Investigation of the role of quasiprojectile isospin in nuclear fragmentation

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In recent studies [1-3], fragment yield data form heavy ion collisions in Fermi energy domain have been have been analyzed using the Landau free energy approach, which is applicable to the systems in the vicinity of a critical point [4,5]. This approach was extended to interpret the mirror nuclei yield ratios in the fragmentation of quasiprojectile [6]. In the Landau free energy approach, the isospin asymmetry of a fragmenting source, arising from the difference between the neutron and proton chemical potentials, acts as an external field which can modify the fragment yields. A similar dependence of fragment yields on the isospin asymmetry of the quasiprojectile can also be realized in grand-canonical calculations [7]. In the present study, fragment yield data from ^{78,86}Kr+^{58,64}Ni reactions at E_{lab}=35 MeV/nucleon were analyzed within the framework of Landau free energy approach to investigate the role of quasiprojectile isospin.

Experiments were performed using a ^{78,86}Kr beam from K500 superconducting cyclotron at the Cyclotron Institute, Texas A&M University. Fragments were measured using the 4π charged particle array NIMROD, which was surrounded by theTAMU neutron ball to detect free neutrons. Details about the experiment and the procedure to determine the fragment yields can be found in Ref [8,9]. In the present analysis, yields of fragments arising from the fragmentation of quasiprojectiles having *Z* in the range of 30-34 have been used. Limits were placed on the deformation of the quasiprojectile through a quadrupole cut to minimize the contribution from events dominated by non-equilibrium emission [8,9]. The isospin asymmetry (m_s) of the quasiprojectile was calculated on an event-by-event basis from the *A* and *Z* of the detected fragments. The m_s values were corrected for free neutrons using the neutron data from TAMU neutron ball [9,10]. Since the analysis required *A* as well as *Z* of the detected fragments, only the events with full isotopic identification were included in the analysis. Fragment yield data in the m_s range of -0.03 to 0.21 were divided into four m_s bins, each of width 0.06. The mean m_s values corresponding to these m_s bins were 0.01, 0.06, 0.11 and 0.17.

According to the modified Fisher model [11-13] the fragment yield is given by

$$Y = y_0 A^{-\tau} e^{-\frac{F}{T}A} \qquad (1)$$

where *F/T* is free energy per nucleon normalized with respect to the temperature *T*. A is mass number, τ is a critical exponent and y_0 is a constant. In ref [1,11], it was shown that *F/T* is dominated by the symmetry free energy in the vicinity of a critical point, which can be expressed by the following expression, within the framework of Landau free energy approach

$$\frac{F(m)}{T} = \frac{1}{2}am^2 + \frac{1}{4}bm^4 + \frac{1}{6}cm^6 - \frac{H}{T}m + O(m^8) \qquad (2)$$

where m is an order parameter and H is an external field. In the studies of ref. [1-3], m was identified as the isospin asymmetry of a fragment and the external field H was related to the isospin asymmetry of the source (m_s). *a*, *b* and *c* are fit parameters [1,4]. *F/T* values of $N=Z$ nuclei, particularly of lighter isotopes calculated using eq. 1 after normalizing with respect to the yield of ^{12}C as was done in ref. [1,6], showed significant deviation from the plot of *F/T* values of $N \neq Z$ nuclei. Based on liquid drop mass formula, a coefficient to correct for the odd-even effect was obtained from the analysis of $N=Z$ nuclei. This analysis also gave the value of constant y_0 which was used in Eq. 1 for the calculation of *F/T* without normalizing with respect to the yield of ^{12}C. The plots of *F/T* values for different m_s bins are shown in Fig. 1. Solid lines are fit to the free energy data using Landau equation as given by Eq. 2 with *a*, *b*, *c* and H/T as free

