Highlighting critical phenomena using nuclear fragment yield ratios

R. Tripathi, A. Bonasera, S. Wuenschel, L. W. May, Z. Kohley, G. A. Souliotis, S. Galanopoulos, K. Hagel, D. V. Shetty, K. Huseman, S. N. Soisson, B. C. Stein, and S. J. Yennello

Investigation of the nuclear phase transition is currently one of the important research objectives of heavy-ion collisions in the Fermi energy domain. Recently, Bonasera *et al.* [1,2] used fragment yield data from different reactions to investigate nuclear phase transition using the Landau free energy approach [3,4], which is applicable to the systems in the vicinity of the critical point. In this approach, the free energy per nucleon F of a fragment is related to an order parameter m, where $m = (N-Z)/A$, N, Z and A are the neutron, proton and mass numbers of the fragment respectively. The quantity m can be defined as an order parameter if $m = -\partial F/\partial H$, where H is its conjugate variable [3,4], which acts as an external field. Ignoring the higher order terms in the external field, dependence of fragment yield ratio on the isospin asymmetry of the source (m_s) and that of fragment (m) can be expressed by the following equation

$$\frac{1}{A}\ln\left(\frac{Y_2}{Y_1}\right) = a\left(m_{S2}m_2 - m_{S1}m_1\right) \qquad (1)$$

Using Eq. (1), fragment yields can be used to test the applicability of Landau approach to nuclear phase transition. In the present work, the yield ratios of mirror nuclei pairs for A=3 (^{3}H, ^{3}He) and A=7 (^{7}Li, ^{7}Be) formed in the fragmentation of the quasiprojectiles in the reactions ^{78,86}Kr+^{58,64}Ni at beam energy of 35MeV/nucleon have been analyzed.

The experiments were performed at the Texas A&M University K500 superconducting cyclotron. The details of the experiment can be found in [5,6]. With the four reaction systems, the yield ratios of mirror nuclei were determined over a wide range of m_s from -0.03 to 0.21. The m_s values were calculated after correcting for free neutrons emitted by the quasiprojectile [5,6].

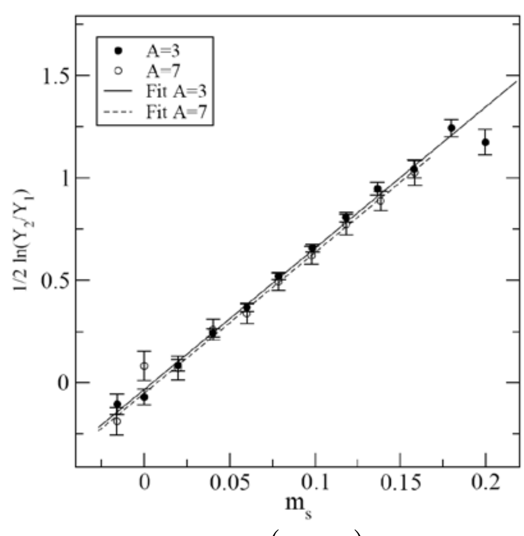

FIG. 1. Plot of '$0.5\ln(Y_2/Y_1)$', averaged over different reaction systems for A=3 and 7 as a function of m_s. Solid and dashed lines are linear fit to the data for A=3 and 7 respectively.

For yield ratios of mirror nuclei arising from a source with given m_s value, Eq. 1 reduces to '$0.5\ln(Y_2/Y_1)=am_s$'. Mirror nuclei yield ratios averaged over different reaction systems along with the fitted lines for A=3 and 7 are shown in Fig. 1. The slope values for A=3 and 7 were 6.90±0.17 and 6.87±0.31 respectively. The observed linearity in Fig. 1

indicates that the condition $m=-\partial F/\partial H$ is fulfilled and m is an order parameter [3,4].

