Investigation of the de-excitation mechanism in Fermi energy heavy ion collisions

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Heavy ion collisions (peripheral and mid-peripheral) in the Fermi energy domain lead to the formation of an excited projectile like source or quasiprojectile. Decay of the excited nuclear system is primarily governed by its excitation energy. A systematic investigation of this aspect requires information about the excitation energy of the decaying system. Reconstruction of a well defined quasiprojectile source provides the opportunity to carry out such a study.

In the present work, fragment yield data from the decay of quasiprojectiles in the reaction $^{78}Kr+^{58}Ni$ at E_{lab}=35 MeV/nucleon have been analyzed to investigate the dependence of the decay mechanism on excitation energy, which, in turn, provids information about the onset of multi-fragmentation. The study involved the analysis of the data of 'biggest fragment in the event', fragment multiplicity and determination of nuclear caloric curves. Nuclear caloric curves were determined using the momentum fluctuation method [1] and the double isotope ratio method [2].

The quasiprojectile source was reconstructed with the condition that sum of the Z of all detected fragments was in the range of 30-34. A quadrupole cut was applied to reject the events dominated by non-equilibrium emission. The excitation energy of the quasiprojectile was determined by a calorimetric method [3]. The
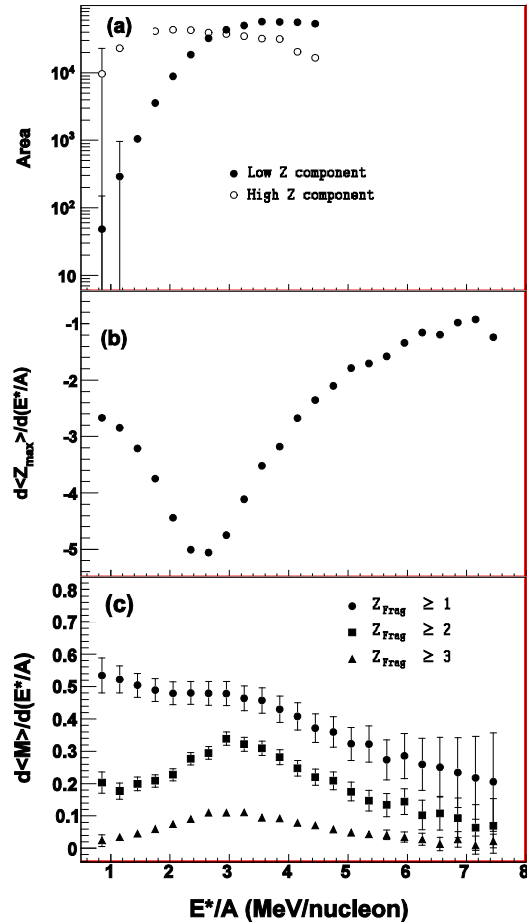

FIG. 1. (a) Plot of the contribution from high Z (evaporation) and low Z (fission / multi-fragmentation) components obtained by Gaussian fit to the Z_{max} distribution. (b) Derivative of $<Z_{max}>$ vs $E*/A$ plot (a) Derivative of average multiplicity $<M>$ vs $E*/A$ plot.

average excitation energy of the quasiprojectile was about 5 MeV/nucleon. For the present study, the total excitation energy range was divided into bins of 0.3 MeV. An examination of the charge of the biggest fragment in the event Z_{max} showed that it can be used to distinguish between the evaporation and multi-fragmentation events. It was observed that, in the low excitation energy region, there was also a contribution from fission type of events in addition to evaporation. The Z_{max} distribution showed two components, namely, evaporation (high Z component) and fission/multi-fragmentation (low Z component). Contributions from the two components, obtained from Gaussian fit, are shown as a function of excitation energy in Fig. 1(a). A crossover region around $E^*/A = 3$ MeV/nucleon can be seen in this figure, beyond which multi-fragmentation events take over. It was not possible to distinguish between the two components above excitation energy of about 4.5 MeV/nucleon. In the same energy range, a minimum in derivative of $<Z_{max}>$ plot (1(b)) can be seen, indicating the onset of multi-fragmentation. This is further confirmed by the maxima in the derivative of multiplicity plot of fragments with $Z \geq 3$ (1(c)).

