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The Dominance of Proton/Neutron Evaporation Exit-Channel in a Fusion-Evaporation Reaction: The Effect of Target Nuclear Ratio (N/Z)

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***Abstract:** Cross section of different evaporation residue have been calculated in ^{112}Sn+^{16}O (Neuron/Proton (N/Z) of the ^{112}Sn target is 1.24) and^{124}Sn+^{16}O reaction (N/Z of the ^{124}Sn is 1.48) with beam energy of 80 MeV using statistical model calculation code PACE4. These calculations predicts that the proton emission channels are predicted to be dominant when the N/Z ratio is small (i.e in the first reaction) whereas the neutron emission outgoing channels dominant in the second reaction when N/Z is large. Experimental phenomenon also revealed the fact that in order to populate the proton or neutron reach nucleus we have to choose the target material accordingly.*

***Keywords :** Angular Distribution, Cross-section, Heavy ion fusion reaction, PACE4.*

I. INTRODUCTION

The decay pattern of nuclei which is exited from the fusion evaporation reaction of heavy ion assumed to be well described by the statistical model calculations. Generally a large number of excided nuclei are being populated in the heavy ion fusion reaction when a projectile bombards a heavy target with energy above the coulomb barrier energy. As different analysis of excited nuclei is not easy, models are formulated based on statistical analysis to investigate the basic mechanism of nuclear reaction.

II. PACE4 FORMALISM

This code is an updated version of code PACE (Projected Angular momentum Coupled Evaporation) originally developed by Gavron [1] which is able to find the value of cross section of the excited nuclei with large angular momentum that are populated in the fusion evaporation reaction. It uses the statistical model approach and engages Monte-Carlo simulation technique for the de-excitation of compound nucleus. Projected angular momentum and hence the angular distributions are deduced after each stage of the de-excitation of compound nucleus.

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The present code PACE4 does not take the pre equilibrium emissions under considerations. The important feature of this code is that most of the nuclear parameters that one has to put individually in the previous code like level densities, Q-value, optical model parameters, gamma ray strength functions are inherent. Aforementioned code uses the multi step procedure to ascertain the order of consecutively emitted particles from the compound nuclear reactions like proton, neutron, alpha, and γ-rays etc. Starting from a compound nucleus having well-defined excitation energy, angular momentum combination, random number selection algorithm allows the final state to be selected based on the partial decay widths for each process. The angular distribution spectrum of the discharged particles is calculated utilizing stored information of the discharged particles in this code. Using the code masses are studied from the Wapstra's atomic mass table [2] and if it does not contain mass, rotating liquid drop mass due to Lysekil is exchanged. Fission is contemplated as decay mode, while the unfinished fusion is not taken into account. The inputs of aforementioned code are charge, mass number of the target and projectile and the bombarding laboratory energy only. This modified version of PACE takes into consideration the energy subservience of the level density parameter 'a' which can be found in Ref.[3]. The level density parameter a= A/K, where A being the mass number of the compound system and K is a free parameter, that can be changed to match the experimental data. Amazing thing of this code that the program itself decides the level density parameter at the very beginning and this is not used as input parameter. Fission probability may be computed with the Bohr-wheeler's saddle point formalism [4]. Fission barriers are those of Sierk [5].

The partial reaction cross section can be calculated using the formula

$$\sigma_l = \pi\Delta^2(2l+1)T_l$$

where Δ is the reduced wavelength and T_l is the transmission coefficient is given by

$$T_l = [1+\exp(\frac{l-l_{\max}}{\Delta})]^{-1}.$$

where Δ is the diffuseness parameter and l_{max} is governed by total fusion cross section σ_F. The σ_F is equal to $\sigma_F = \sum_{l=0}^{\infty}\sigma_l$.

The transmission coefficient for light particles n, p and a-emissions were determined using optical model potentials [6,7].

Input fusion cross-section is enumerated using Bassformula [8].The transitions strengths E1,E2,M1, and M2 are taken from ref [9].

The cross sections of the evaporation residue as well depends on the following parameters i) the proportion of level densities of the saddle also at the ground state (ii) the height of the fission barrier which rely on the spin. The main difference between PACE and PACE4 formulas is in the technique of incorporating the shell corrections to the energy reliance part of the level density. The level density parameter ρ(E,L) used in the calculation above ~5MeV is given by the relation

$$\rho(E,L)=\rho_0(U)(2L+1)\exp\{2[a(U-E_{rot}(L))]^{\frac{1}{2}}\}$$

where U= E-P and P is the pairing energy. $E_{rot}(L)$ is obtained using Ref [10]. ;$\rho_0(U)$ was got hold from the Gilbert and Cameron formalism [11]. The Gilbert and Cameron formalism is no longer a default option in the modified version PACE-4.

III. CALCULATION

The calculated cross sections for the ^{112}Sn+^{16}O (Table I) and ^{124}Sn+^{16}O (Table II) reactions at beam energy of 80 MeV are reported below in the tabular form:

Table I: Cross section calculation of ^{112}Sn+^{16}O

Dominant Nucleus Populated	Emission channel	Cross section in (mb)
^{125}Ce	3n	42.5
^{125}La	**p2n**	**225**
^{125}Ba	2pn	154
^{124}Ba	2p2n	80.1
^{124}Cs	3pn	42.5
^{122}Cs	αpn	130

Table II: Cross section calculation of ^{124}Sn+^{16}O

Dominant Nucleus Populated	Emission channel	Cross section in (mb)
^{136}Ce	4n	186
^{135}Ce	**5n**	**572**
^{136}La	p3n	40
^{135}La	p4n	63.6
^{133}Ba	α3n	26.2
^{132}Ba	α4n	25.3

IV. RESULTS

From the results of the two table it is evident that in proton channel (^{125}La) is the most dominant channel in the first reaction whereas the ^{135}Ce (5n channel) is the most dominant channel in the second reaction where N/Z ratio is high. The choice of the proper target therefore is one of the important aspect of the experimentalist to study a particular nucleus in details.

V. CONCLUSION

Experimentally ^{125}La was studied by K.Starosta et al.,[12] in the ^{112}Sn(^{16}O,p2n) at a beam energy of 79 MeV. This shows that the predicted PACE4 calculation is correctly reproduced (see Table 1) and the effect of target nucleus also plays a dominant role in order to study the proton reach nucleus like ^{125}La. The second reaction was also studied by H.C. Jain et al.,[13] in order to study the neutron reach nucleus ^{135}Ce. Once again the experimental results are exactly match with the PACE4 prediction (see table 2). Therefore it may be concluded that choosing the proper target is the key aspect to study the proton or neutron reach nucleus.

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