ORBITING: TOWARD A UNIFIED MODEL OF NUCLEUS-NUCLEUS COLLISION OR EXCITATION OF NUCLEAR MOLECULAR STATES IN HEAVY ION COLLISIONS?

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It has been suggested¹ that damped reaction products at backward angles from the $^{28}\text{Si}+^{12}\text{C}$ and $^{20}\text{Ne}+^{12}\text{C}$ reactions result from the formation of long-lived orbiting complexes. This suggestion was originally made on the basis of the observation that the total integrated binary yields are much larger than the predictions of compound nucleus calculations although they follow a $1/\sin\theta_{c.m.}$ angular distribution near 180° . Subsequent studies have confirmed the noncompound origin of these yields through a comparison of the back-angle yields for the $^{28}\text{Si}+^{12}\text{C}$ system with the $^{24}\text{Mg}+^{16}\text{O}$ system. However, it has been found that the orbiting process and the associated entrance channel dependence, are not universal. For example comparison of the $^{35}\text{Cl}+^{12}\text{C}$ and the $^{31}\text{P}+^{16}\text{O}$ systems show small back-angle binary yields and lack of any significant entrance channel dependence. Thus, it appears that the orbiting process dominates the back-angle yields for systems that have a small number of open channels. This is similar to the systematic behavior that was observed for the anomalous elastic scattering at backward angles. The observation² of selective population of natural parity states in the $^{24}\text{Mg}+^{12}\text{C}$ orbiting reaction supports a dinuclear reaction mechanism, because in the compound nucleus reaction both natural and unnatural transitions are allowed.

Recently, a complete γ -ray angular correlation study was performed with the $^{28}\text{Si}+^{12}\text{C}$ system at $E_{c.m.}=43.5$ MeV and 48 MeV, using the ORNL Spin Spectrometer. In Fig. 1 we show the measured spin alignment, P_{zz} , for the first 2^+ state in C and Si as a function of scattering angle(c.m.). Both the sticking model prediction of $P_{zz}=1$ and compound nucleus prediction of P_{zz} (shown on Fig. 1 by solid lines) are in disagreement with the observed poor spin alignment. A complete study of the density matrices for these states reveals that the spin angular momentum vector of each fragment lies approximately in a plane perpendicular to the direction of motion of the fragment. The dashed curve in Fig. 1 shows the calculated alignment, P_{zz} , as a function of scattering angle, assuming that the spin vector of each fragment lies in a plane normal to the body-fixed symmetry axis of the dinuclear system. The observation of the spin vector lying in a plane perpendicular to the dinuclear axis implies that the rotating dinuclear system undergoes spin dealignment via bending and wriggling motions, but not much by twisting motion with respect to the dinuclear symmetry axis.

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Fig.1 The spin alignment parameter of 1.78 MeV γ rays for $-10 < Q < 0$ MeV and of 4.44 MeV γ rays for $-22 < Q < -10$ MeV at $E_{c.m.} = 43.5$ MeV. The solid curves and dashed lines are statistical and dinuclear orbiting model calculations as explained in the text.

Orbiting yield clearly originates from a long-lived noncompound process and appears to dominate in certain systems having a small number of open channels. An equilibrium orbiting model³ based on a nonresonant nucleon exchange picture was proposed earlier. Although this model is able to explain the large orbiting yield of the $^{28}\text{Si}+^{12}\text{C}$ system, it fails to explain the observed entrance channel dependence, poor spin alignment, and lack of orbiting yield in many other systems.

So what is orbiting? Is orbiting a nonresonant particle exchange process like deep inelastic collisions and should it therefore be understood in terms of a suitably modified particle exchange model which could explain all the observed features, in particular the selectivity of the process, or, should orbiting be classified as a resonant process? Future experiments should be planned toward answering this question. ORNL is managed by Martin Marietta Energy Systems Inc. under contract number DE-AC05-84OR21400 with the US Department of Energy.

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