第23卷 第11期 高能物理与核物理 Vol.23, No.11
1999 年11月 HIGH ENERGY PHYSICS AND NUCLEAR PHYSICS Nov., 1999

Isospin Effect on the Emission Mechanism of Hot Nuclei in 35MeV/u ^{40}Ar + ^{112}Sn / ^{124}Sn Reactions *

Wu Heyu Xiao Zhigang Li Zuyu Wang Hongwei Duan Limin
Zhang Baoguo Liu Yongying Wang Sufang Jin Genming
Xiao Guoqing Guo Zhongyan Zhu Yongtai
(*Institute of Modern Physics, The Chinese Academy of Sciences, Lanzhou* 730000)

Abstrct As an extension of radioactive ion beam physics, the research on isospin dependent properties of hot nuclei has increasingly attracted considerable interest. The isospin effect on the decay of hot nuclei in reactions 35MeV / u ^{40}Ar + ^{112}Sn / ^{124}Sn has been investigated. It is concluded that due to Coulomb repulsion and instability, proton-rich hot nuclei probably emit particles such as α with high energy to increase their neutron-proton ratio. Moreover, the decay chain for those particles is seemingly long and the emission probability is high. Thus, the conventional observations, for instance, the 'slope temperature' extracted from energy spectrum, may vary appreciably with the measured particles.

Key words hot nucleus, isospin effect, nuclear temperature

Radioactive ion beam physics, as a new frontier developed in recent years, is and will be one of the focuses of nuclear physics researches. It extends the region of around 300 stable nuclides to a region of more than 4000 unstable nuclides, which brings about plenty of opportunities to the researches in nuclear reaction, nuclear structure and nuclear astrophysics, as well as synthesis of new nuclides and super heavy elements. A degree of freedom of isospin should be introduced in hope of a breakthrough in the investigation of the formation and decay properties of hot nuclei in the nucleus-nucleus collision with proton-or neutron-rich beams[1]. The main subjects of such studies are: to relate the nuclear size, temperature and isospin to the critical fluctuation effect, which is found to be the causality of multifragmentation, to explore the isospin effects on the nuclear properties such as temperature, compressibility and nucleon free energy, to verify the transition mechanism from sequential decay of hot nuclei with low excitation energy to the prompt decay at high excited state, to probe the differences, as well as the transition behavior, such as the excitation mechanism of between normal nuclear matter and extreme neutron-abundant

Received 18 June 1999
* Project supported by One Hundred Talents and Special Foundation of Chinese Academy of Sciences and project 19505007, 19675053 and 19775045 supported by National Natural Science Foundation of China

nuclear matter, and to establish the transport process of isospin equilibrium[2].

During the nucleus–nucleus collision, the isospin effects lie mainly on the mean field effect, the cross section of nucleon–nucleon interaction and the isospin–induced selectivity of outgoing channels. The 'transparence' and the duration of the projectile–target system are mainly dependent on the mean field interaction. The nucleon and energy exchanging process, which plays a key role in the energy deposition into hot nuclei, is ruled by the isospin dependent nucleon–nucleon cross section. The selectivity of outgoing channels, which reflects the isospin dependence on decay mechanism, as shown in this article, can bring about deviation of the observations of hot nuclei from traditional way. Up to now, the relative weightiness of those three effects of isospin has not been discussed much.

At present, the low beam intensity makes it difficult to directly measure the isospin dependent properties of hot nuclei by using radioactive secondary beam, and also, the available secondary beams are rather finite even if the 4π detector array is used.

In this experiment, hot nuclei with proton or neutron excess were produced by using a stable proton–rich target ^{112}Sn and a stable neutron–rich one ^{124}Sn, respectively. Moreover, the probability of α particle emission of hot nuclei was demonstrated, and the isospin dependence of nuclear temperature, as well as excitation energy was investigated.

The experiment was performed at the Radioactive Ion Beam Line, Lanzhou (RIBLL) with stable beam ^{40}Ar of 35MeV / u provided by Heavy Ion Research Facility, Lanzhou (HIRFL) bombarding on the ^{112}Sn and ^{124}Sn targets, respectively. The target thickness is 1.78mg / cm^2 for ^{112}Sn and 1.57mg / cm^2 for ^{124}Sn with abundance of 73% and 84%, respectively. In order to eliminate the disturbance of pre–equilibrium emission in the measurement of emission probability and temperature of the equilibrated hot nuclei, three telescopes with ϕ = 10mm sensitive area were placed at backward angles 130°, 140° and 150°, 8cm from the target, each consisting of a fully depleted silicon unit as ΔE detector and a piece of CsI(Tl) crystal of $20 \times 20 \times 70$mm^3 as residual energy detector. The thicknesses of these three silicon ΔE detectors are 150μm, 50μ and 50μm respectively. The residual energy signal was read out by photo diode, which was adhered closely with the CsI crystal. The recoil residues were selected by the 0° magnetic spectrometer at RIBLL and then stopped in a Si (Au) surface barrier detector with ϕ = 50mm. To eliminate the influence brought by the shifts of either the beam or the electronics, and to demonstrate authentically the different decay behaviors between the neutron–rich (target ^{124}Sn) and the proton–rich (target ^{112}Sn) hot nuclei, we exchanged the two targets frequently in experiment. For statistical reason, only the inclusive α energy spectra obtained by the single detector at 140° are shown in Fig 1. The parts below 20MeV in both spectra are ignored for the unreliability caused by insufficient precision of calibration and unpredicted triggers of noises.

