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Understanding of the dissipation mechanism in ternary fission for the system ^{197}Au+^{197}Au*

TIAN Jun-Long(田俊龙)[1,2] LI Xian(李贤)[1,2] WU Xi-Zhen(吴锡真)[3,4]
LI Zhu-Xia(李祝霞)[3,4] YAN Shi-Wei(晏世伟)[1,2,4;1)]

1 (College of Nuclear Science and Technology, Beijing Normal University, Beijing 100875, China)
2 (Beijing Radiation Center, Beijing 100875, China)
3 (China Institute of Atomic Energy, Beijing 102413, China)
4 (Center of Theoretical Nuclear Physics, National Laboratory of Heavy Ion Accelerator of Lanzhou, Lanzhou 730000, China)

Abstract The mass number distributions of three fragments from the ternary fission of the system ^{197}Au+^{197}Au are reproduced rather well by using the improved quantum molecular dynamics (ImQMD) model without any adjusting parameter. It is found that the probability of ternary fission evidently depends on the incident energy and the impact parameter, and the two-body dissipation is the main mechanism responsible for the formation of the third fragment with comparable mass.

Key words ImQMD, ^{197}Au+^{197}Au, ternary fission, two-body dissipation

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A dynamic origin of dissipative motion observed in a finite many-body system is a fundamental problem in various fields of contemporary science[1]. The nucleus provides us with a very nice benchmark field to explore this subject, because it shows a coexistence of “macroscopic” and “microscopic” effects in association with various “phase transitions”, and a mutual relation between “classical” and “quantum” effects related to the macro-level and micro-level variables, respectively. At certain energy region, the nucleus exhibits some statistical aspects which are associated with dissipation phenomena.

It is commonly believed that at low and intermediate energies there are two kinds of dissipation mechanisms: one-body[2, 3] and two-body dissipation[4, 5]. In one-body dissipation process, nucleons are considered to collide with the nuclear surface generated by the common self-consistent mean field, and in two-body dissipation process, nucleons interact with one another. However, their interplay and mutual balance are still a question of debate and represent a long-term controversy.

In Ref. [6], Carjan, Sierk and Nix indicated that the observation of the mass distribution in the ternary fission of heavy nuclear system might be a suitable way to distinguish these two kinds of dissipation mechanisms. In the case of the two-body dissipation, the formation of the third fragment with a comparable mass was predicted in the ternary fission of very heavy fission system. On the contrary, in the case of the one-body dissipation, the third fragment should be expected to be much smaller. Recently, the ternary fission of a very heavy system ^{197}Au+^{197}Au at 15 AMeV were carried out by I. Skwira-Chalot et al.[7] in 4π geometry using the multidetector array CHIMERA at LNS Catania. The mass number distribution of fragments was shown as a function of the mass A_1 (the heaviest fragment), A_2 (the less heavy fragment) and A_3 (the lightest fragment), respectively. The peak of mass distribution for

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1) Corresponding Author, E-mail: yansw@bnu.edu.cn

the third fragment A_3 was found to locate at about 100. This result of the third fragment with a relatively large mass is considered as an experimental evidence for clarifying the competition between one- and two-body dissipation processes and understanding the microscopic dynamics for those two mechanisms. In this paper, we will carry out a theoretical study on the ternary fission for very heavy nuclear systems based on the improved Quantum molecular dynamics(ImQMD) model and reproduce the experimental data. The quantum molecular dynamics (QMD) model being successfully used in intermediate energy heavy-ion collisions was successfully extended to heavy ion collisions at energies near the barrier by making a serious improvements[8, 9]. In the model both the mean field and collision term are treated properly. Thus, in principle, the dissipation, diffusion and correlation effects are all included without introducing any freely adjusting parameter. The procedure of making initial nuclei of projectile and target is similar to that in Refs. [9, 10]. The binding energy and root mean square radius for ^{197}Au are required to be 7.92±0.05 MeV/nucleon and 5.35±0.2 fm, respectively. The prepared nuclei are also required to evolve stably without spurious emission within 6000 fm/c. In our calculation the fragment recognition is in terms of the conventional coalescence model[11]. In the simulation, we select a class of ternary events satisfying nearly complete balance of mass numbers:

