第 30 卷 增刊 II
2006 年 12 月
高 能 物 理 与 核 物 理
HIGH ENERGY PHYSICS AND NUCLEAR PHYSICS
Vol. 30, Supp. II
Dec., 2006

Study of Isoscaling in Projectile Fragmentation and the Nuclear Symmetry Energy Coefficient*

FANG De-Qing[1)] MA Yu-Gang MA Chun-Wang ZHONG Chen CAI Xiang-Zhou CHEN Jin-Gen GUO Wei SU Qian-Min TIAN Wen-Dong WANG Kun YAN Ting-Zhi SHEN Wen-Qing

(Shanghai Institute of Applied Physics, Chinese Academy of Sciences, Shanghai 201800, China)

Abstract The isoscaling behavior in projectile fragmentation has been systematically investigated by a modified statistical abrasion-ablation (SAA) model. The reduced isoscaling parameters are found to decrease with the excitation energy per nucleon and have no significant dependence on the size of reaction systems. Assuming a Fermi-gas behavior, the excitation energy dependence of the symmetry energy coefficients are tentatively extracted from α and β which looks consistent with the experimental data.

Key words statistical abrasion-ablation model, fragmentation reaction, isospin effect

1 Introduction

Recently, study of the nuclear symmetry energy has become a very important topic in nuclear physics. The isoscaling approach for light fragment composition produced in the multifragmentation of very hot source has become an important observable in heavy ion collisions since this method can isolate the nuclear symmetry energy in the fragment yields[1—3]. The scaling law relates ratios of isotope yields measured in two different nuclear reactions, 1 and 2, $R_{21}(N,Z)=Y_2(N,Z)/Y_1(N,Z)$. In multifragmentation events, such ratios are shown to obey an exponential dependence on the neutron number N or proton number Z of the isotopes or isotones characterized by three parameters α, β and C[1]:

$$R_{21}(N,Z)=\frac{Y_2(N,Z)}{Y_1(N,Z)}=C\exp(\alpha N+\beta Z), \qquad (1)$$

here C is an overall normalization constant. In the grand-canonical limit, α and β will have the form,

$$\alpha=\frac{4C_{\rm sym}}{T}\Delta\left[\left(\frac{Z}{A}\right)^2\right]=\frac{4C_{\rm sym}}{T}\left[\left(\frac{Z}{A}\right)_1^2-\left(\frac{Z}{A}\right)_2^2\right] \qquad (2)$$

and

$$\beta=\frac{4C_{\rm sym}}{T}\Delta\left[\left(\frac{N}{A}\right)^2\right]=\frac{4C_{\rm sym}}{T}\left[\left(\frac{N}{A}\right)_1^2-\left(\frac{N}{A}\right)_2^2\right], \qquad (3)$$

where $C_{\rm sym}$ is symmetry energy coefficient (MeV), $\left(\frac{Z}{A}\right)_{\rm i}^2$ or $\left(\frac{N}{A}\right)_{\rm i}^2$ $(i=1,2)$ means the square of Z or N over A for system 1 and 2. T is the temperature of the system in MeV. Since the symmetry energy determines nuclear structure of neutron-rich or neutron-deficient rare isotopes, studies on the isoscaling behavior can be used to probe the isospin dependent nuclear equation of state[1—8].

So far, the isoscaling behavior has been studied experimentally and theoretically for different reaction mechanisms. However, most studies focus on the isoscaling behaviors for light particles with Z=2—8. A few studies on the heavy projectile-like residues

* Supported by National Natural Science Foundation of China (NNSFC) (10405032, 10405033, 10475108, 10535010, 10328259, 10135030), Shanghai Development Foundation for Science and Technology (06QA14062, 06JC14082, 05XD14021, 03QA14066)
1) E-mail: dqfang@sinap.ac.cn
274 — 276

in deep elastic collisions and fission fragments have been reported[8—12]. In this paper, we will present our studies on the systematic isoscaling behaviors for projectile-like fragments in the framework of statistical abrasion-ablation model[13—15]. Extraction of the symmetry energy coefficient from the isoscaling parameters will also be investigated.

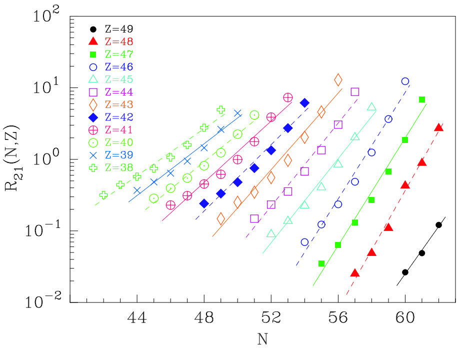

Fig. 1. Yield ratios of fragments from the reactions of $^{124/112}$Sn+^{112}Sn at 60A MeV versus N for the selected isotopes. Different symbols are used for different isotopes as shown in the legend. The lines represent the exponential fits.

