Isotope distributions in Fermi energy heavy ion reactions

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Isotope distributions from the multifragmentation process are studied for heavy ion reactions near the Fermi energy domain. The ions, ^{64}Zn, ^{70}Zn and ^{64}Ni, were bombarded on targets of ^{58}Ni, ^{64}Ni, ^{112}Sn, ^{124}Sn, ^{197}Au and ^{232}Th at 40A MeV. Isotopes were measured inclusively at $\theta = 20^{o}$ using quad-Si detector telescopes. Isotopes are clearly identified up to Z<= 18. The measured energy spectrum of each isotope is integrated using a moving source fit to evaluate the multiplicity. The obtained isotope multiplicity is studied using a Modified Fisher Model [1]. The observed isotope multiplicities of all reaction systems are rather well reproduced in height and shape of the distributions for 3<=Z<= 18.

According to the Modified Fisher Model, the isotope yields can be given by the following expression:

$$Y(N_f, Z_f) = y_0 A_f^{-\tau} \exp\{[w(N_f, Z_f) + \mu_n N_f + \mu_p Z_f]/T\}, \tag{1}$$

Where y_0 is a normalization constant, τ is the exponent of the mass distribution, *W(N$_f$,Z$_f$)* is Gibbs free energy. For the ground state nucleus *W(N$_f$,Z$_f$)* can be expressed using the Weizecker-Beth Mass formula:

$$w(N_f, Z_f) = a'_v A_f - a'_s A_f^{2/3} - a'_c Z_f^2 / A_f^{1/3} - a_a A_f I_f^2 - \delta, \tag{2}$$

$$I_f = (N_f - Z_f)/A_f, \tag{3}$$

$$\begin{aligned} &= a_p / A_f^{0.5} && \text{for odd-odd nuclei,} \\ \delta &= 0 && \text{for odd-even nuclei,} \\ &= -a_p / A_f^{0.5} && \text{for even-even nuclei} \end{aligned} \tag{4}$$

The coefficients in Eq. (2) represent the volume, surface, Coulomb, asymmetry and possible pairing contributions to the free energy. When $\tau \neq 0$ is taken, the coefficients are not necessarily the same as those in the mass formula. The μ_n, μ_p and T denote neutron and proton chemical potentials, and temperature, respectively.

As the first step of this analysis, τ=0 is taken and all coefficients in Eq. (2) are fixed to Rohlf's parameters [2], which are a_V=15.75, a_S=17.8, a_C=0.71, a_a=23.7 and optimized a_p, T, μ_n and μ_p to reproduce the experimental multiplicity distributions. The optimization is made for the light isotopes with Z≤9 and the heavier isotopes, separately. In Fig.1, typical results are shown for the multiplicity distribution obtained from the ^{64}Ni+^{112}Sn reaction.

