Validation of Bohr's independent hypothesis in heavy-ion interactions

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The compound nucleus theory, wherein the formation and decay of compound nucleus is assumed to be independent of each other, was introduced in 1936 as Bohr's independent hypothesis [1]. Accordingly, a nuclear reaction may be considered to proceed in two steps i.e; (i) the formation of quasi stable compound nucleus formed via complete absorption of incident particle with the target nucleus, where energy is shared among all the nucleons of the composite system and (ii) after a sufficient long time the decay of compound nucleus. The validity of Bohr's independent hypothesis was demonstrated in the experiments by Ghoshal [2], where the same compound nucleus (^{64}Zn*) was formed via two different entrance channels by bombarding α-particles of suitable energy on ^{60}Ni and protons on ^{63}Cu. It was concluded that the excitation functions corresponding to the decay of the CN in the same exit channel almost matches with each other. The small discrepancies observed in the two excitation functions for the same decay channel could be attributed due to experimental uncertainties and slight differences in the angular momentum and isospin distributions of the same compound nucleus formed by the two different channels. This provided first direct test for the validity of Bohr's independent hypothesis using beams of protons and α-particles. In case of light ion induced reactions, the input angular momentum involved is relatively small and hence the decay of the compound nucleus is entirely governed by the excitation energy. However, due to relatively higher mass, the heavy ions impart larger angular momentum resulting in the population of the residues in high spin states along with high excitation energy. As such, it may influence the decay probability of the CN formed in HI collision. In the present work, an attempt has been made to verify Bohr's independent hypothesis using heavy ion beams for the systems viz., ^{12}C+^{165}Ho [3] and ^{18}O+^{159}Tb [4]. These two systems form the same compound nucleus (^{177}Ta). The detailed description of measurement of cross sections for both these systems is given in Ref.[3,4].

In the present work, the measured excitation functions (EFs) for ^{174}Ta(3n), ^{173}Ta(4n), ^{172}Ta(5n) and ^{171}Ta(6n) residues populated in ^{12}C+^{165}Ho system have been compared with the predictions of theoretical model code PACE4 [5] as shown in Fig.1(a-b). As can be seen from this figure, the experimental EFs for 5n and 6n channels populated via two different systems ^{12}C+^{165}Ho and ^{18}O+^{159}Tb forming the same CN matches well over the entire range of excitation energy. This may indicate that the Bohr's independent hypothesis, in general, holds good in this case. However, at low excitation energy values (< 50 MeV), the cross sections for residues ^{174}Ta(3n) and ^{173}Ta(4n) populated via two different entrance channels i.e. ^{12}C+^{165}Ho and ^{18}O+^{159}Tb, are not in good agreement with each other. As such, it may be conjectured that the independent hypothesis in the lower excitation energy region may not be valid. This anomaly suggests that the Bohr's independent hypothesis needs to be explored and understood particularly in this region of lower excitation energy. To look into this aspect, the angular momentum distribution for the above two systems forming the same compound nucleus (^{177}Ta) have been obtained. The fusion distribution (σ_ℓ) has been plotted as a function of angular momentum (ℓ) at excitation energies 47 and 52 MeV respectively as shown in Fig.2(a-b). As observed from these figures that at lower excitation energies, the mean input angular momentum values are substantially different, however, as the excitation energy increases, the mean angular momenta for the two systems under study are nearly close to each other.

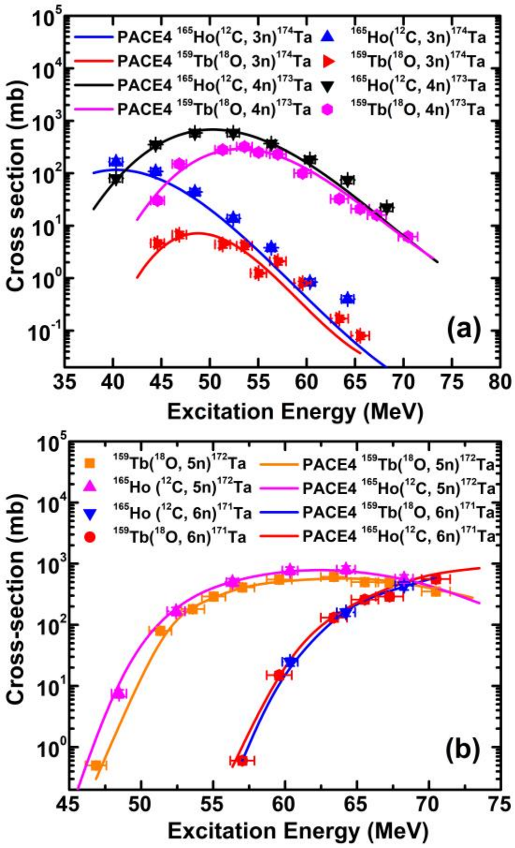

Fig.1. Variation of experimental cross section as a function of excitation energy for (a) ^{174}Ta(3n), ^{173}Ta(4n) (b) ^{172}Ta(5n) and ^{171}Ta(6n) residues populated in ^{12}C+^{165}Ho and ^{18}O+^{159}Tb system.

Therefore, the observed differences in the cross sections for 3n and 4n emitting channels in ^{12}C+^{165}Ho and ^{18}O+^{159}Tb systems may be attributed to the differences in the mean input angular momentum at lower energies. As such, the observed discrepancy may be important in the sense that for the validity of Bohr's independent hypothesis, not only excitation energy but also the angular momenta of the system should also match. However, due to experimental limitations sometimes it is difficult and impossible as well to match both excitation energy and angular momentum simultaneously in the entrance channel. Further details will be presented.

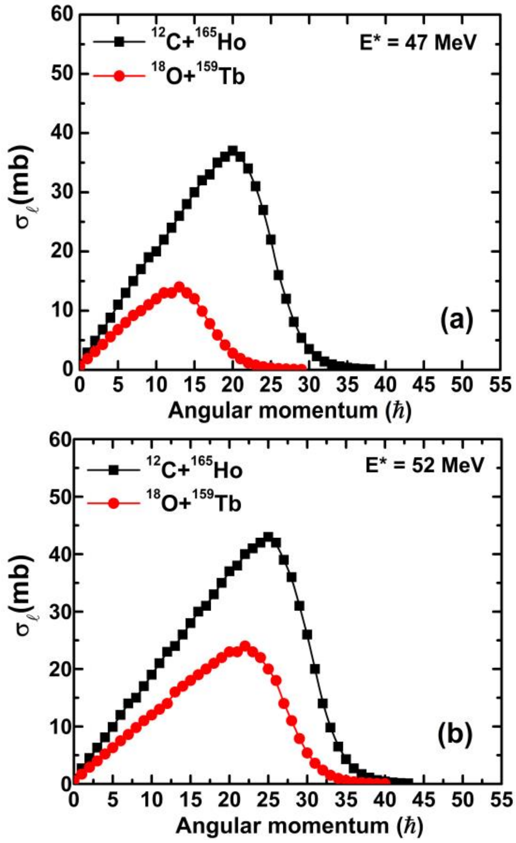

Fig.2. The fusion ℓ distribution (σ_ℓ) as a function of angular momentum for ^{12}C+^{165}Ho and ^{18}O+^{159}Tb systems at excitation energy of (a) 47 MeV and (b) 52 MeV.

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