Chemical potential and symmetry energy for intermediate mass fragment production in heavy ion reactions near Fermi energy

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Ratios of differential chemical potential values relative to the temperature, $\Delta\mu/T=(\mu_n-\mu_p)/T$, extracted from isotope yields of thirteen reaction systems at 40 MeV/nucleon are compared to those of a quantum statistical model to determine the temperature and symmetry energy values of the fragmenting system.

In a series of our recent works [1-4], the isotopic yield ratio method has been applied to extract the density, temperature, and symmetry energy of the fragmenting source. In the present study, the experimentally extracted $\Delta\mu/T$ values are compared with the Quantum statistical model [5] to determine the temperature and symmetry energy of the fragmenting system. The experimental $\Delta\mu/T$ values are extracted based on the Modified Fisher Model.

The experiment was performed at the K-500 superconducting cyclotron facility at Texas A&M University. The system studies are ^{64,70}Zn and ^{64}Ni beams were used to irradiate ^{58,64}Ni, ^{112,124}Sn, ^{197}Au, and ^{232}Th targets at 40 MeV/nucleon. 13 reaction systems were analyzed for the present work.

The experimentally observed $\Delta\mu/T$ values are shown in Fig.1 as a function of the Z/A value of the nucleon-nucleon system, which are evaluated from the moving source fit of all ejected particles, including neutrons. When fragments are emitted from the source, many of them are in excited states and cool by evaporation processes before they are detected. The sequential decay of these primary hot

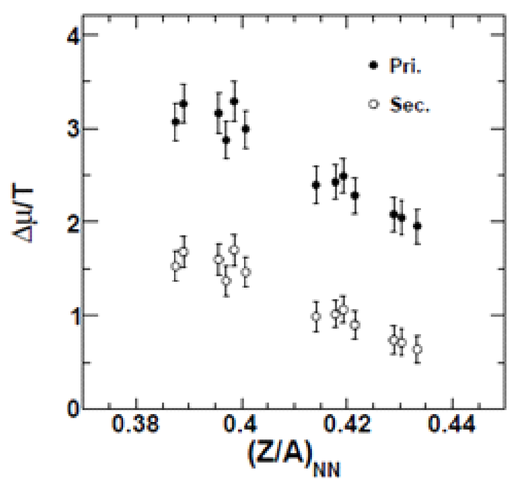

FIG. 1. Open circles: the $\Delta\mu/T$ values from the experimentally observed IMF yields from all 13 systems as a function of $(Z/A)_{NN}$. Full circles: the "primary" $\Delta\mu/T$ values with the sequential decay correction.

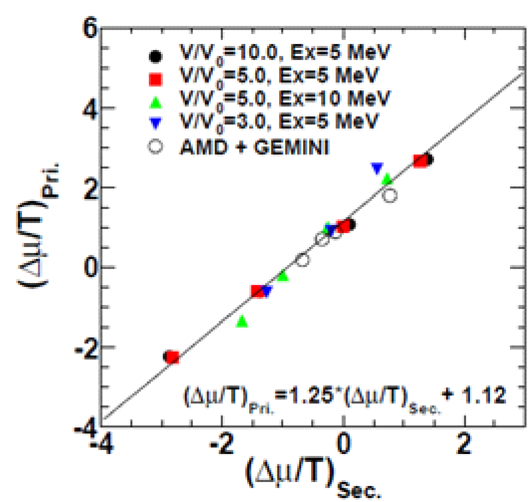

FIG. 2.. Calculated primary $\Delta\mu/T$ vs secondary $\Delta\mu/T$. The results from the SMM calculations are shown by solid symbols and those from the AMD-GEMINI are shown by open circles.

fragments significantly alters the yield distribution and distorts the information in the primary yields. Here the statistical multifragmentation model (SMM) is employed to evaluate the effect. The evaluated primary Δμ/T and the secondary Δμ/T ratios are shown in Fig.2. For some of the systems, the values are calculated and plotted for AMD + Gemini calculations. The calculated ratio between $(\Delta\mu/T)_{pri}$ and $(\Delta\mu/T)_{sec}$ are well fit by a linear function as

$$(\Delta\mu/T)_{Pri.} = 1.25 \cdot (\Delta\mu/T)_{Sec.} + 1.12,$$

Using this relation, the primary Δμ/T values are calculated from the experimentally extracted values (secondary) and shown in Fig.3. These results are compared with the QSM calculations [5].

