Moduli Fields in String Phenomenology

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In superstring theory, it is needed to compactify the extra dimensions in order to construct four-dimensional effective theory. Then there appear moduli fields, which correspond to the degrees of freedom to deform continuously the compactified space. These fields are classified to three types: Kähler moduli, complex structure moduli and axio-dilaton. From the perspective of the low-energy effective theory, the moduli fields must be stabilized in the appropriate vacuum expectation value with appropriate mass. If the moduli fields cannot be stabilized, the massless moduli fields appear as fifth force in our universe. In addition, because the vacuum expectation values specify the size of compactified space and the parameters of the effective theory, the moduli stabilization is a serious problem. Thus, the moduli stabilization has been studied for a long time. Especially, the stabilization of Kähler moduli is an important problem. It is known that the Kähler moduli cannot be stabilized in tree level potential.

In this thesis, we present our three studies: the first one is a use of moduli fields for the inflation model. We show that "poly-instanton effect" makes moduli potential appropriate to the inflation naturally. The poly-instanton effect is a correction that, when multiple non-perturbative effects exist, they affect non-perturbatively each other. The second one is a new mechanism of the Kähler moduli stabilization. Because our universe is chiral, we studied the moduli stabilization using the chiral superfield. We show that the Kähler modulus can be stabilized if the chiral superfield couples to the Kähler modulus and certain conditions are satisfied. Also, we show that, in the mechanism called "Large Volume Scenario" (LVS), the chiral superfield could uplift the vacuum energy of the potential to the Minkowski one. The third one is the instability of supersymmetric vacuum in higher-dimensional gauge theories. Superstring theory in low-energy would lead to a higher-dimensional gauge theory which preserves supersymmetry. So, this study is an approach from the effective theory. In higher-dimensional gauge theories, it is known that Fayet-Iliopoulos term (FI-term) is induced in fixed points by radiative corrections. In the supersymmetric vacuum, the FI-term generates the vacuum expectation value of a bulk field. The vacuum triggers the localization of charged fields, which is very interesting for phenomenology. We investigated the instability of the vacuum in five- and six-dimensional models, and found that the instability may occur. Moreover, we claim that, in the six-dimensional

case the instability could be associated with moduli stabilization of the complex structure. Through these studies, we give implications about constructing string derived model.

This thesis is organized as follows. In Chapter 2, we introduce the axion inflation model based on the poly-instanton effect. We treat the axion which is included in the imaginary part of Kähler moduli as the inflaton. We show that the potential generated by the poly-instanton effect can have a flat region naturally, and the model which is consistent with observations can be constructed concretely. Therefore, we claim that the moduli are useful for solving the cosmological problems, for example, inflation.

In Chapter 3, we introduce the possibility of moduli stabilization using a chiral matter. This is because the Standard Model is a chiral theory. From this viewpoint, we show in what kind of situation the chiral multiplets make the Kähler moduli stabilized. Furthermore, we introduce the possibility of uplifting of vacuum energy using a chiral matter. The LVS is known as a mechanism of Kähler moduli stabilization, where the size of the six-dimensional volume can be exponentially large. We show that, in the LVS vacuum with negative energy, the chiral multiplets can uplift the energy to positive one without breaking the LVS vacuum structure extremely. Especially, in the both cases of stabilization and uplifting, we find that the form of the superpotentials is crucial, which means that the origin of the superpotentials is restricted.

In Chapters 4 and 5, we describe the vacuum instability triggered by the 1-loop FI-term. In Chapter 4, we consider the case of S^1/Z_2 orbifold model. In the orbifold model, the FI-term is generated by loop corrections, and it shifts the supersymmetric vacuum to another one. We confirm that the 1-loop FI-term could be induced again in the new supersymmetric vacuum. The FI-term that is generated in the new supersymmetric vacuum causes shift of the supersymmetric vacuum, which trigger the vacuum instability. Further, we see that the supersymmetric vacuum is stable when the configuration of brane modes that live in fixed points is symmetric. In Chapter 5, we introduce the extensions of the S^1/Z_2 orbifold model to the T^2/Z_2 orbifold model. We see that, even in the T^2/Z_2 orbifold model, the 1-loop FI-term triggers the vacuum instability, and the supersymmetric vacuum is stable when the configuration of brane modes is symmetric. Furthermore, we associate the vacuum instability with the moduli stabilization. This is because the instability occurs in the situation where the induced FI-term cannot vanish in the new supersymmetric vacuum and the potential energy arises from the non-vanishing FI-term. Therefore, we discuss which complex structure should be chosen, in other word, what value the complex structure is stabilized in.

In Chapter 6, we summarize the results of this thesis.