$$A_{\rm P}+A_{\rm T}-70\leqslant A_1+A_2+A_3\leqslant A_{\rm P}+A_{\rm T}\ ,$$

where $A_{\rm P}+A_{\rm T}$ is the total mass number. This criterion is adopted in Ref. [7]. Through counting the number of A_1, A_2 and A_3 at each impact parameter b, the production cross sections for A_1, A_2 or A_3 are obtained with the expression

$$\sigma(A_i)=2\pi\int_0^{b_{\max}}bP(A_{\rm i},b){\rm d}b\simeq\sum_{b=0}^{b_{\max}}2\pi b\Delta b\frac{N(A_{\rm i},b)}{N_0},$$

where $P(A_{\rm i},b)=N(A_{\rm i},b)/N_0$ is the production probability of fragment $A_{\rm i}$ with the impact parameter b, $N(A_{\rm i},b)$ denotes the number of $A_{\rm i}$ producing at each impact parameter in ternary events, and N_0 denotes total ternary fission events.

Figure 1 shows the mass distributions for three fragments of A_1, A_2 and A_3 in selected ternary fission of ^{197}Au+^{197}Au at the energy of 15 AMeV. The experimental data and the calculation results are normalized with 6000 and 35 mb in terms of the experimental counts and the calculated cross section. From Fig. 1, one can easily see that the calculated results can reproduce the experimental data rather well and the most ternary events involve the formation of three comparable fragments. This means that the ImQMD model may provide us with a satisfied description of the ternary fission events of very heavy system ^{197}Au+^{197}Au.

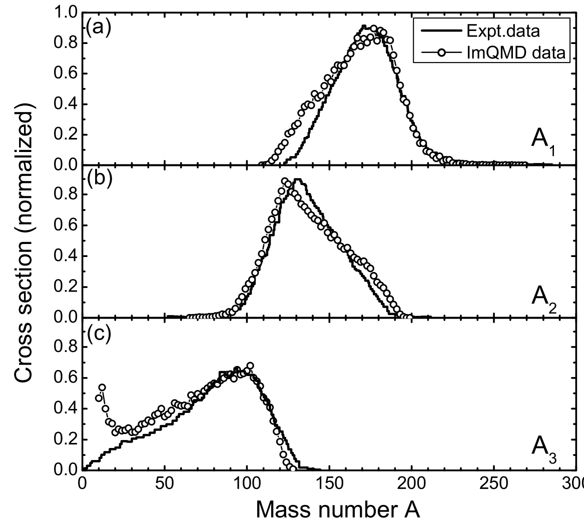

Fig. 1. Mass number distributions of (a) A_1, (b) A_2, and (c) A_3 fragments in selected ternary reactions of ^{197}Au+^{197}Au at energy of 15 A MeV. The histograms denote the experimental data[7], and the lines with open circles are the results with the ImQMD model.

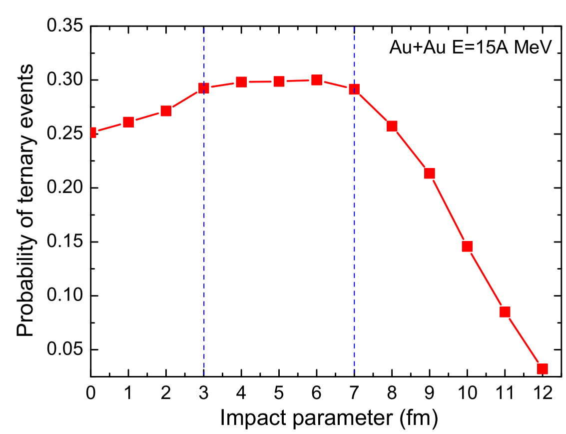

Fig. 2. Impact parameter dependence of production probability of ternary fission for ^{197}Au+^{197}Au system at energy of 15 A MeV.

