Xt} and S_{Xe} are the standard deviation of the theoretical and experimental cross-sections respectively. Each mentioned variable represents the following mathematical relations:

$$\langle X_t \rangle = \frac{1}{N}\sum_{i=1}^{N}(X_{ti}) \qquad S_{Xt} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(X_{ti} - \langle X_t \rangle)}$$

$$\langle X_e \rangle = \frac{1}{N}\sum_{i=1}^{N}(X_{ei}) \qquad S_{Xe} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(X_{ei} - \langle X_e \rangle)}$$

The value of R is in between -1 and 1. Where, 1 is the total positive linear correlation, 0 is no linear correlation, and −1 is total negative linear correlation. If $0 < R < 0.3$, the correlation is weak and positive, if $0.3 \le R < 0.7$, it describes moderate correlation and for $0.7 \le R < 1$, the correlation is strong and positive. The results for each data in this thesis have been calculated by using Pearson's correlation coefficient calculator (statistics calculator).

Results and discussions

The computed cross-sections induced by alpha particle on niobium isotope are listed in Tables 1-4 along with experimental cross-sections [15-21] are plotted with total cross-section against the projectile energies. The level density parameters $a = \frac{ACN}{10}$, the initial exciton number $n_o = 4(4p+0h)$ has been taken for α-particles, as best fit for all reactions.

Comparison of theory

The experimental values by different authors [16-22], are compared with theoretical predications by the code COMPLET.

In the pre-equilibrium part the calculation starts with the initial exciton number $n_o = 4(4p+0h)$ for α-particles as projectile, that means the particles above and holes below the fermi sea during the initial stages of interaction. It proceeds quickly to the states with increasing exciton number. For each state, the emission probability is calculated and finally the integrated yield the cross sections for individual reactions. The mean free path multiplier was kept for all the competitions. The level density parameters $a = \frac{ACN}{10}$ was used globally. The crucial parameter in the calculation is initial exciton number n_o (i.e. particle above and hole below fermi sea). A general recommendation for the initial exciton number varies between A_o and $A_o + 2$ (A_o is mass number of the projectile) for alpha particles. The reasonable choice used in the calculation is $n_o = 4(4p+0h)$ as the initial configuration. In general, it is observed that in all the four reactions $(4p+0h)$ gives good agreement with experiment.

Table 1: Theoretical and experimental cross section for 93_{Nb} (α,*n*) 96_{Tc} reactions.

Reaction Cross section (mb)	Experimental cross section 93_{Nb} (α, *n*)			Theoretical cross section (mb)
E_α (Mev)	K Kim, et al. [16]	MK, Sharma. et al. [17]	FK, Amanuel, et al. [18]	
10.26	7.3±0.4	-	-	6.45
11.9	-	16.9±2	-	34.09
12.45	51.4±2.6	-	-	117.4
15.58	689±34.5	310.8±1	-	474.2
17.29	784±39.2	-	-	432.6
19.87	601±30.1	265.4±2.3	-	191.6
21.36	429±21.5	-	-	95.31
22.4	-	146.1±5.9	-	72.3
23.63	180±9.1	-	64.7	57.78
24.93	128±6.4	-	-	48.16
25.2	-	45.5±1.9	-	42.8
26.6	-	29.5±2.7	30	38.26
27	74.2±3.8	-	-	34.9
28.2	60.2±3.1	20.5±1.6	24.5	31.6
30.4	47.6±2.4	16.6±3.1	19.2	26.7
31.22	38.8±2	-	-	24.78
32.7	-	8±1.5		22.66
33	34.8±1.8	-	16.7	21.12
34.05	28.6±1.5	10.3±1.5	-	19.47
35.71	28.5±1.5	-	17.9	17.91
36.71	23.2±1.2	-	-	16.58
37	-	6.5±1	14.3	15.53
38.71	23.2±1.2	-	-	14.15
39.25	18.3±1	5.9±0.7	-	12.95

Table 2: Theoretical and experimental cross section for 93_{Nb} (α, 2*n*) 96_{Tc} reactions.