In the literature [1,2], a physical interpretation of the slope parameter 'a' can be obtained from the equivalence of the quantity F/T with the symmetry energy per nucleon normalized with respect to the temperature of the source. In order to investigate the evolution of nuclear symmetry energy with the excitation energy of the source, slope parameter a was deduced from the mirror nuclei yield ratio data gated with excitation energy. It can be seen from Fig. 2 that slope parameter a decreases with increasing excitation energy, indicating a decrease in nuclear symmetry energy. This observation is similar to that in conventional isoscaling studies.

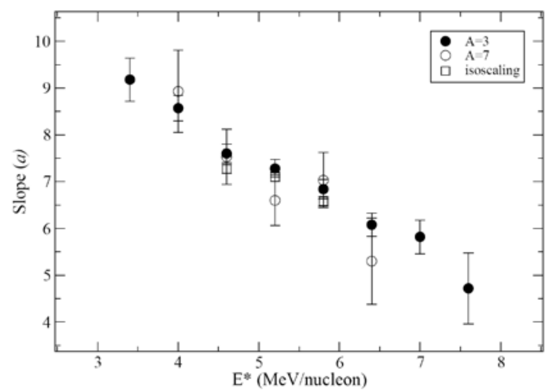

FIG. 2. Slope (a) values, obtained by fitting the plots of mirror nuclei yield ratios for A=3 (filled circle) and A=7 (open circle), as a function of excitation energy of the quasi projectile. Squares were obtained by fitting the isoscaling plots, similar to that in FIG. 3 with a gate on excitation energy.

The comparison of the Landau approach with the conventional isoscaling was further extended by taking the ratio of yields of the same fragments arising from two sources with different m_s values as done in isoscaling. For this case, Eq. 1 reduces to '$(1/A)\ln(Y_{ms2}/Y_{ms1})=am(m_{s2}-m_{s1})$'. where Y_{ms2} and Y_{ms1} are, respectively, the yields of a given fragment with mass A from fragmenting sources with isospin asymmetry values m_{s1} and m_{s2}. A reasonably good linearity in Fig. 3, further suggests that m is an order parameter and H is its conjugate field. The slope of this plot gives the value of the parameter a as 6.82±0.10, close to that obtained from the mirror nuclei yield ratio data. Moreover, the slope values were also determined from the isoscaling plots for E^*/A=4.6, 5.2 and 5.8 MeV/nucleon. This excitation energy range was chosen due to the larger statistics of the data. The slope values obtained from the isoscaling plots at different excitation energies (open

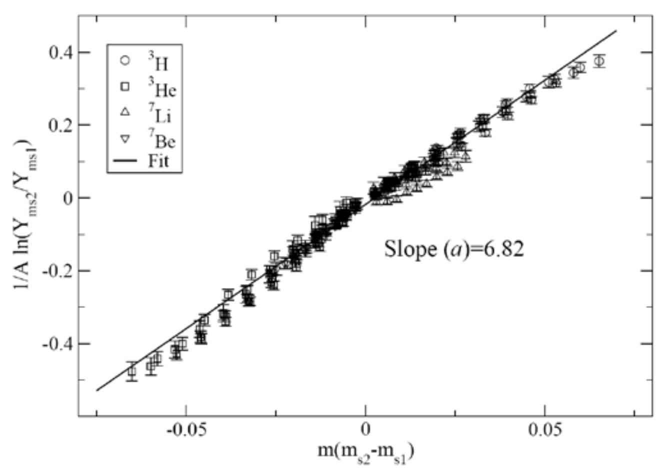

FIG. 3. Plot of '$1/A\ln\left(Y_{ms2}/Y_{ms1}\right)$' as a function of $m(m_{s2}-m_{s1})$. Y_{ms1} and Y_{ms2} are, respectively, the yields of a fragment from sources with isospin asymmetry of m_{s1} and m_{s2}. m is the isospin asymmetry of the fragment.

squares in Fig. 2) were in reasonable agreement with those obtained from the analysis of the data of mirror nuclei yield ratios.

Thus, the mirror nuclei yield ratios and isoscaling gave consistent results within the framework of Landau free energy approach for critical phenomena. The successful application of Landau approach, justifies the isospin asymmetry (*m*) as an order parameter for nuclear phase transition.

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