Isobaric yield ratios and the symmetry energy in Fermi energy heavy ion reactions

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According to the Modified Fisher model[1,2], the fragment yield of A nucleons with I = N-Z, Y(A,I) is given by,

$$Y(A,I) = CA^{-\tau} \exp\{[(W(A,I) + \mu_n N + \mu_p Z)/T] + N\ln(N/A) + Z\ln(Z/A)\}. \qquad (1)$$

C is a constant. The $A^{-\tau}$ term originates from the entropy of the fragment and the last two terms are from the entropy contributions for the mixing of two substances in the Fisher Droplet Model [3]. μ_n is the neutron chemical potential and μ_p is the proton chemical potential. W(A,I) is the free energy of the cluster at temperature T. In the model W(A,I) is given by the following generalized Weiszacker-Beth semi-classical mass formula at a given temperature T and density ρ,

$$\mathrm{W}(A,I) = a_v(\rho,T)A - a_s(\rho,T)A^{2/3} - a_c(\rho,T)Z(Z-1)/A^{1/3} - a_{\mathrm{sym}}(\rho,T)I^2/A - \delta(N,Z). \qquad (2)$$

The indexes, v, s, c and sym represent volume, surface, Coulomb, and symmetry energy, respectively. I=N-Z.

The isotope yield ratio between isobars differing by 2 units in I, R(I,I+2,A) can be deduced from Eq. (1) and Eq. (2),

$$\begin{aligned} R(I+2,I,A) = \exp\{[(\mu_n - \mu_p) + 2a_c(Z-1)/A^{1/3} - 4a_{sym}(I+1)/A \\ -\delta(N+1,Z-1) - \delta(N,Z)]/T + \Delta(I+2,I,A)\}. \end{aligned} \qquad (3)$$

Hereafter, in order to simplify the description, the density and temperature dependence of the coefficients in Eq.(2) is omitted as $a_i = a_i(\rho,T)$ (i=v,s,c,sym,p).

^{64}Zn, ^{70}Zn and ^{64}Ni projectiles were incident on targets of ^{58}Ni, ^{64}Ni, ^{112}Sn, ^{124}Sn, ^{197}Au and ^{232}Th at 40A MeV. Isotopes were measured inclusively at θ = 20° using quad-Si detector telescope. Isotopes are clearly identified up to Z<= 18. The measured energy spectrum of each isotope was integrated using a moving source fit to evaluate the multiplicity.

Initially we focus on the isobars with I= -1 and 1. For these isobars the symmetry term in Eq. (3) drops out and, since these isobars are even-odd nuclei, the pairing term also drops out. Taking the logarithm of the resultant equation, one can get

$$\ln R(1,-1,A) = [(\mu_n - \mu_p) + 2a_c(Z-1)/A^{1/3}]/T. \qquad (4)$$

In Fig.1 the experimental values of ln[R(1,-1,A)] plotted for $^{64}Zn+^{112}Sn$ reactions as a function of A. Fitting these values using $(\mu_n - \mu_p)/T$ and a_c/T as fitting parameters, Eq.(3) leads to $(\mu_n - \mu_p)/T=0.71$ and $a_c/T=0.35$.

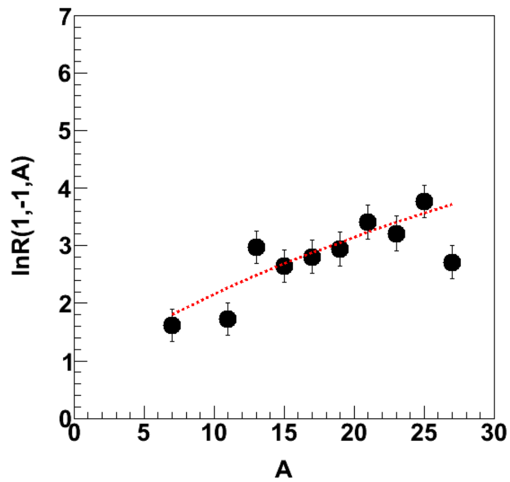

FIG. 1. The experimental values (solid circles) of ln[R(1,-1,A)] for $^{64}Zn+^{112}Sn$ reactions is plotted as a function of A for the isobars of I=-1. The dotted line shows the result of fitting with Eq.(4) **.**

We next compare isobars with I=1 and 3, the symmetry energy coefficient term in Eq.(3) is given as a function of A by

$$a_{\mathrm{sym}} / T = -A/8\{\ln[R(3,1,A)] - [(\mu_n - \mu_p) + 2a_c(Z-1)/A^{1/3}]/T - \Delta(3,1,A)\} \qquad (5)$$

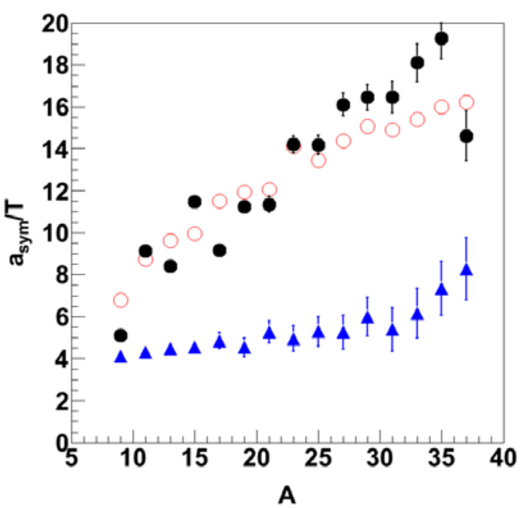

FIG. 2. Extracted values of the symmetry energy coefficient from ^{64}Zn + ^{112}Sn reactions (solid circles) and results of calculations for the secondary fragments (circles). Triangles show results obtained for primary fragments.

In Fig.2 results for $^{64}Zn+^{112}Sn$ reactions (solid circles) of a_{sym}/T calculated from Eq. (5), using the values $(\mu_n- \mu_p)/T$ and a_c/T determined in Eq. (4), are plotted as a function of A. The extracted values from the experiments are in good agreement with those calculated for the secondary fragments. In general the values increase from ~5 to ~16 as cAincreases from 9 to 37. These values are generally much larger than those extracted for the primary fragments (triangles) observed in the AMD calculations. Over the same mass interval the primary fragment values range from 4 to 5. The comparisons between the experimentally extracted results and those of the calculations indicate that the experimental determination of symmetry energy coefficients, a_{sym}/T, are significantly affected by these secondary decay processes of the primary fragments.

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