Reaction Cross section (mb)	Experimental cross section 93_{Nb} (α, 2n)			Theoretical cross section (mb)
E_{α} (Mev)	S Mukherjee, et al.	GN Kim, et al.	MK Sharma, et al.	
17.3	153±14.3	40.7±2.3	-	102.4
19.87	-	422±21.1	244±2.7	630.1
20.8	694±61.8	-	-	804.1
21.36	-	601±30.2	-	922.1
22.4	-		632.1±2.6	1005
23.63	-	898±24.9	-	1057
24.93	1046±95.7	999±50.1	-	1084
25.2	-	-	692.1±6.4	1025
26.6	-	-	741.5±6.8	897.5
27	-	1050±52.4	-	747
28.2	858±50.3	1080±54	718.7±6.3	598.3
30.4	-	942±42.1	558.3±4.4	520.1
31.22	-	849±42.6	-	429.2
32.7	-	-	378.2±2.7	361.9
33	-	599±30	-	305.9
34.9	467±28.1	514±24.8	247.9±2.3	269.2
35.71	-	362±18.1	-	238.2
36.71	-	300±15.1	-	216.7
37	-	-	159.1±1.9	202.4
38.71	-	219±11	-	186.9
39.25	-	188±9.5	121±1.9	169
40.2	114.25±7.02	-	-	157
46.2	54.55±3.02	-	-	114
51.6	33.01±1.92	-	-	88.43
57.2	25.61±1.51	-	-	80.47
63.2	20.47±1.01	-	-	63.3
64.4	15±0.9	-	-	58.24
69.2	14.76±0.81	-	-	47.35
70.6	12±0.7	-	-	45.23
75.9	9.7±0.6	-	-	37.02
81	7.76±0.6			35.37
86.1	6.33±0.43	-	-	29.34
91.2	5.28±0.37	-	-	23.85
96.4	4.4±0.33	-	-	19.79

Table 3: Theoretical and experimental cross section for 93_{Nb} (α, 3*n*) 94_{Tc} reactions.

Reaction Cross section (mb)	Experimental cross section 93_{Nb} (α, 3*n*)			Theoretical cross section (mb)
E_{α} (Mev)	K. Kim et al.	CL. Branquinho et al.	FK. Amanuel et al.	
23.3	-	-	24.2	0.00
26.1	-	-	18.5	11.98
28.2	23.9±1.2	86	57.7	195.7
30.1	178.2±10.7	-	239.9	478.8
31.22	274.2±15.8	-	-	594
33	515.3±26.1	-	649	749.2
34.05	584.3±31.3	876	-	803.6
35.71	729.2±39.7	-	835.9	758.4
36.71	755.6±41.3	-		786.9
37	-	-	912.3	796.3
38.71	826.3±45.2	1060	-	771.4
39.25	788.9±43.8	-	-	793.3
43.7	-	596	-	576.2
48	-	449	-	354
52	-	277	-	273.4
55.9	-	176	-	230.7
60.2	-	118	-	184.7
64.1	-	89	-	187.9
68.2	-	59	-	168.3
71.9	-	54	-	146.3

Table 4: Theoretical and experimental cross section for 93_{Nb} (α, 4*n*) 93_{Tc} reactions.

Reaction Cross section (mb)	Experimental cross section 93_{Nb} (α, 4*n*)			Theoretical cross section (mb)
E_{α} (Mev)	J. Ernst, et al.	CL Branquinho, et al.	VN. Levkovski	
38.8	6	-	-	17.4
39.8	27	-	-	47.23
40.7	-	-	63	89.95
41.7	-	-	92	143.8
42.6	-	-	122	196.1
43.6	102	134	158	252.5
44.5		-	193	304.4
46.1	234	-	211	377
48	-	326	260	417.8
49.2	300	-	-	381.7
51.9	374	-	-	385.2
52	-	400	-	369.5
55.9	-	420	-	317.1
57	384	-	-	274.8
60.2	-	-	-	226.5
62.2	267	290	-	204.9
64.1	-	-	-	210.8
66.9	180	230	-	196.9
68.2	-	-	-	185.1
71.1	142	145	-	168.2
75.7	98	101	-	137.5
79.9	73	-	-	123.7
83.8	67	-	-	113.5
86.8	58.7	-	-	107.2
91.3	51	-	-	106.4
96.8	38.5	-	-	94.49

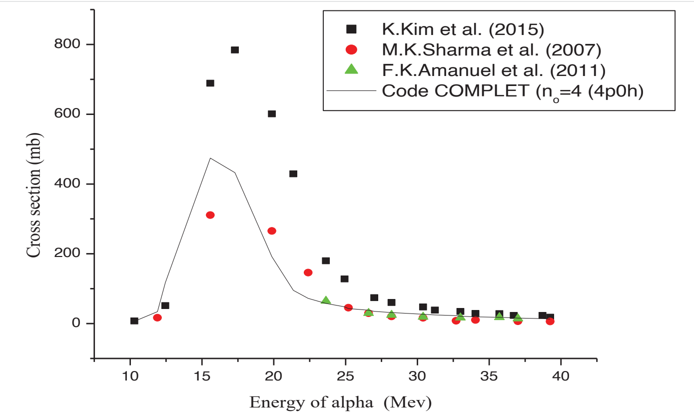

Figure 1: Comparison of theoretical and experimental cross section for 93_{Nb} (α, *n*) 96_{Tc} reactions.