Some interesting phenomena are shown in Fig 1. First, although the excitation energy of the hot nuclei formed in the reaction ^{40}Ar + ^{124}Sn is lower than that in ^{40}Ar + ^{112}Sn, the nuclear temperature of 5.1MeV in the former is observed higher than

4.9MeV as in the latter. Second, the probability of emission of α particles is about 4.8 times higher in proton–rich hot nuclei than that in neutron–rich nuclei after normalization to the beam integration. Third, the appreciably enhanced tail of high energy in the spectrum of the proton–rich hot nuclei indicates that the yield of higher energy α particles is more abundant than that in neutron–rich hot nuclei.

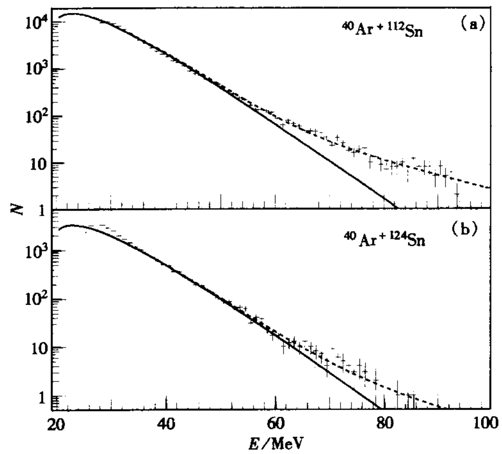

Fig.1 α energy spectra obtained by the single telescope at 140° of the proton–rich (a) and the neutron–rich (b) hot nuclei, respectively
Solid curve is the fitting result, and dashed curve is drawn to guide the eyes.

The reaction mechanism in heavy ion collision is rather complicated. The size and excitation energy of hot nuclei formed in the collision vary largely with the impact parameters. For a certain hot nucleus, its mass, as well as excitation energy, is quite different in different stage along the long decay chain. Usually, the nuclear temperature measured in experiment is a so–called 'apparent temperature', which is averaged over the whole decay chain of a certain kind of hot nuclei.

In this experiment, since the measurement is averaged over all impact parameters, the difference of the results of the two systems comes presumably from their isospin difference by the way of the selection of outgoing channels. In the case of center collision in this energy region, the hot nuclei are formed up to very high temperature[3] and close to the multifragmentation region[4]. Due to the Coulomb repulsion, the protonrich system of ^{40}Ar + ^{112}Sn is transiently put to the Coulomb unstable region, where its α decay chain starts at very highly excited state or even non–equilibrated stage with affluent emission of high energy particles. Furthermore, selectivity of outgoing particles governs the decay behavior in the long decay chain for a hot nucleus far from stability line to de–excite to its destination[5] i.e. emission of protons and α particles is suppressed in neutron–rich system but dominant in proton–rich case. Thus, α emission mainly occurs at earlier stage on the de–excitation chain in neutron–rich hot nuclei with higher excitation energy in ^{40}Ar + ^{124}Sn. As a result, the measured 'slope temperature', as an average parameter along the de–excitation chain, should be higher, although the average excitation energy is lower than that for ^{40}Ar + ^{112}Sn reaction. Moreover, in the spectrum of α particles for ^{40}Ar + ^{112}Sn, the obvious deviation of the high energy tail from exponential law indicates that these α particles may be mainly emitted before the system reaches equilibrium due to the increasing Coulomb instability of hot nuclear system far from β instability line.

The author wishes to express his appreciation for the assistance given by the staffs of HIRFL and the cooperation of the RIBLL group.

References

1 Li B A, Ko C M, Bauer W. International Journal of Modern Physics, 1998, **E7**:147
2 Johnston H, Winger J, White T et al. Phys. Lett., 1996, **B371**:186
3 Wu H, Jin G, Li Z et al. Nucl. Phys., 1997, **A617**:385
4 Wu H, Y, Dai G X, Jin J G. et al. Phys. Rev., 1998,**C57**:3178
5 Hilscher D. In: Strohmaier B. Proc. Of a specialist's Meeting on Preequilibrium Nuclear Reactions, OECD, Paris, 1988. 245

35MeV / u ^{40}Ar + ^{112}Sn / ^{124}Sn 反应中热核的同位旋对热核发射机制的影响*

吴和宇 肖志刚 李祖玉 王宏伟 段利敏 张保国
柳永英 王素芳 靳根明 肖国青 郭忠言 诸永泰

(中国科学院近代物理所 兰州 730000)

摘要 作为放射性束物理的延伸,热核的同位旋效应引起了理论和实验研究的广泛重视. 给出 35MeV / u ^{40}Ar + ^{112}Sn / ^{124}Sn 实验中,热核的同位旋对热核衰变出射道机制的影响:由于库仑不稳定性和库仑力作用,丰质子热核达到系统平衡前,很容易出现大量有利于增加余核中质比的高能粒子出射(如 p、^{3}He、α等);该类轻粒子在热核的衰变链中发射几率较大而且衰变链很长. 这样,传统的热核测量量(如能谱斜率温度)将受到测量粒子种类的较大影响.

关键词 热核 同位旋效应 核温度

1999-06-18收稿
* 中国科学院百人计划,中国科学院九·五重点项目,国家自然科学基金资助项目19505007,19675033,19775045