励起超変形核の崩壊過程の研究

Barrier penetration and rotational damping of thermally excited superdeformed nuclei[1]

吉田　光次
Koji Yoshida
教養部

Quasi-continuum gamma-ray spectra observed in heavy ion fusion reactions have attracted much attention recently as they carry information on structure of rapidly rotating and thermally excited nuclei. Indeed studies of the ridge and valley structures and the fluctuations in the double coincident spectra revealed occurrence of the rotational damping. Namely the collective rotation of a deformed nucleus becomes a damped motion when the thermal excitation energy is provided to the nucleus [1]. This is in contrast to the rotational band structures known for the levels near the yrast line. The rotational damping is intimately related to a basic feature of highly excited compound states that the wave functions of excited levels become complex mixture of many-particle many-hole or manyquasiparticle configurations due to the residual two-body nuclear interaction [1,2].

The quasi-continuum gamma-rays are also produced in the reactions forming superdeformed (SD) nuclei. However, their properties are much more complex than in normal deformed (ND) nuclei. Recent experiments reveal that the continuum gamma-rays in superdeformed nuclei contain more than one components. This complexity arises from a characteristic feature that the superdeformed and the normal deformed states coexist in the same region of spin and excitation energy. It is known that the observed SD rotational bands keep their identity remarkably well even though the SD bands are embedded in a sea of compound levels having normal deformation. This is because the SD and ND states are separated by a potential barrier in the deformation space. On the other hand, observed SD rotational bands terminate suddenly at spin value around 10-30h by decaying to ND states. The sudden decay-out of the SD rotational bands are interpreted as a barrier penetration phenomenon [3]., As thermally excited superdeformed states relevant for the quasi-continuum gamma-ray spectra are concerned, the barrier penetration is expected to be more effective.

[1] This work has been supported by the Special Research Grant-in-Aid of the NaraUniversity.

Therefore, it is important to incorporate not only the rotational damping effects (or the complex configuration mixing) but also the barrier penetration in order to describe the thermally excited superdeformed states.

It is interesting to study the thermally excited SD bands bacause we can learn about the collective rotational motion and the collective motion in the shape degrees of freedom at the same time. The rotational damping phenomenon is related to the study of quantum chaos and is crucial to investigate the very existence of rotation bands in nuclei at thermally excited states. The decay-out of the SD bands as a barrier penetration problem tells us information on how nuclear shape evolves as a function of the excitation energy and the angular momentum.The potential energy surface in deformation coordinates is often used in the nuclear structure problems, but the reliability of the energy surface has been tested only near the minimum points in most cases. The barrier penetration problem gives a rare chance to explore the portions of the energy surface far from the minimum points, i.e. it reflects the effect of the large amplitude shape dynamics extending from one minimum to the other through a barrier region. The significance of studying the thermally excited SD bands is similar to that of spontaneous fissions, but the present problem is unique in the sense that it gives possibility to examine such shape dynamics under the influences of the thermal motion and collective rotational motion.

In the present paper, we attempt to construct a microscopic nuclear structure model including both the rotational damping and decay-out effects. Theoretical treatment of the barrier penetration mechanism relevant to the decay-out of the SD bands was formulated in a consistent way firstly by Vigezzi et al. The validity of the theory have been checked by more firm theoretical considerations, and also by analysis of the experimental data. The calculation based on this theory combined with a microscopic potential energy surface of the cranked Nilsson-Strutinsky type and the collective mass parameter of the pair hopping model gives good account of the sudden decay-out of the SD bands in A ◆ 150 nuclei. On the other hand, a microscopic model of the rotational damping in thermally excited rotating nuclei has been formulated also on the basis of the cranked Nilsson-Strutinsky mean-field [2]. This model treats not only the mean-field but also the shell model configuration mixing by incorporating the many-particle many-hole excitations built on the cranked Nilsson potential and by performing a shell model diagonalization of the residual effective interactions. Quantitative success of the model has been demonstrated recently for normal deformed nuclei in the rare-earth region [2] and also in A ◆ 110 deformed nuclei. It was also applied to the rotational damping in the superdeformed nuclei [4,5]. However, so far the model dose not take into account decay-out caused by the barrier penetration. In this paper, we extend this approach by combining with the barrier penetration model [3]. Previously Monte-Carlo statistical simulation models that combine the two effects were proposed. However, these models are designed in phenomenological ways so that they can be used to analyze the experimental data with parameter fitting or with use of deduced parameter values. It is important for further quantitative study to construct a theoretical model on the basis of the microscopic description of the rotational damping and the decay-out. The purpose of the present paper is to provide with such a microscopic model.

We have constructed a microscopic model of thermally excited superdeformed states that describes both the barrier penetration mechanism, leading to the decay-out transitions to normal deformed states, and the rotational damping causing fragmentation of rotational E2 transitions. We have described the barrier penetration by means of a tunneling path in the two-dimensional deformation energy surface, which is calculated with the cranked Nilsson-Strutinsky model. The individual excited superdeformed states and associated E2 transition strengths are calculated by the shell model diagonalization of the many-particle many-hole excitations interacting with the delta-type residual two-body force. The effect of the decay-out on the excited superdeformed states have been discussed in detail for ^{152}Dy, ^{143}Eu and ^{192}Hg. The model predicts that the decay-out brings about characteristic decrease in the effective number of excited superdeformed rotational bands.

References

[1] B. Laurizen, T. D ▲ ssing, and R. A. Broglia, Nucl. Phys. A457(1986)61.
[2] M. Matsuo, T.D ▲ ssing, E.Vigezzi, R. A. Broglia, and K. Yoshida, Nucl. Phys. A617(1997)1.
[3] Y. R. Shimizu, F. Barranco, R. A. Broglia, T. D ▲ ssing, E. Vigezzi, Phys. Lett. B274(1992)253.
[4] K. Yoshida and M. Matsuo, Nucl. Phys. A612(1997)26.
[5] K. Yoshida and M. Matsuo, Nucl. Phys. A636(1998)169.