2 Calculations and discussion

To study systematic behaviors of the isoscaling phenomena, reactions of $^{40/36}$Ar, $^{48/40}$Ca, $^{64/58}$Ni, $^{86/78}$Kr, $^{124/112}$Sn and $^{129/136}$Xe on ^{112}Sn at 60A MeV are simulated by the SAA model. The yield ratios $R_{21}(N,Z)$ are made using the convention that index 2 refers to the more neutron-rich system and index 1 to the less neutron-rich one. As an example, Fig. 1 shows the yield ratios $R_{21}(N,Z)$ as a function of neutron number N for selected isotopes and Z for selected isotones from $^{124/112}$Sn + ^{112}Sn reactions in log-scale. From this figure, we observe that the ratio for each isotope Z or isotone N exhibits a remarkable exponential behavior. For each isotope (Z) or isotone (N), an exponential function form $C\exp(\alpha N)$ or $C'\exp(\beta Z)$ is used to fit the calculated points and the parameters α or β are obtained for all isotopes or isotones.

The extracted α and $|\beta|$ parameters show a decreasing trend with the increasing of E^*/A and their values are different for different reaction systems.. According to Eqs. (2) and (3), α and β have a linear dependence on $\Delta\left[\left(\frac{Z}{A}\right)^2\right]$ or $\Delta\left[\left(\frac{N}{A}\right)^2\right]$. Since this parameter is dependent on the reaction system, we divide α (β) by $\Delta\left[\left(\frac{Z}{A}\right)^2\right]$ $\left(\Delta\left[\left(\frac{N}{A}\right)^2\right]\right)$ to remove the system isospin and size dependences and call them reduced isoscaling parameters. The results are given in Fig. 2. After the reduction, $\alpha/\Delta\left[\left(\frac{Z}{A}\right)^2\right]$ $\left(\beta/\Delta\left[\left(\frac{N}{A}\right)^2\right]\right)$ of different reaction systems demonstrate almost same dependence with E^*/A.

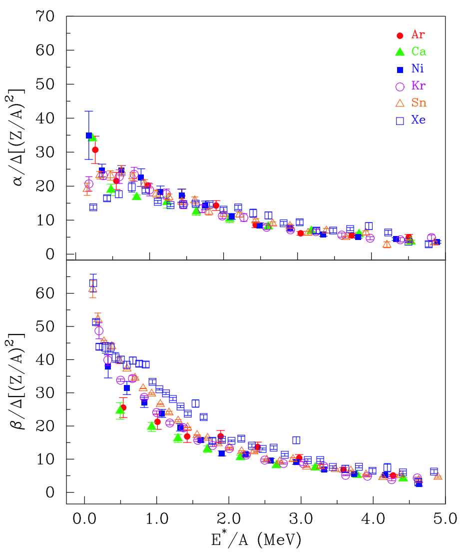

Fig. 2. The reduced isoscaling parameters $\alpha/\Delta\left[\left(\frac{Z}{A}\right)^2\right]$ (upper panel) and $\beta/\Delta\left[\left(\frac{N}{A}\right)^2\right]$ (lower panel) as a function of E*/A. Different symbols are used for projectiles with different Z as shown in the legend.

If we use the Fermi-gas relationship $E^*/A=\frac{1}{a}T^2$ to calculate T, with a=8—13 (in our calculation a=10 is used), the symmetry energy coefficient ($C_{\rm sym}$) could be extracted. Results extracted from $\alpha/\Delta\left[\left(\frac{Z}{A}\right)^2\right]$ and $\beta/\Delta\left[\left(\frac{N}{A}\right)^2\right]$ are shown in Fig. 3. For E^*/A around 1MeV, $C_{\rm sym}$ from α or β is a little lower than the standard value 25MeV in liquid drop model[3], but it seems consistent with the experimental data by Fevre et al.[7]. The obtained $C_{\rm sym}$ is not a constant and decreases with the increase of E^*/A. Similar dependence was also observed in the experimental studies as shown in the figure[7, 8].

