Evidence of Critical Behavior in the Disassembly of Nuclei with $A \sim 36$


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Most efforts to determine the critical point for the expected liquid gas-phase transition in finite nucleonic matter have focused on examinations of the temperature and excitation energy region where maximal fluctuations in the disassembly of highly excited nuclei are observed. Data from the EOS and ISIS collaborations have been employed to construct a co-existence curve for nucleonic matter [1]. Those analyses have proceeded under the assumption that the point of apparent critical behavior was the true critical point of the system. However, some recent theoretical treatments suggest that apparent critical behavior may be encountered well away from the actual critical point [2] that excited lighter nuclei provide the most favorable venue for investigation of the critical point in finite nuclei. In this work we report results of an extensive investigation of nuclear disassembly in nuclei of $A \sim 36$, excited to excitation energies as high as 9 MeV/nucleon.

Using the TAMU NIMROD detector and beams from the TAMU K500 super-conducting cyclotron, we have probed the properties of excited projectile-like fragments produced in the reactions of $^{40}\text{Ar} + ^{27}\text{Al}$, $^{48}\text{Ti}$ and $^{58}\text{Ni}$ at 47 MeV/nucleon. Earlier work on the reaction mechanisms of near symmetric collisions of nuclei in the $20<A<64$ mass region at energies near the Fermi energy have demonstrated the essential binary nature of the collisions, even at relatively small impact parameters [3]. As a result, these collisions prove to be very useful in preparing highly excited light nuclei with kinematic properties which greatly simplify the detection and identification of the products of their subsequent de-excitation.

A wide variety of observables indicate that maximal fluctuations in the disassembly of hot nuclei with $A \sim 36$ occur at an excitation energy of $5.6 \pm 0.5$ MeV and temperature of $8.3 \pm 0.5$ MeV.

Associated with this point of maximal fluctuations are a number of quantitative indicators of apparent critical behavior. First, the charge distribution shows a minimum power-law parameter $\sim 2.2$ which is consistent with the critical behavior predicted by Fisher’s Droplet Model. Second, a number of indicators show the largest fluctuation, for instance, a Campi scatter plot shows that equal branches for the liquid and gas phases, the charge distribution of the largest fragment ($Z_{\text{max}}$) and the total kinetic energy show the maximum fluctuations, the behavior of the $\Delta$-scaling of $Z_{\text{max}}$ [4] shows a change from $\Delta=1/2$ to
∆=1 scaling around the critical point (see Fig.1). Third, the fragment topological structure also indicates critical behavior, for instance, the Zipf law, which describes the mean sizes of the rank-ordered fragments as a function of the rank, is satisfied in the critical point [5] (see Fig.2), the charge correlation between the heaviest fragment and the second heaviest fragment also display behavior change around the critical point. Moreover, analysis of bimodality and critical exponent are consistent with the phase change at that point. The associated caloric curve does not appear to show a plateau such as that seen for heavier systems (see Fig.3). This may indicate that, in contrast to quasi-plateauing of caloric curves in heavier nuclei, the observed behavior in these very light nuclei may well be associated with a phase change in an equilibrated system at, or extremely close to, the critical point.

References