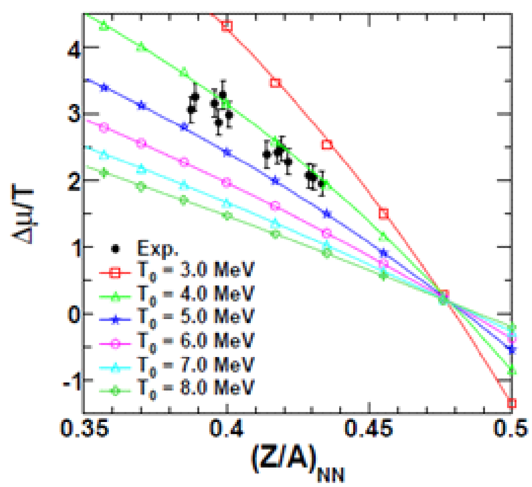

FIG. 3. The comparison between the Δμ/T values from the calculations with different temperature inputs from 3 - 8 MeV and the experimentally extracted primary ones. The curves are the results of polynomial fits to the calculated values for each given T value.

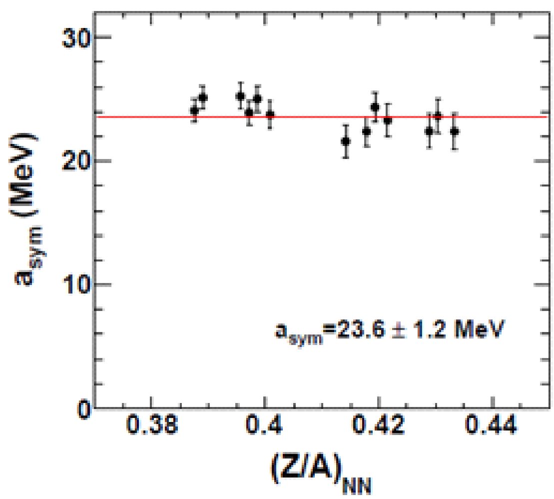

FIG. 4. The resultant symmetry coefficient values as a function of $(Z/A)_{NN}$. The line is the constant fit of the data points.

Within QSM, one cannot determine the density and temperature values uniquely from the experimental isotope yield ratios. In the present analysis, therefore, the source density of $\rho/\rho_0 = 0.65$ is used, which has been determined from the experimentally reconstructed primary hot isotope yields in the reaction system $^{64}Zn+^{112}Sn$ in our previous studies [2,3]. The calculated results for different temperatures are shown together with the experimental ones in Fig.3. From these comparisons, T=4.3±0.4 MeV is extracted.

The differential chemical potential, Δμ, can be given as

$$\Delta\mu = 2 \cdot \frac{\partial(E_{total}/A)}{\partial\delta}.$$

When we approximate the total energy by a semi-classical mass formula, one can get

$$\Delta\mu = 4\delta a_{sym}(T,\rho) - a_c(\rho)A^{2/3}(1-\delta).$$

From the experiments, $\Delta\mu$ can be calculated as $\Delta\mu/T = T\bullet(\Delta\mu/T)$ from the primary $\Delta\mu/T$ values in Fig.3 and the NN- source temperature obtained above. Therefore a_{sym} coefficient in the above formula can be rewritten as

$$a_{sym} = \frac{\Delta\mu + a_c(\rho)\cdot(\rho/\rho_0)^{1/3}A^{2/3}(1-\delta)}{4\delta}.$$

$a_c(\rho) = a_c(\rho_0) \bullet (\rho/\rho_0)^{1/3}$, where $a_c(\rho_0)$ = 0:67 MeV is the Coulomb coefficient at the saturation density. The resultant a_{sym} values are shown in Fig.4 as a function of (Z/A) of the NN source. From this figure a_{sym}= 23.6 ± 1.2 MeV is obtained.

The extracted T=4.3±0.4MeV and a_{sym}= 23.6 ± 1.2 MeV values are consistent to those of the previous work [3] where T=5.0±0.4MeV and a_{sym}= 23.1 ± 0.6 MeV are extracted together with ρ/ρ_0 = 0.65, using a self-consistent method from the experimental single reaction system of $^{64}Zn+^{112}Sn$ at 40 A MeV.

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