Effect of the Target Nuclear Ratio (*N/Z*) on the Evaporation Exit-channel in a Heavy-ion Induced Fusion-evaporation Nuclear Reaction

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Abstract:

Cross section of different evaporation residue have been calculated in ^{112}Sn+^{32}S (*N/Z* = 1.24 for ^{112}Sn) and ^{124}Sn+^{32}S reaction (*N/Z* = 1.48 for ^{124}Sn) with beam energy of 155 MeV and 150 MeV using statistical model calculation code PACE4. These calculations predicts that the proton emission channel [^{140}Eu$_{63}$ (3pn) or ^{140}Gd$_{64}$ (2p2n)] are predicted to be dominant when the *N/Z* ratio is small (*i.e.* in the first reaction) whereas the neutron emission outgoing channels [^{151}Dy$_{66}$ (5n) ; ^{150}Dy$_{66}$ (6n)] 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 rich nucleus we have to choose the target material accordingly.

Keywords: Heavy-ion fusion reaction, Cross-section, PACE4

PACE4 Formalism:

The decay pattern of the excited nuclei from the heavy ion fusion evaporation reaction 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. Since a separate study of each excited nuclei is very difficult, models based on the statistical methods are important tool for the study of the nuclear reaction mechanism.

This code is an updated version of code PACE (Projected Angular momentum Coupled Evaporation) originally developed by Gavron [1] which is able to calculate the cross section of the excited nuclei with large angular momentum that are populated in the fusion evaporation reaction. It is based on the statistical model approach and uses the Monte-Carlo simulation technique for the de-excitation of compound nucleus. The projected angular momentum and hence the angular distributions are calculated at each stage of the de-excitation of the compound nucleus. 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 and gamma ray strength functions are inbuilt. This code uses the multi step procedure to determine the sequence of successively emitted particles from the compound nuclear reactions like proton,neutron, alpha, and γ-rays etc. Starting from a compound nucleus with 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 emitted particles calculated utilizing the stored information of the emitted particles in this code. In this code masses are read from theWapstra's atomic mass table [2] and if the table does not contain mass, rotating liquid drop mass due to Lysekil is substituted. Fission is also considered as a decay mode, while the incomplete fusion is not taken into account. The inputs of this code are charge, mass number of the target and projectile and the bombarding laboratory energy only. This modified version of PACE takes into account the energy dependence of the level density parameter 'a' which can be found in Ref.[3]. The level density parameter a= A/K, where A the mass number of the compound system and K is a free parameter, which may be varied to match the experimental data. The 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 calculated using 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 $\sigma_l = \pi ƛ^2 (2l+1) T_l$, where ƛ 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 α-emissions were determinedusing optical model potentials [6,7]. The input fusion cross-section is calculated using Bassformula [8].The transitions strengths E1,E2,M1, and M2 are taken from ref [9]. The cross sections of the evaporation residue are also depends on the following parameters i) the ratio of level densities of the saddle and at the ground state (ii) the height of the fission barrier which depends on the spin. The main difference between PACE and PACE formulas is in the method ofincorporating the shell corrections to the energy dependent part of the level density. The level density parameter ρ(E,J) used in the calculation above ~5MeV is given by the relation $\rho(E,J) = \rho_0(U)(2J+1)\exp\{2[a(U - E_{rot}(J))]^{\frac{1}{2}}\}$ where U= E-P and P is the pairing energy. $E_{rot}(J)$ is obtained using Ref [10].]; $r_0(U)$ was taken from the Gilbert and Cameron formalism [11]. The Gilbert and Cameron formalism is no longer a default option in themodified version PACE-4.

Calculation Results:

The calculated cross sections for the ^{112}Sn+^{32}S (Table 1) and ^{124}Sn+^{32}S (Table 2) reactions at beam energy of 155 MeV and 150 MeV are reported below in the tabular form:

Table-1: (^{112}Sn+^{32}S@155MeV)

Dominant Nucleus Populated	**Emission channel**	**Cross section in (mb)**
^{140}Gd	**2p2n**	**101**
^{140}Eu	**3pn**	**161**
^{137}Sm	4p3n	90.6
^{140}Sm	4p	33.3
^{139}Sm	4pn	30.6
^{137}Eu	2p2n	22.2

Total Cross Section: 634 mb

Table-2: (124Sn+32S @150 MeV)

Dominant Nucleus Populated	**Emission channel**	**Cross section in (mb)**
^{151}Dy	**5n**	**146**
^{150}Dy	**6n**	**261**
^{147}Gd	α5n	96.6
^{148}Gd	α4n	67.8
^{150}Tb	p5n	38.8
^{151}Tb	p4n	32.4

Total Cross Section: 695mb

From the results of the two table it is evident that in proton channel (^{140}Eu) is the most dominant channel in the first reaction whereas the ^{150}Dy (6n channel) is the most dominant channel in the second reaction where N/Z ratio of the target is high. The choice of the proper target therefore is one of the important aspects of the experimental to study a particular nucleus in details.

Experimentally one of the Gd isotopes (^{141}Gd) was studied by S. M. Mullinset al., [12] in the ^{112}Sn(^{32}S, 2pn) at a beam energy of 155 MeV. Similar nucleus is predicted to be populated with similar energy (see Table 1) and the effect of target nucleus also plays a dominant role in order to study the proton-rich nucleus like Gd. The second reaction was also studied by B. Haas et al [13] in order to study the neutron-rich nucleus ^{148,149,151,152}Dy. Once again the experimental results are similar with the PACE4 prediction (see table 2). Therefore, it may be conclude that choice of the proper target is one of the key aspects to study the proton or neutron rich nucleus.

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