Temperature measurements in reactions at low excitation energies to probe a possiblephase transition

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Exploration of the nuclear phase diagram provides for a way to explain the fundamental properties of nuclear matter. Searching for a possible liquid---gas phase transition requires a way to probe the temperature. Several thermometers have been developed to measure the temperature of nuclear systems. The quadrupole momentum fluctuation thermometer [1] calculates the temperature using a classical approach. The recently developed quantum thermometer [2] uses a quantum treatment of the quadrupole momentum fluctuation thermometer to derive the temperature, which allows for Fermi motion. This thermometer can be used with fermions such as neutrons, protons, and tritons. When the temperature is calculated using the quadrupole momentum fluctuation thermometer for various energy densities, the energy density is shown to decrease with decreasing temperature from higher temperature to around 3 MeV. The temperature then curves back as the energy density decreases, indicating a possible signature of a phase transition. This phase transition is shown in the Constrained Molecular Dynamics (CoMD) simulation [2] and hinted at by experimental data [3] shown in Fig. 1.

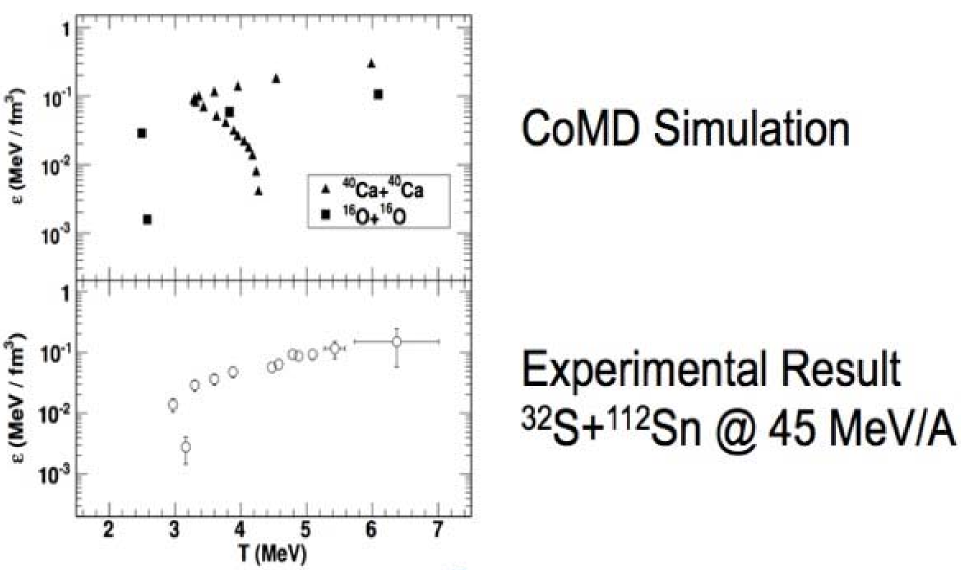

FIG. 1. Energy Density vs Temperature for CoMD Simulation of ^{40}Ca + ^{40}Ca and ^{16}O + ^{16}O at energies of 4 MeV/A to 100 MeV/A and impact parameter of 1 fm to a time of 1000 fm/c [4] and experimental data of ^{32}S + ^{112}Sn at 45 MeV/A [3]

A CoMD simulation of ^{64}Ni + ^{27}Al at 25 MeV/nucleon to 3000 fm/c was performed in order to observe what fragments are produced in the region near this phase transition. Determining what fragments are prevalent at these temperatures, and what properties they have, can help to provide a possible way to measure them in an experimental setup in order to probe the phase transition further using experimental data. Properties such as size, energy, and angle of detection can help to determine what experimental setup could be used to best detect these fragments. A more complete detection of the fragments should lead to a better analysis and better understanding of the region at the phase transition. The phase transition is present at a relatively low temperature, which corresponds to low excitation energy. Shown in Fig. 2 are the products from the simulation that show how the excitation energy corresponds to other useful properties.

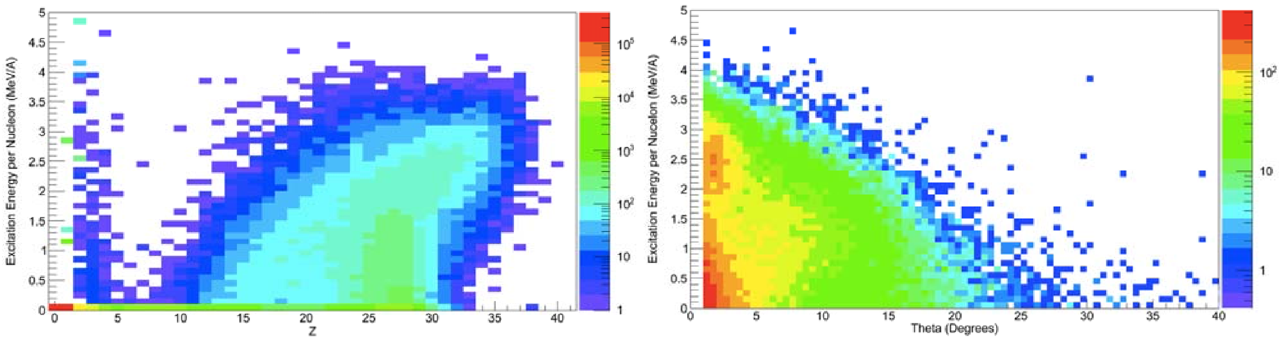

FIG. 2. Fragments from a CoMD simulation of ^{64}Ni + ^{27}Al at 25 MeV/A plotted as (left) excitation energy per nucleon vs the charge of the fragment and (right) excitation energy per nucleon vs the angle of the fragment relative to the beam axis.

In the plot on the left in Fig. 2, it is shown that the CoMD simulation produces fragments with low excitation energy mostly at high charge, close to the charge of the projectile. It should be noted that a majority of the fragments produced in this reaction are either very light, such as neutrons and protons, or large projectile---like residues. Light fragments with high excitation energy should also be produced in the reaction, but are absent in this plot due to a lack of yield. The plot to the right shows that low excitation energy fragments also occur at a very low theta angle relative to the beam axis. From these two figures, it can be seen that in the region of interest, the low excitation energy region, fragments with a large size and fragments close in angle to the beam axis are very prevalent and are of great interest for pursuit of information at low temperatures.

Determining the properties of the fragments that occur in the area near the phase transition will help to further the study of this area. Knowing the size and detection angle of the fragments of interest also provides information that can be used for experiments in the future in order to probe this interesting phase transition. Being able to explore this phase transition further by extracting temperatures from experimental data will allow for the study of the fundamental properties of nuclear matter.

[1] S. Wuenschel *et. al.*, Nucl. Phys. **A843**, 1 (2010).

[2] H. Zheng and A. Bonasera, Phys. Lett. B **696**, 178 (2011).

[3] B. Stein, arXiv:1111.2965

[4] H. Zheng and A. Bonasera, arXiv:1112.4098v1 [nucl---th] (2011)