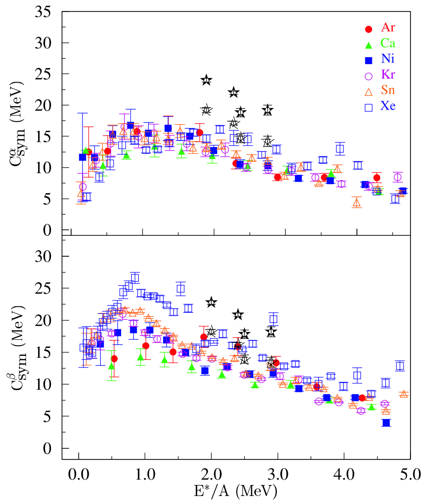

Fig. 3. Same as in Fig. 2 but for the extracted symmetry energy coefficient from α ($C^{\alpha}_{\rm sym}$, upper panel) and β ($C^{\beta}_{\rm sym}$, lower panel) as a function of E^*/A. The solid and open stars are the experimental data taken from Ref. [28] with temperature calculated by Fermi gas and expanding mononucleus model respectively.

3 Summary

In summary, the isoscaling behavior of projectile-like fragments from $^{40/36}$Ar, $^{48/40}$Ca, $^{64/58}$Ni, $^{86/78}$Kr, $^{124/112}$Sn and $^{129/136}$Xe on ^{112}Sn at 60A MeV have been studied by a modified statistical abrasion-ablation model. The isoscaling parameters α and β are extracted for the produced isotopes and isotones, and they show different values for different systems. However, the reduced isoscaling parameters $\alpha/\Delta\left[\left(\frac{Z}{A}\right)^2\right]$ and $\beta/\Delta\left[\left(\frac{N}{A}\right)^2\right]$ show almost same dependence with E^*/A for different systems. Assuming a Fermi-gas behavior, the symmetry energy coefficients are tentatively extracted from α and β and it seems that the results are consistent with the experimental data.

References

1 Tsang M B et al. Phys. Rev. Lett., 2001, **86**: 5023
2 Tsang M B et al. Phys. Rev., 2001, **C64**: 041603
3 Botvina A S, Vlozhkin O, Trautmann W. Phys. Rev., 2002, **C65**: 044610
4 MA Y G, SHEN W Q. Nucl. Sci. Tech., 2004, **15**: 4
5 MA Y G et al. Phys. Rev., 2004, **C69**: 064610
6 TIAN W D et al. Chin. Phys. Lett., 2005, **22**: 306
7 Fevre A L et al. Phys. Rev. Lett., 2005, **94**: 162701
8 Souliotis G A et al. Phys. Rev., 2006, **C73**: 024606
9 Souliotis G A et al. Phys. Rev., 2003, **C68**: 024605
10 Friedman W A. Phys. Rev., 2004, **C69**: 031601(R)
11 Veselsky M, Souliotis G A, Jandel M. Phys. Rev., 2004, **C69**: 044607
12 MA Y G et al. Phys. Rev., 2005, **C72**: 064603
13 Brohm T, Schmidt K H. Nucl. Phys., 1994, **A569**: 821
14 FANG D Q et al. Phys. Rev., 2000, **C61**: 044610; High Energy Phys. & Nucl. Phys., 2000, **24**: 949 (in Chinese) (方德清等. 高能物理与核物理, 2000, **24**: 949)
15 FANG D Q et al. Eur. Phys. J., 2001, **A10**: 0381

弹核碎裂反应的同位旋标度率及核的对称能系数研究*

方德清[1)] 马余刚 马春旺 钟晨 蔡翔舟 陈金根
郭威 苏前敏 田文栋 王鲲 颜廷志 沈文庆

(中国科学院上海应用物理研究所 上海 201800)

摘要 用统计擦碎模型对中能区弹核碎裂反应中的同位旋标度率现象进行了系统研究. 发现在弹核碎裂反应中存在同位旋标度率现象, 但同位旋标度率参数随每核子的激发能的增加迅速下降. 而影响同位旋标度率参数变化的最主要的因素是由于激发能不同及蒸发效应. 采用费米气体模型的激发能与核温度的关系, 从同位旋标度率参数提取出核的对称能系数, 值的大小及其与激发能的变化趋势跟实验数据基本一致.

关键词 统计擦碎模型 弹核碎裂反应 同位旋效应

---

* 国家自然科学基金(10405032, 10405033, 10475108, 10535010, 10328259, 10135030)和上海市科技发展基金(06QA14062, 06JC14082, 05XD14021, 03QA14066)资助

1) E-mail: dqfang@sinap.ac.cn