scattering of ^{7}Be, ^{8}B and ^{9}C isotones also shows the same tendency. It indicates that the effect of breakup reaction channel on the elastic scattering for the proton-rich nuclei can be neglected. The elastic scattering measurement has been done for another proton-rich isotones ^{12}N and ^{13}O and the data analysis is under way. The detector system for the elastic scattering research is also being continuously developed. The effective geometrical efficiency has been improved from 20% to 70%. The readout channels reach 500.

There is a big progress on the analysis of the breakup reaction of ^{9}Li on Pb target. The t + ^{6}He cluster structure is observed experimentally at the excited ^{9}Li with the excited energy of 9.8 MeV by an invariant mass method as shown in Fig. 1. The spin and parity of this resonance state are determined by the angle correlation analysis of the two decay products, t and ^{6}He, and the CDCC calculations. The strength of the monopole transition from the ground state to this excited state is extracted as 5.0 fm^2. This is the first experimental evidence of the t + ^{6}He cluster state in excited ^{9}Li which is predicted by Yoshiko Kanada-En'yo *et al.*[4,5]. An advanced and compact array detector is under developing for light charged particles.

References

[1] J. Su, W. P. Liu, N. T. Zhang, et al., Phys. Lett. B, 756(2016)323.

[2] K. L. Wang, J. G. Wang, X. H. Zhou, et al., Phys. Rev. C, 94(2016)044316.

[3] Y. Y. Yang, X. Q. Liu, D. Y. Pang, Phys. Rev. C, 94(2016)034614.

[4] Y. Kanada-En'yo, T. Suhara, Phys. Rev. C, 85(2012)024303.

[5] Y. Kanada-En'yo, Phys. Rev. C, 94(2016)024326.

2 - 25 Revisit of Density, Temperature, Symmetry Energy Determination Based on MFM Formalism

Liu Xingquan, Yang Yanyun and Wang Jiansong

In 1967, Fisher proposed a droplet model of a second-order phase transition to describe the power law behavior of the "fragment" mass distribution around the critical point for a liquid-gas phase transition[1]. Decades later, the Purdue group generated a novel classical droplet model, which was the so-called Modified Fisher Model (MFM), based on the Fisher Model (FM) and introduced it into nuclear physics[2−4]. Taking into account the basic nuclear properties, such as the Coulomb force, pairing effect, proton-neutron two-component mixture, the MFM is capable of describing the general features of the mass and isotopic yields with a minimum number of free parameters[2−4].

In 2014, isotope yields from ^{64}Zn + ^{112}Sn at 40 MeV/u were utilized to extract the density, temperature and symmetry energy of the fragmenting system, based on the modified Fisher model (MFM)[5]. This is one of the series of similar analyses[6−10]. From the pioneering works of Purdue group in Refs. [2−4], the isotope yield with N neutrons and Z protons was expressed as

$$Y(I,A)=Y_0\cdot A^{-\tau}\exp\left[\frac{W(I,A)+\mu_{\mathrm{n}}N+\mu_{\mathrm{p}}Z}{T}+N\ln\left(\frac{N}{A}\right)+Z\ln\left(\frac{Z}{A}\right)\right]. \quad (1)$$

Here $A=N+Z$ and $I=N-Z$. Following to Refs. [2−4], $W(I,A)$ is given along with the generalized Weiszäcker-Bethe semiclassical mass formula when the mixing entropy is defined along the standard positive definition as

$$S_{\mathrm{mix}}(N,Z)=-\left[N\ln\left(\frac{N}{A}\right)+Z\ln\left(\frac{Z}{A}\right)\right], \quad (2)$$

Eq.(1) is rewritten as

$$Y(I,A)=Y_0\cdot A^{-\tau}\exp\left[\frac{W(I,A)+\mu_{\mathrm{n}}N+\mu_{\mathrm{p}}Z}{T}-S_{\mathrm{mix}}(N,Z)\right]. \quad (3)$$

As one can see easily, in the above equation the symmetry energy and the mixing entropy have the same sign. As shown in the appendix, the mixing entropy sign should be opposite. The corrected MFM formula is

$$Y(I,A)=Y_0\cdot A^{-\tau}\exp[\frac{W(I,A)+\mu_{\mathrm{n}}N+\mu_{\mathrm{p}}Z}{T}+S_{\mathrm{mix}}(N,Z)]. \quad (4)$$

