ANALYSIS OF FUSION-FISSION DYNAMICS BY PRE-SCISSION NEUTRON EMISSION IN $^{58}\text{Ni} + ^{208}\text{Pb}$ SYSTEM

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Many experiments on the induced fission at near and below Coulomb barrier in superheavy-mass region have been done and the mass and kinetic energy distributions of fission fragments were measured [1]. In these phenomena, the reaction process is classified into several characteristic processes, they are the fusion-fission process (FF), the quasi-fission process (QF) and the deep inelastic collision process (DIC). Depending on the shell effect of the compound nucleus or the composite nucleus, the deep quasi-fission process (DQF) can be seen in a certain reaction system [2]. In the DQF process, mass symmetric fission fragments are observed but no compound nucleus is formed.

Each process has its own characteristic reaction time from the contact of the colliding partner to the scission point. This was shown by the dynamical calculation for the time development of the nuclear shape in terms of the Langevin equation [2]. The different reaction time means that each reaction process associates the different pre-scission neutron multiplicity.

We undertake to extend our model discussed in reference [2], by taking into account the effect of neutron emission. We combine the Langevin calculation with the statistical model which calculates the neutron emission. We apply our model to the recent experiment, in which the pre-scission neutron multiplicity correlated with the mass distribution of fission fragments has been measured in the reaction $^{58}\text{Ni} + ^{208}\text{Pb}$ at the incident energy corresponding to the excitation energy of compound nucleus $E^* = 185.9$ MeV [3].

This experiment was done by DéMoN group [3].

An interesting feature of the distribution of pre-scission neutron multiplicity is its shape having two components, which are located around $\nu = 4$ and $8$. This structure may be the sign of a simultaneous coexistence of two mechanisms corresponding to different life time of the composite system but to the phenomena giving nearly the same mass fragment in the fission process. The first one, defined as the QF process, would lead to the emission of about 4 neutrons only and for the second one, associated here with the FF process via a compound nucleus, would be found around 8 neutron emission. In this case, the fission process would tail long enough time to allow the emission of nearly 8 neutrons.

By our model calculation, we try to confirm that the different dynamical processes, i.e., the FF process and the QF process, are giving different pre-scission neutron multiplicities in spite of the phenomenon associated with the similar mass fragment. For the QF process, we calculate the pre-scission neutron multiplicity in correlation with fission fragments with mass numbers greater than $A/2-30$ and less than $A/2+30$. To classify the FF trajectory, the definition of the fusion area in the deformation space is very important. Here, we define the fusion area (fusion box) as the inside of the fission saddle point in the system. The idea behind the
The definition of the fusion box is the same as that in reference [2]. The FF trajectory is identified as that which enters the fusion box.

In Fig. 1, the position at \( z=\alpha=\delta=0 \) corresponds to a spherical compound nucleus. The injection point of this system is indicated by the arrow. We start the calculation of the three-dimensional Langevin equation at the point of contact, which is located at \( z=1.575, \delta=0.0, \alpha=0.564 \). All trajectories start at this point with momentum in the initial channel. The initial velocity is directed in only the \( z \) direction.

Next, we discuss the details on this calculation. Figures 2(a) and (b) show the potential energy surface of the liquid drop model for \( ^{266}\text{Ds} \) on the \( z-\alpha (\delta=0) \) plane and \( z-\delta (\alpha=0) \) plane, respectively, in the case of \( l=0 \). This potential energy surface is calculated using the two-center shell model code [4,5]. The contour lines of the potential energy surface are drawn at steps of 2 MeV in (a) and 5 MeV in (b). Similar to the deformation parameters of nuclear shape described in reference [2], \( z \) is defined as \( z=z_0/(R_{CN}B) \), where \( R_{CN} \) denotes the radius of the spherical compound nucleus. The parameter \( B \) is defined as \( B=(3+\delta)/(3-2\delta) \).

In Fig. 2, the position at \( z=\alpha=\delta=0 \) corresponds to a spherical compound nucleus. The injection point of this system is indicated by the arrow. The top of the arrow corresponds to the point of contact in the system. We start the calculation of the three-dimensional Langevin equation at the point of contact, which is located at \( z=1.575, \delta=0.0, \alpha=0.564 \). All trajectories start at this point with momentum in the initial channel. The initial velocity is directed in only the \( z \) direction.

The sample trajectories of the QF process and the FF process are shown in Figs. 2(a) and (b). The trajectories are projected onto the \( z-\alpha \) plane (\( \delta=0 \)) in Fig. 2(a) and \( z-\delta \) plane (\( \alpha=0 \)) in Fig. 2(b). The trajectories of the QF and the FF processes are denoted by gray line and white line, respectively.
This study will be the cornerstone for further study which develops the methods of the classification between the FF process and the DQF process. The DéMon group already has measured the pre-scission neutron multiplicity in reactions, $^{48}$Ca+$^{208}$Pb, $^{48}$Ca+$^{244}$Pu and $^{58}$Fe+$^{248}$Cm at $E^*\sim 40$ MeV [6,7]. In the next study, we would like to analyze these reactions.

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This work has been reported in the conferences and published [8-14]. The details are shown in the references.

**REFERENCES**