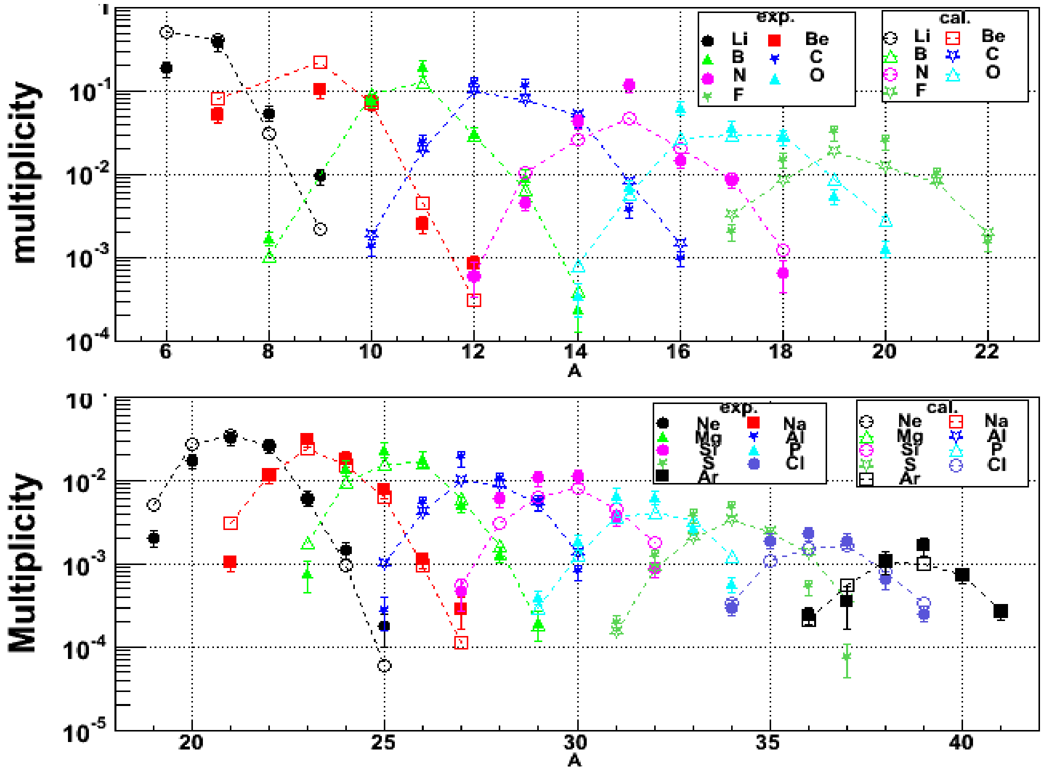

FIG. 1. Isotope multiplicity distributions for $3 \le Z \le 9$ (upper panel) and $10 \le Z \le 18$(lower panel) for ^{64}Ni+^{112}Sn. The solid symbols are experimental data and the open ones are calculated values.

In Fig. 2 the extracted neutron and proton chemical potentials, μ_n and $\mu_{p,}$ are plotted as a function of Z/A of the reaction systems. One can see clear linear correlations between the extracted chemical potentials and Z/A of the system, which indicates that the emitting source of the observed isotopes has higher (lower) neutron density for the neutron rich (poor) system and vice versa. The difference between μ_n and μ_p for the light fragments is larger than that for the heavier ones in all cases. Clear distinction is observed in the chemical potentials between lighter isotopes and heavier ones for a given Z/A of the system. The μ_n and μ_p values of the heavier isotopes for the neutron rich system become closer to those of the lighter isotopes for more symmetric systems. This suggests that the N/Z values of the emitting sources for lighter and heavier IMF are different. This may indicate the fact that the heavier IMF is emitted from the source after many neutrons are evaporated (neutron distillation). Extracted temperature are around 2.5 MeV for the lighter isotopes and about 3.5MeV for the heavier. The obtained pairing energy coefficient, $a_{p,}$ are about a half in the value of the mass formula. Further studies with different parameter sets for the mass formula are now underway.

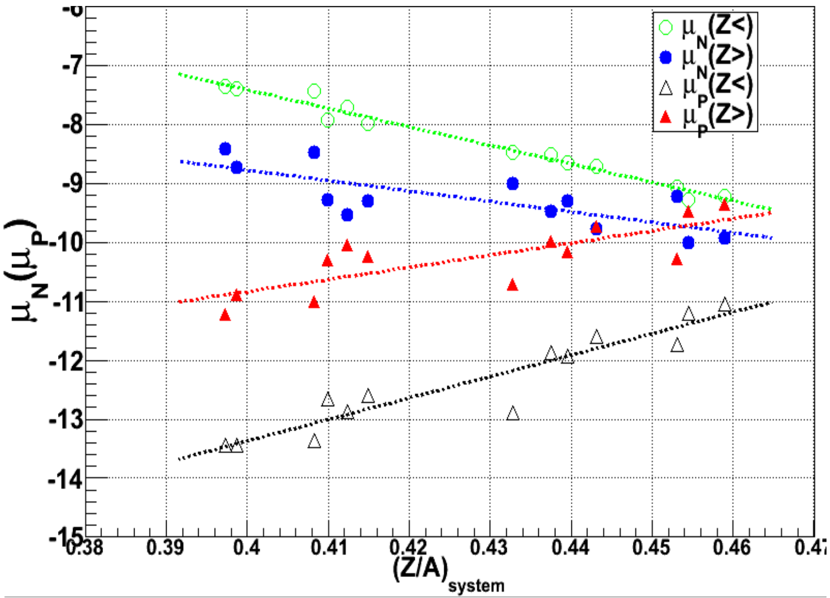

FIG. 2. Chemical potentials vs. the reaction system ratio (Z/A) for ^{64}Zn, ^{70}Zn and ^{64}Ni at 40 AMeV on targets of ^{58}Ni, ^{64}Ni, ^{112}Sn, ^{124}Sn, ^{197}Au and ^{232}Th. Green open circles are the neutron chemical potential for $3 \leq Z \leq 9$ isotopes and blue solid circles are $9 < Z \leq 18$ ones. Black open triangles are the proton chemical potential for $3 \leq Z \leq 9$ isotopes and red solid triangles are $9 < Z \leq 18$ ones.

[1] R. W. Minich *et al.*, Phys. Lett. B **118**, 458 (1982).

[2] James William Rohlf, *Modern Physics from a to Z0*, (Wiley, 1994).