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Nuclear orbiting and anomalies in nuclear reactions

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Abstract. In this paper,we report our measurements of back-angle oxygen and carbon particle yields from ^{16}O + ^{89}Y, ^{12}C + ^{93}Nb reactions forming the same compound nucleus ^{105}Ag at the same excitation energy and spin distribution. We find anomalously large oxygen yield and entrance channel dependence at high excitation energies from ^{16}O + ^{89}Y reaction implying formation of a dinuclear orbiting complex. Possible connection between nuclear orbiting and fast fission is also discussed.

Keywords. Entrance channel dependence; orbiting.

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1. Introduction

The concept of nuclear orbiting, although an old idea, is continuously being used under different names such as fast fission, dynamical fission, orbiting etc. to give qualitative explanations of different observed anomalies in nuclear reactions over a wide energy region and projectile–target combinations. Any dynamical picture of nuclear fusion must consider the evolution of an orbiting dinuclear complex into an equilibrated compound nucleus. In some situations, the dinuclear complex may only reach thermal equilibration, but never achieve shape equilibration. Such a dinuclear orbiting complex will have a large probability to break into entrance channel and should show strong entrance channel dependence over a large excitation energy region. Earlier works on back-angle study of target-like fragments [1–3] near $A = 40$ compound nucleus showed that ^{28}Si + ^{12}C, ^{24}Mg + ^{16}O etc. have strong entrance channel dependence and entrance channel yields. Studies of fusion–fission cross-sections from compound nuclei near $A = 100$ mass region also showed anomalies which could be interpreted as fast fission. Nagame *et al* [4] studied ^{37}Cl + ^{68}Zn and ^{16}O + ^{89}Y reactions using ^{37}Cl beam at 160 MeV and 177 MeV and ^{16}O beam at 140 MeV. They found that the observed mass, angular and total kinetic energy distributions of the fully energy damped symmetric mass division products are consistent with statistical liquid drop model. However the observed broad widths of mass and total kinetic energy cannot be accounted for within liquid drop model. The observation of broadening of the mass distributions with partial wave ℓ was interpreted as a signature of fast fission process which comes into play when the fission barriers vanish. However it was never clearly established whether the observation of broadening of mass and total kinetic energy distributions really imply a fast fission process where complete fusion does not take place. The objective of the present work is to look for orbiting effect in $A = 100$ mass region and establish a direct relationship between nuclear orbiting seen near $A = 40$ mass region and so called fast fission or dynamical fission effects reported near $A = 100$ mass region. An understanding of such relationship should give us new insight about the fundamental physics behind nuclear orbiting.

2. Experimental method and results

We form the same compound nucleus ^{105}Ag at the same excitation energy ($E_X = 76$ MeV) and with very similar spin distributions using two different reaction channels ^{16}O + ^{89}Y reaction at $E(^{16}\text{O}) = 95.9$ MeV and ^{12}C + ^{93}Nb reaction at $E(^{12}\text{C}) = 85.6$ MeV. The experiments were performed at BARC-TIFR Pelletron machine in Mumbai and Nuclear Science Center Pelletron machine in New Delhi. A 10 pna ^{16}O beam from BARC-TIFR Pelletron machine was used to bombard a 1 mg/cm^2 thick ^{89}Y foil. Four $\Delta E - E$ telescopes were placed between 140° to 170° to detect different fragments from alpha to oxygen. Similarly a 10 pna ^{12}C beam having 85.6 MeV energy was used to bombard a 1 mg/cm^2 thick ^{93}Nb foil and $\Delta E - E$ telescopes were placed at back-angles to detect different fragments. In this report, we shall discuss about oxygen and carbon particles emitted at back-angles. The data analysis for other fragments is still going on. The back-angle yields of oxygen and carbon particles were found to follow a 1/sin(θ) angular distribution in the centre of mass frame. The entrance channel dependence was studied from the ratio of back-angle oxygen to carbon yields as a function of exit channel energies for both ^{16}O + ^{89}Y and ^{12}C + ^{93}Nb reactions and a strong entrance channel dependence was seen in the strongly damped region. In figure 1, we plot the ratio of oxygen to carbon yields integrated over few MeV bins as a function of excitation energy for both ^{16}O + ^{89}Y and ^{12}C + ^{93}Nb reactions. We find that the two data sets overlap at low excitation energies, but differ greatly at high excitation energy. This result is very similar to what was found earlier for ^{28}Si + ^{12}C and ^{24}Mg + ^{16}O reactions. A comparison with ^{28}Si + ^{12}C and ^{24}Mg + ^{16}O reactions reveals that for the lighter systems the entrance channel dependence is dominant in the lower excitation energy region whereas for heavier system the entrance channel dependence is dominant in higher excitation energy region. We also find from figure 1 that the ratios of oxygen to carbon yields in different excitation energy bins for ^{12}C + ^{93}Nb system agree very well with compound nucleus CASCADE code predictions. Absolute yields of oxygen and carbon for ^{12}C + ^{93}Nb reaction also agree reasonably well with statistical model predictions. So we find that only the oxygen and carbon yields from ^{16}O + ^{89}Y reaction are anomalous and point to the formation of a long-lived dinuclear orbiting complex which is responsible for such large oxygen yield and entrance channel dependence.

