博士論文 要旨

Role of noncollective excitations in low-energy heavy-ion fusion reaction and quasi-elastic scattering
(低エネルギー重イオン核融合反応及び準弾性散乱における非集団励起の効果)

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In heavy-ions reactions, a cancellation between an attractive nuclear potential and the repulsive Coulomb potential makes a potential barrier called the Coulomb barrier between the colliding nuclei. In heavy-ion reactions around the Coulomb barrier energy, the coupling between the relative motion and internal excitations of the colliding nuclei has been found to play an important role. It has been well known that subbarrier fusion cross sections are significantly enhanced due to the coupling effect, compared to a prediction of a simple potential model.

In order to take into account the coupling effect, a coupled-channels method has been employed as a standard approach. Conventionally, only a few low-lying collective excitations such as vibrational excitation or rotational excitations in deformed nuclei have been taken into account. The coupled-channels method has successfully accounted for experimental data for heavy-ion fusion reactions as well as quasi-elastic scattering.

Recently, however, a few experimental data which cannot be accounted for by the conventional coupled-channels method have been obtained. These include the quasi-elastic scattering experiment for ^{20}Ne + ^{90,92}Zr systems and the fusion and quasi-elastic scattering experiments for ^{16}O + ^{208}Pb system. The conventional coupled-channels calculations, which take into account only the collective excitations of the colliding nuclei, failed to reproduce the data, and the noncollective excitations, which are not included in the usual coupled-channels calculations, are suggested to play an important role in these systems. The noncollective excitations have not been taken into account explicitly in previous studies of the low-energy heavy-ion reactions, and their role has not been clarified. In this thesis, we explicitly take into account the noncollective excitations in the coupled-channels calculations and clarify their role in low-energy heavy-ion reactions.

At first, the fundamental properties of the collective and the noncollective excited states are reviewed. By using the liquid drop model, we discuss how the regularity of the collective excited states appears. We also mention an interpretation of the collective and the noncollective excited states from a microscopic point of view.

The theoretical framework for the study of the low-energy heavy-ion reactions is discussed in the next. The coupled-channels formalism is reviewed and the barrier distribution method is introduced. We discuss the effect of the collective excitations on heavy-ion fusion reactions through the calculation of the fusion barrier distribution. We also review the random matrix theory and its applications, as we employ the model of Weidenmüller *et al.* for deep inelastic collisions based on the random matrix theory for the description of the noncollective excitations.

We start our investigation of the role of the noncollective excitations with ^{16}O + ^{208}Pb system[2]. For this system, the energy dependence of the Q-value distribution (a distribution of the energy of a scattered particle) has been experimentally obtained. The experimental data show that the contribution from the higher excitation energy region, which can be considered as the noncollective excitations, increases as the incident energy increases. For ^{208}Pb, the information on the excited states up to a rather high excitation energy has been obtained by the high precision proton inelastic scattering experiments. We describe the noncollective excitations of ^{208}Pb using this information as inputs of calculations. We show that the energy dependence of the calculated Q-value distribution is consistent with the experimental data.

We then study the role of the noncollective excitations in the quasi-elastic scattering for ^{20}Ne + ^{90,92}Zr systems. For these systems, the experimental quasi-elastic barrier distributions show different behavior between the two systems, that is, the barrier distribution for the ^{20}Ne + ^{92}Zr system is much more smeared than that of the ^{20}Ne + ^{90}Zr system. However, the coupled-channels calculation cannot yield smeared barrier distribution for ^{20}Ne + ^{92}Zr system, and thus cannot account for the difference in the barrier distribution if only the collective excitations are taken into account. In order to see whether the noncollective excitations cure this problem, we take into account the noncollective excitations of Zr isotopes in the calculation. For the description of the noncollective excitations, we use the random matrix theory, because the information on the excited states has not been sufficiently obtained for Zr isotopes in contrast to the case of ^{208}Pb. We show that, by taking into account the noncollective excitations, the quasi-elastic barrier distribution for the ^{20}Ne + ^{92}Zr system is significantly altered, while for the ^{20}Ne + ^{90}Zr system, the effect of the noncollective excitations is found to be small. Although our calculation does not improve the agreement of the quasi-elastic scattering cross sections below the barrier, we show that the magnitude of the noncollective effect is considerably different between the two systems. This difference originates from the level density of the Zr isotopes. That is, since ^{90}Zr is a closed shell nucleus with 50 neutrons and ^{92}Zr has two extra neutrons, a large number of the noncollective excited states appear in ^{92}Zr nucleus. We also show that our calculation predicts a similar effect of the noncollective excitations for ^{24}Mg + ^{90,92}Zr systems.

[1] S. Yusa, K. Hagino, N. Rowley, Phys. Rev. C **82**, 024606(2010).

[2] S. Yusa, K. Hagino, N. Rowley, Phys. Rev. C **85**, 054601(2012).