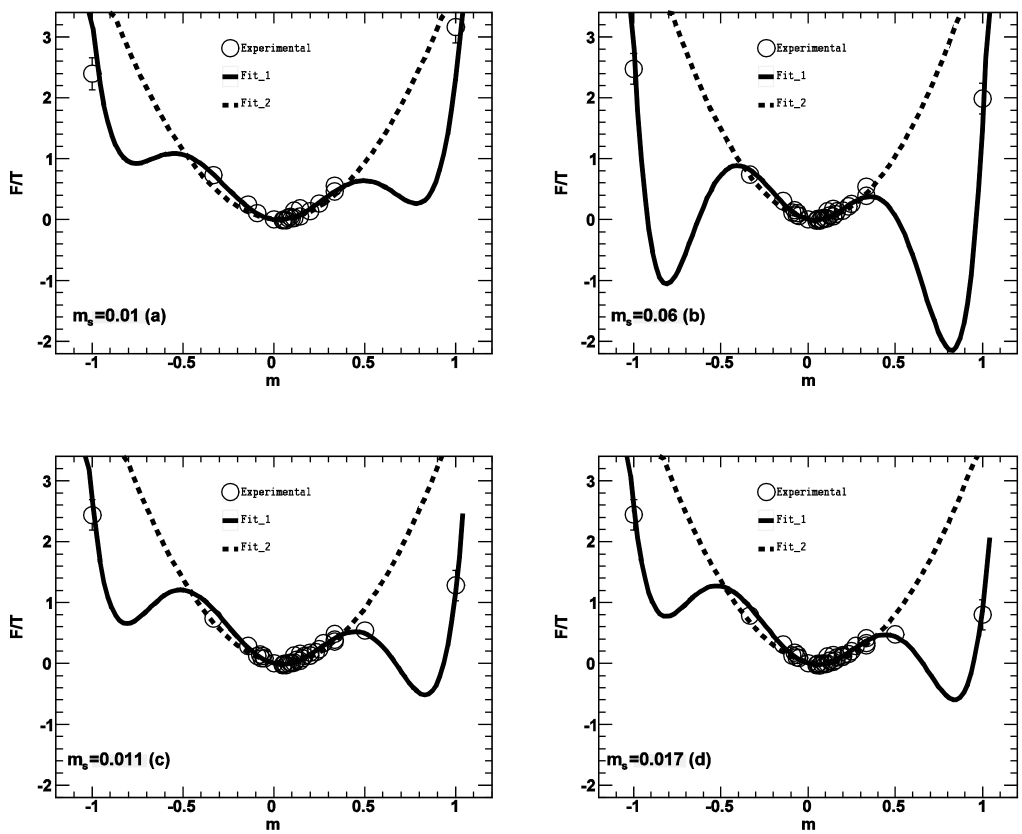

FIG. 1. Plot of F/T calculated from fragment yields for m_s=0.01 (a), 0.06 (b), 0.11 (c) and 0.17 (d).

parameters. Dashed lines are fit using only first and last term of Eq. 2. It can be seen from the figure that the Landau equation provides a better fit to the free energy data. The three minima in the free energy plot indicate the system to be in the regime of a first order phase transition, however, it is difficult to draw any definitive conclusion on this aspect due to the absence of data points at large m values. The fit parameters *a*, *b*, *c* and *H/T* are plotted as a function of m_s in Fig. 2. The parameters *a*, *b* and *c* do not show any significant dependence on m_s. The parameter *H/T* which is related to the isospin asymmetry of the source shows a systematic increase with increasing m_s. This demonstrates the role of quasiprojectile isospin in governing the fragment yields in nuclear fragmentation. In earlier studies [2,6], it has been shown that the position of the central minimum of the fit (ε_0) is equal to $(H/T)/a$. The ε_0 values, calculated using the parameter H/T and a, were observed to be in reasonable agreement with the average isospin asymmetry of fragments $<m_f>$.

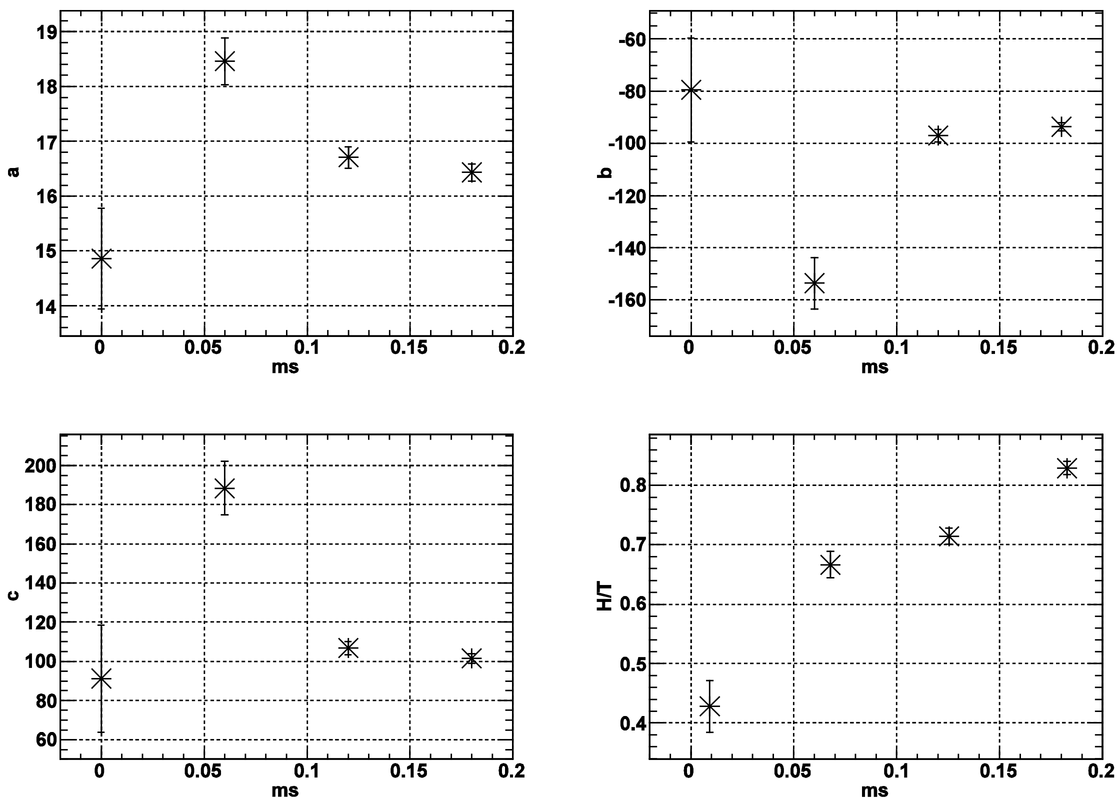

FIG. 2. Plot of fit parameters *a, b, c* and *H/T* as a function of quasi-projectile isospin m_s.

In summary, Landau free energy approach was successfully used to explain fragment yield data, indicating the system to be in the vicinity of a critical point. The analysis demonstrated the role of quasiprojectile isospin in governing the fragment yields.

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