In the theoretical calculations by Gross [4], the onset of multi-fragmentation was proposed to be the region of a first order phase transition. The calculations showed a plateau for the source A around 130, though no plateau was observed for A~90. Calculations by Bondorf et al. [5] showed a plateau in the caloric curve for A~100 with change in de-excitation mechanism from evaporation to multi-fragmentation. In order to investigate this aspect, caloric curves were determined by the momentum fluctuation method [1] and the double isotope ratio method [2]. Caloric curves determined by the momentum fluctuation method [1] for ^{1}H, ^{2}H, ^{3}H, ^{3}He, ^{4}He, ^{6}Li, ^{7}Li, ^{7}Be and ^{9}Be are shown in Fig. 2. A plateau in the caloric curve around the onset of multi-fragmentation can be seen for various isotopes except for proton. The temperature values are on the higher side on absolute scale, which may be due to a number of reasons, namely, Coulomb effect, Fermi momentum and classical treatment of momentum
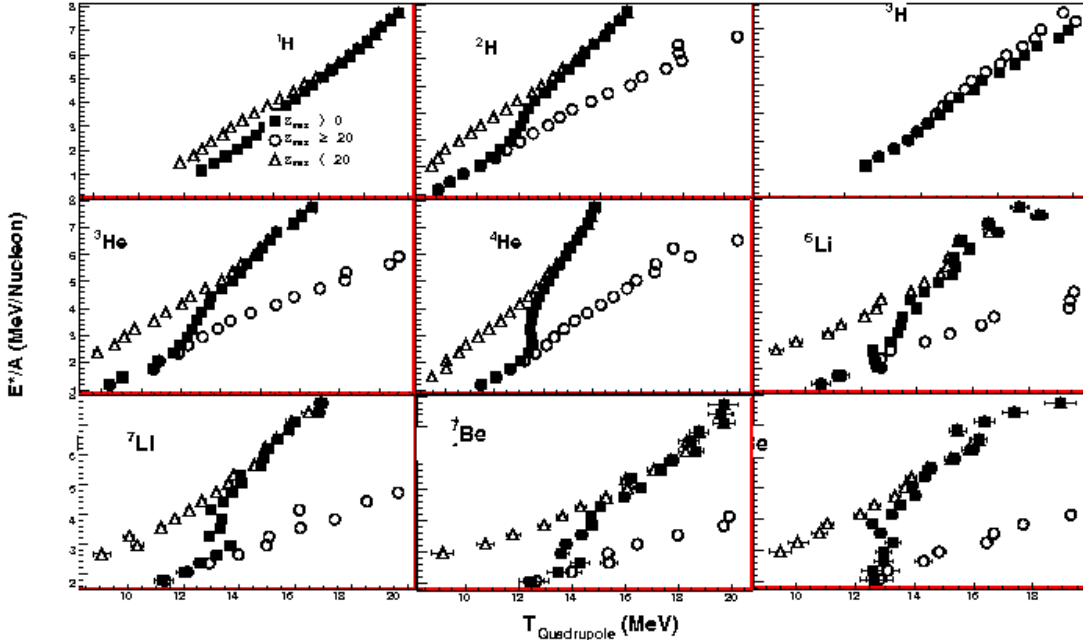

FIG. 2. Plot of nuclear caloric curve obtained by momentum fluctuation method [1].

distribution [6]. The different branches for evaporation and multi-fragmentation can be distinguished by selecting the data with $Z_{max} \geq 20$ and $Z_{max} < 20$. A similar behavior can be seen in the caloric curves obtained from the double isotope ratio method (HeDT and HeLi thermometers), though less pronounced.

Thus, the present study shows various signatures of onset of multi-fragmentation. Observation of the plateau in the caloric curve is consistent with the onset of multi-fragmentation.
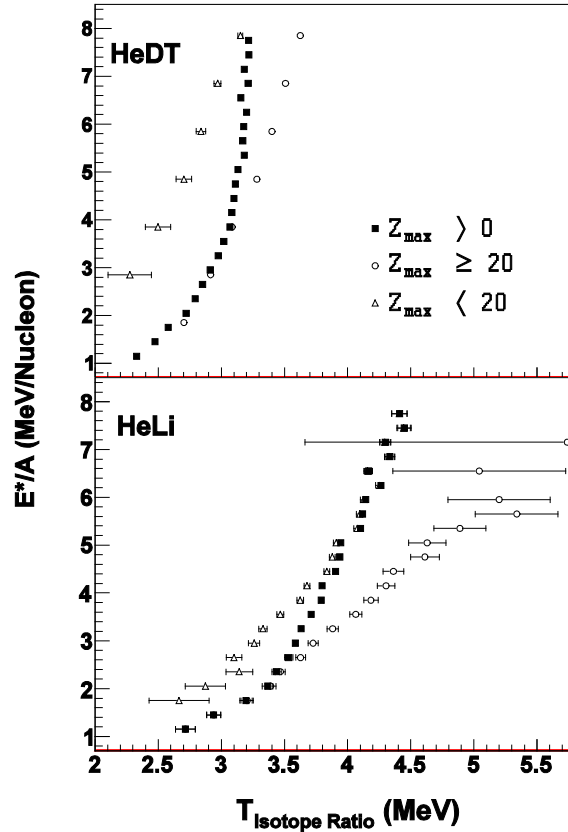

FIG. 3. Plot of nuclear caloric curve obtained by double isotope ratio method [2].

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