Excitation function studies of proton induced reactions for niobium and pre-equilibrium effect

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Introduction

The effect of Pre-equilibrium (PE) emission followed by Equilibrium (EQ) decay on the excitation function studies in the multi-particle emission process, has been a point of interest for the last several years. The presence of a PE component in any reaction can be observed from the high-energy tail of the excitation function (EF), which can not be reproduced by the statistical model. Many attempts have been made to understand such reactions. Although excitation functions for ^{93}Nb were measured by several groups [1-7], their results differ to a large extent; hence precise and accurate measurements are still needed. With this motivation, the present work was undertaken to measure the excitation functions for ^{93}Nb using proton beam. A theoretical analysis of the data has also been carried out under the prescription of the GDH model of Blann [8].

Experimental

A sample of the element under study was made from SPECPURE niobium foil of thickness 10.5 mg/cm^2. The stack comprising of eight target and degrader foils was irradiated for ≈30 minutes with 12.5 MeV diffused beam of diameter 5 mm and beam current ≈100 nA, at the Variable Energy Cyclotron Centre (VECC) Kolkata. The efficiency and energy calibration of the detector were done using various standard sources of known strengths.

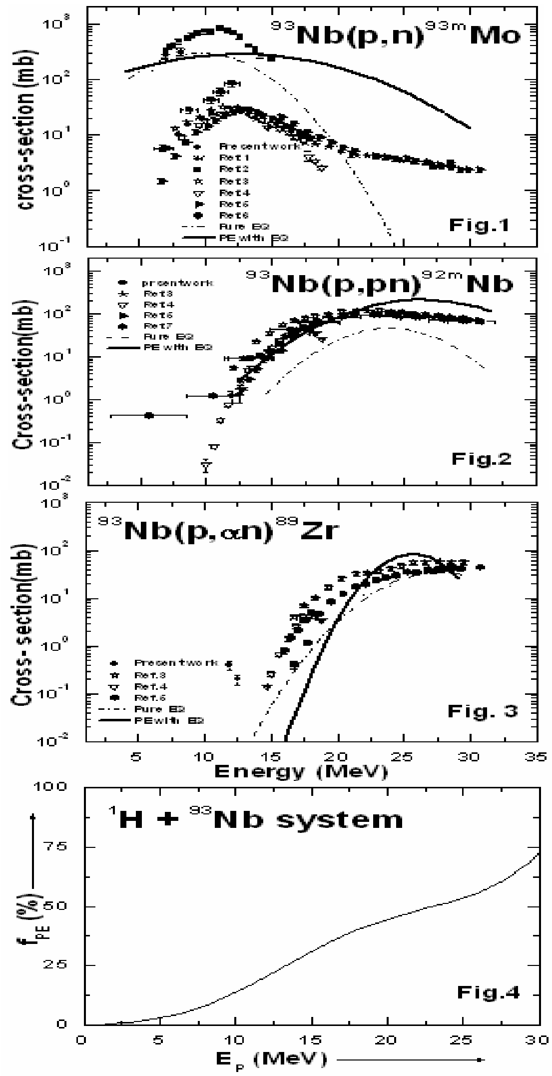
After the irradiation of the stack, the characteristic γ-activities induced in the individual foils were recorded with a high resolution (2 keV for 1332 keV γ-ray of ^{60}Co) HPGe detector (100 cm^3 active volume) coupled to the ORTEC PC based multi-channel analyzer. Evaporation residues were identified using their characteristic γ-rays. The expression used for computing the experimentally measured cross-section has been described in Ref. [9]. The overall errors in the present measurements were estimated to be lying between 5-40% including the statistical errors.

Model Calculations

The excitation functions were evaluated theoretically using the computer code ALICE-91 [10]. This code employs the Weisskopf-Ewing model [11] for statistical component and geometry dependent hybrid (GDH) model of Blann [8] for the PE emission. Since several authors have already discussed the code and the theories involved, we restrict ourselves here by referring only to the review of Blann [12] on PE decay. In this code, the level density parameter constant K may be varied to match the experimental data. In the present calculations, a value of K = 8 has been taken. For the PE calculations the initial exciton number (n_0) was taken to be 3 (1p+1n+1h) as it was derived from the investigation of nucleon spectra [13].

Results and Discussion

The measured excitation functions together with the literature values [1-7] and ALICE-91 [10] calculations are shown in Figs. 1-3. Though our measurements were done up to 12.5 MeV beam energy, comparison of theory with literature values has been made up to 30 MeV, to see the pre-equilibrium effect. The excitation function of the $^{93}Nb\,(p,n)^{93m}Mo$ reaction measured in this work [Fig.1], was found to be in good agreement with the values reported by Levskovskij [3], Avila- Rodriguez et. al [4] and



Ditroi et al. [5]. The data of Albert [1], Chodil [2] and Singh et al. [6] for the nuclear reaction shows considerable discrepancies in the magnitude of cross-sections. A better agreement in the trend of the excitation functions of our measured data, the literature and the theoretical values was found when executing GDH model (solid line) calculations using ALICE-91 code. The theoretical and the experimental data for the ^{93}Nb(p,pn)^{92m}Nb reaction is shown in Fig.2. The best agreement between the experimental data and the theoretical values was found when executing GDH model (solid line) calculations using the ALICE-91 code. Fig.3 shows the excitation function of ^{93}Nb(p.αn)^{89}Zr reaction. Again, the trend of the excitation functions of literature values and theoretical values in the high energy range agree well with the ALICE-91 GDH Model calculations (solid line).

The present analysis indicates clearly the presence of significant pre-equilibrium contribution in proton induced reactions. In a given target nucleus the total PE fraction, for all types of reactions like (p,xnα) reactions, are calculated using the ALICE-91 code. The calculated f_{PE} for ^{93}Nb is shown in Fig.4, as a function of bombarding energy in the energy range 4-30 MeV.

Conclusions

In general, it is evident from Figs.1-3, that PE emission of multi-particles is necessary before the system is equilibrated and hence the experimentally observed high energy tail of the EFs can be explained only when the contribution of semi-classically treated PE emission (GDH Model) followed by particle evaporation from the equilibrated system (Weisskopf Ewing model) is taken into account. The pure compound reaction mechanism in its decay is unable to explain the experimental data. The f_{PE} has also been calculated at different proton energies. It is found that f_{PE} increases with particle energy.

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