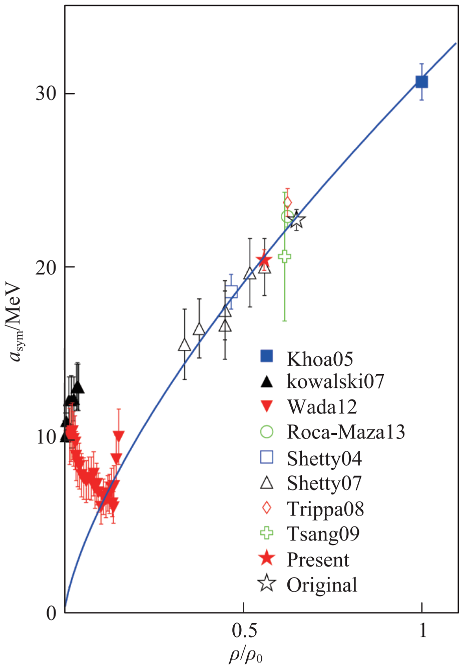

Fig. 1 (color online) Comparisons between the new and old results together with available published results. The line is from the fitting of the available data using Eq. (5). Data are taken from Khoa 2005:[11], Kowalski 2007:[12], Wada 2012:[13], Roca-Maza 2013:[14], Shetty 2004:[15], Shetty 2007:[16], Trippa 2008:[17], Tsang 2009:[18].

However when the mixing entropy is defined as Eq.(2), comparing Eqs.(3) and (4), one may find all the formulations in Refs. [6-10] are identical, except for the sign change of the mixing entropy term. Fortunately in this analysis and in Refs. [6−10], isotope yield ratios between isobars have been utilized and the errors occurred from this mistake is in the difference of the mixing entropies between two isobars, and become rather small, *i.e.*, ~20% at most. All qualitative discussions in these articles are therefore still valid.

The new and old values are $\rho/\rho_0 = 0.56 \pm 0.02(0.65 \pm 0.02)$, $T = 5.2 \pm 0.6(5.0 \pm 0.4)$ MeV, and $a_{\rm sym} = 20.8 \pm 0.6(23.1 \pm 0.6)$ MeV, where the values inside the parenthesis are the old values. In order to support the validity of the qualitative discussion made in Refs. [6-10], the new and old values are compared together with available published data in Fig. 1. At $0.1 \lesssim \rho/\rho_0 \leq 1.0$, the existing data points are consistent with each other within the errors and distribute along a line systematically, which is optimized within the mean-field theory

$$a_{\rm sym}(\rho/\rho_0) = 31.5 \cdot (\rho/\rho_0)^{0.69}. \tag{5}$$

The new and old values are both along the same curve. This observation indicates that in this work the errors caused by the mistake are of a order of 10%, but they do not change the basic conclusions reached.

References

[1] M. E. Fisher, Rep. Prog. Phys., 30(1967)615.
[2] R. W. Minich, S. Agarwal, A. Bujak, et al., Phys. Lett. B, 118(1982)458.
[3] A. S. Hirsch, A. Bujak, J. Finn, et al., Nucl. Phys. A, 418(1984)267c.
[4] A. S. Hirsch, A. Bujak, J. Finn, et al., Phys. Rev. C, 29(1984)508.
[5] X. Liu, W. Lin, R. Wada, et al., Nucl. Phys. A, 933(2015)290.
[6] M. Huang, Z. Chen, S. Kowalski, et al., Phys. Rev. C, 81(2010)044620.
[7] W. Lin, X. Liu, M. R. D. Rodrigues, et al., Phys. Rev. C, 90(2014)044603.
[8] X. Liu, W. Lin, R. Wada, et al., Phys. Rev. C, 90(2014)014605.
[9] W. Lin, X. Liu, M. R. D Rodrigues, et al., Phys. Rev. C, 89(2014)021160(R).
[10] X. Liu, W. Lin, M. Huang, et al., Phys. Rev. C, 92(2015)014623.
[11] D. T. Khoa, H. S. Than, et al., Phys. Rev. C, 71(2005)044601.
[12] S. Kowalski, J. B. Natowitz, S. Shlomo, et al., Phys.Rev. C, 75(2007)014601.
[13] R. Wada, K. Hagel, L. Qin, et al., Phys. Rev. C, 85(2012)064618.
[14] X. Roca-Maza, M. Brenna, B. K. Agrawal, et al., Phys. Rev. C, 87(2013)034301.
[15] D. V. Shetty, S. J. Yennello, A. S. Botvina, et al., Phys. Rev. C, 70(2004)011601(R).
[16] D. V. Shetty, S. J. Yennello, G. A. Souliotis, et al., Phys. Rev. C, 76(2007)024606.
[17] L. Trippa, Gianluca Colo, Enrico Vigezzi, Phys. Rev. C, 77 (2008)061304(R).
[18] M. B. Tsang, Y. Zhang, P. Danielewicz, et al., Phys. Rev. Lett., 102(2009) 122701.