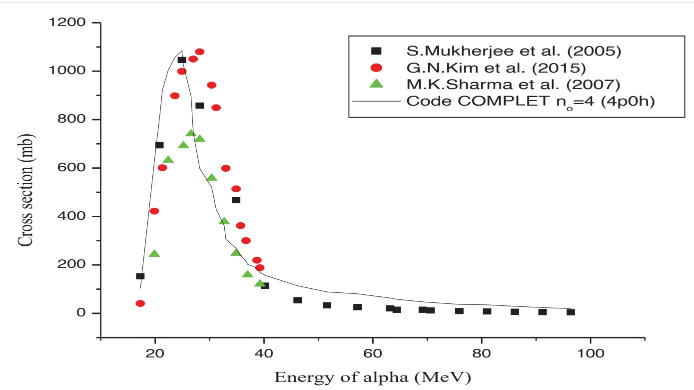

Figure 2: Comparison of theoretical and experimental cross section for 93_{Nb} (α, 2*n*) 95_{Tc} reactions.

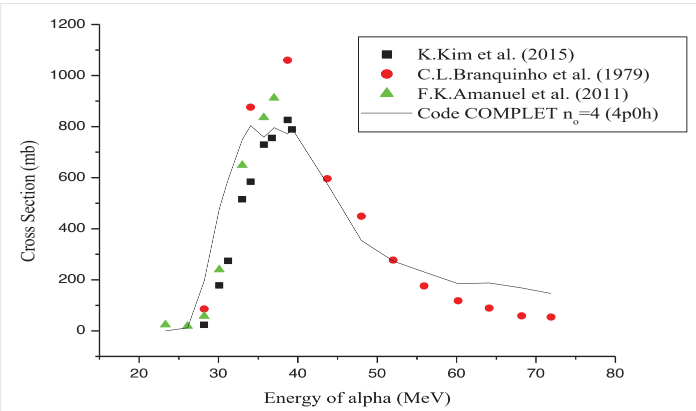

Figure 3: Comparison of theoretical and experimental cross section for 93_{Nb} (α, 3*n*) 94_{Tc} reactions.

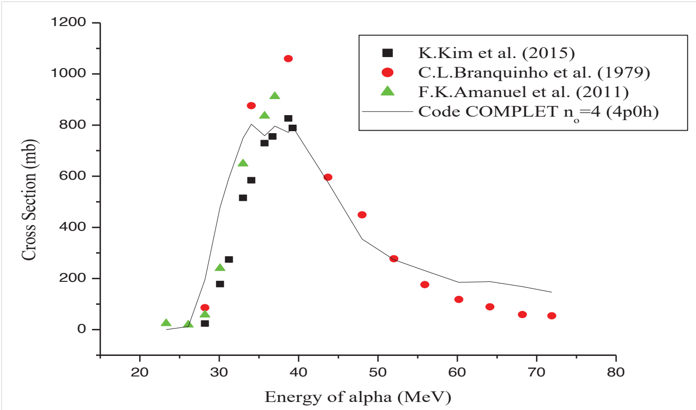

Figure 4: Comparison of theoretical and experimental cross section for 93_{Nb} (α, 4*n*) 93_{Tc} reactions.

Figures 1-4 show the excitation functions for the for the reactions 93_{Nb} [(α, *n*), (α, 2*n*), (α, 3*n*), (α, 4*n*)] along with the theoretical predications by COMPLET code. The experimental values in all the four reactions are in better agreement with the computed cross sections by COMPLET code is pre-equilibrium dominated energy region 20 MeV - 100 MeV. As can be seen in Figures 2,4 while theoretical values give excellent agreement with all other authors of experiment, the values reported by K. Kim, et al. [16], values are systematically underestimated this could be due to the variation in experimental techniques employed in their measurements. However, there is an overall agreement between experiment and theory using initial configurations $n_o = 4(4p+0h)$.

Conclusion

Excitation functions of four reactions of the type 93_{Nb} (α, *xn*); *x* = 1-4; are studied in the present work. From an overall comparison between experimental values and theoretical predictions, one can infer that COMPLET code gives a satisfactory prediction on account of nucleons emission in the medium mass nuclei like Niobium. The initial exciton number $n_o = 4(4p+0h)$ choice justifies with the basic premise of pre-equilibrium decay that only a small number of degrees of freedom are initially excited in a nuclear reaction. In short, pre-equilibrium phenomena are a few degree phenomena.

Acknowledgment

The authors are profoundly thankful to Dr. AV Mohan Rao (Associate Professor) who with his unique research competence, selfless devotion, thoughtful guidance, inspirational thoughts, wonderful patience and above all parent like directions and affections motivated them to pursue this work. The authors wish to express their gratitude to all those who contributed various ways to make this work a reality.

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