Here it is worthwhile to clarify the main ingredients which affect the production of the three fragments. In this study, we find that both impact parameter b and incident energy E play a crucial role. Fig. 2 shows the impact parameter dependence of the production probability of ternary events for the system of ^{197}Au+^{197}Au. The production probability increases with the impact parameter in the region of

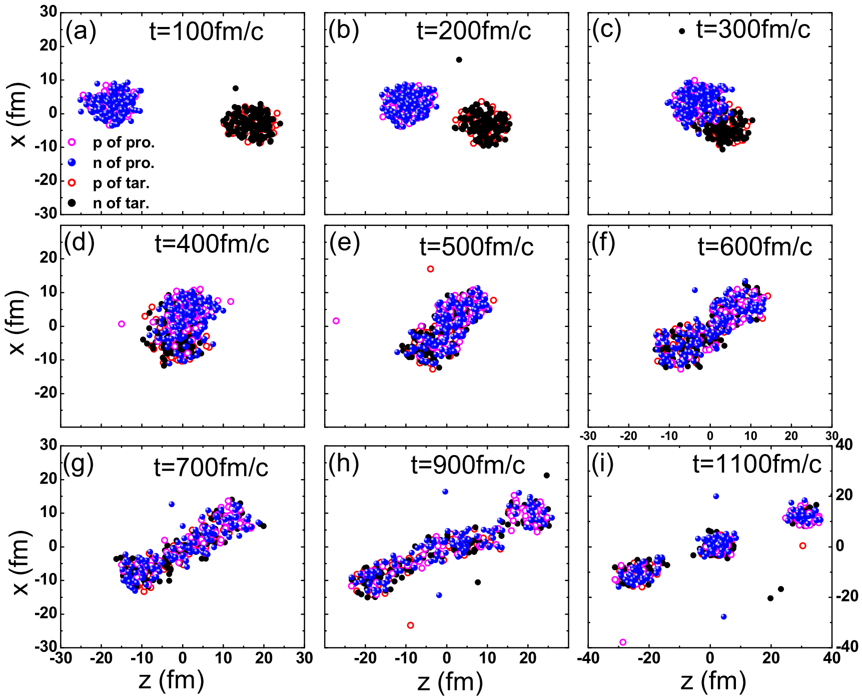

Fig. 3. (color online) Snapshots of a typical ternary event of ^{197}Au+^{197}Au with $b=6$ fm at different time. The open circles represent protons and solid ones for neutrons.

0—3 fm and appears a plateau between 3—7 fm. After that, it will rapidly decrease to almost zero. It implies that the semi-central collisions of ^{197}Au+^{197}Au is responsible for producing ternary events.

The dynamic process of the ternary events is simulated by the snapshots of a typical ternary event with $b=6$ fm shown in Fig. 3. Two approaching nuclei collide each other at about $t=300$ fm/c, and they form an elongated composite system which evolves some time and finally re-separates into three fragments at $t=1000$ fm/c. During this process massive nucleons collide with each other and a large part of translational kinetic energy dissipates to single-particle motions which accelerates the nucleon motion. The strong correlation and collision between nucleons may result in the two-body dissipation and the formation of the relatively large third fragment.

The impact parameter dependence also can be seen from Fig. 4. Because the third fragment A_3 mainly comes from the participants and the participants become smaller and smaller with b increasing, the mass of third fragment A_3 decreases, while A_1 and A_2 increase, specially when $b \geqslant 6$ fm.

Now let us turn to discuss the effect of incident energy. Fig. 5 shows the numerical results for ^{197}Au+^{197}Au system with impact parameter $b=1$ fm. It is shown that the production probability of ternary events monotonously increases with the energy in the range of 5—24 AMeV, and it reaches the maximum value at about $E=24$ AMeV, then it rapidly decreases from 24 to 30 AMeV. When $E<8$ AMeV, ternary events can not be found due to the Coulomb barrier(662 MeV of ^{197}Au+^{197}Au)[12]. At the energy region $E=24$—30 AMeV, ternary events decreases rapidly since multifragmentation events (more than 3 fragments) starts to be produced. From this figure we can see that the production probability of ternary events are very sensitive to the incident energy for ^{197}Au+^{197}Au with $b=1$ fm, the most suitable incident energy is about 24 AMeV.