3. Discussion

This work establishes very clearly the similarity between nuclear orbiting seen in certain lighter systems ($A = 40$ mass region) and fast fission seen near $A = 100$ mass region.

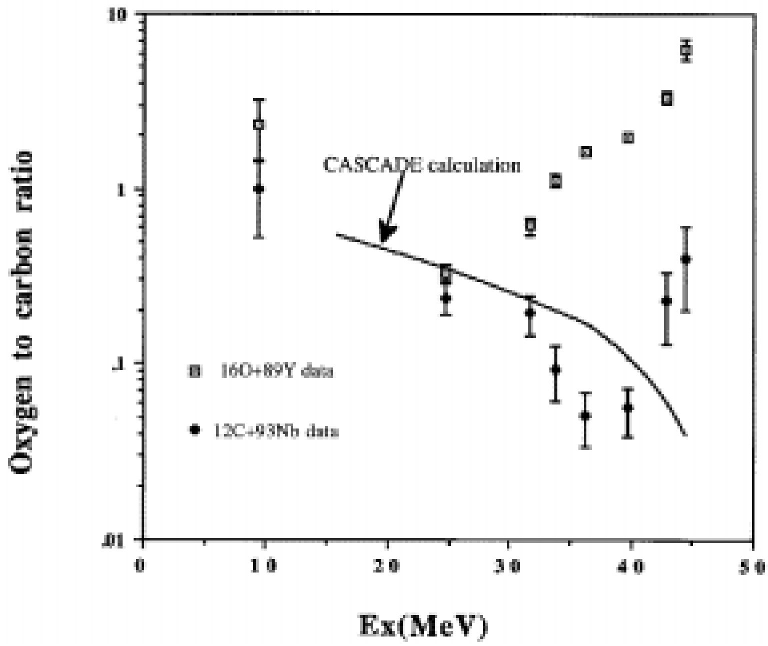

Figure 1. Ratio of oxygen to carbon yields versus excitation energy.

We also find that ^{12}C + ^{93}Nb system does not show any anomalous behaviour, but ^{16}O + ^{89}Y system shows orbiting type characteristics. So clearly all systems near $A = 100$ mass region do not show orbiting or fast fission type behaviour. It is very interesting to try to understand the fundamental reasons behind such dinuclear orbiting type behaviour and why this effect is seen selectively in certain systems only. Beck *et al* [5] proposed an explanation in terms of the number of open channels. Although Beck's explanations in terms of number of open channels seem to be adequate for systems around $A = 40$ mass region, it clearly cannot explain our observation of orbiting effect in ^{16}O + ^{89}Y system and the absence of such effect for ^{12}C + ^{93}Nb system. The numbers of open channels for both the systems are very large and much greater than those for $A = 40$ systems. So following Beck's arguments, the orbiting effect should not take place in such heavy mass regions. The number of open channels argument also cannot explain our earlier observations [6] regarding the lack of any orbiting effect for ^{4}He + ^{27}Al and ^{4}He + ^{40}Ca reactions.

We have not yet fully understood these effects and are now looking for an explanation in terms of nuclear structure physics.

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