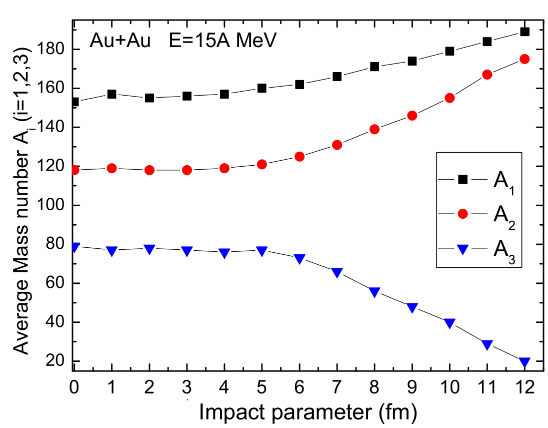

Fig. 4. (color online) Impact parameter dependence of average mass number of fragments A_1, A_2, and A_3 in selected ternary reactions for ^{197}Au+^{197}Au system.

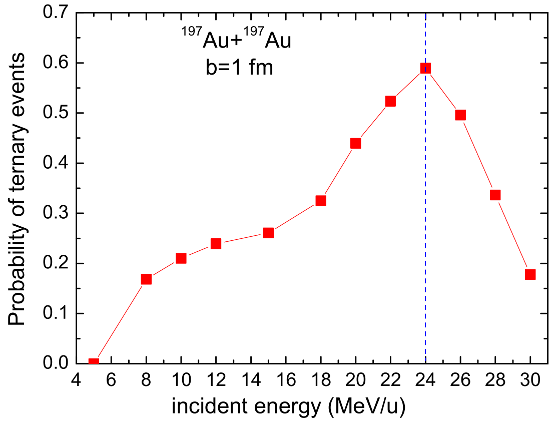

Fig. 5. The incident energy dependence of the production probability of ternary events for ^{197}Au+^{197}Au system with $b=1$ fm.

In summary, the ternary fission of the very heavy system ^{197}Au+^{197}Au has been simulated by using the ImQMD model. The mass number distributions of promptly produced three fragments in ternary fission of ^{197}Au+^{197}Au shown in[7] are reproduced rather well with the parameter set IQ2 shown in[10] without any change. It has been found that the probability of ternary fission depends on the incident energy and the impact parameter, and the two-body dissipation is the main mechanism responsible for the formation of the third fragment with a comparable mass.

It is worthwhile to mention that there still remains some problems, such as, what is the underlying microscopical dynamics of two-body dissipation and whether there is a competition between one- and two-body dissipation mechanism. Some aspects of those problems are in progress.

References

1 YAN S W, Sakata F, ZHUO Y Z, WU X Z. Phys. Rev. E, 2001, **63**: 021116

2 Gross D H, Nucl. Phys. A, 1975, **240**: 472

3 Randrup J, Swiatecki W J. Ann. Phys., 1980, **125**: 193

4 Davies K T, Sierk A J, Nix J R. Phys. Rev. C, 1976, **13**: 2385

5 Danielewicz P. Phys. Lett. B, 1984, **146**: 168

6 Carjan N, Sierk A J, Nix J R. Nucl. Phys. A, 1986, **452**: 381

7 Skwira-Chalot I et al. Int. J.Mod. Phys. E, 2006, **15**: 495; Skwira-Chalot I et al. Int. J.Mod. Phys. E, 2007, **16**: 511

8 WANG N, LI Z X, WU X Z. Phys. Rev. C, 2002, **65**: 064608

9 WANG N, LI Z X, WU X Z et al. Phys. Rev. C, 2004, **69**: 034608

10 WANG N, LI Z X, WU X Z et al. Mod. Phys. Lett. A, 2005, **20**: 2619

11 Kruse H, Jacak B V, Molitoris J J et al. Phys. Rev. C, 1985, **31**: 1770

12 Bass R. Nucl. Phys. A, 1974, **213**: 45