D-brane Models and D-brane Instantons in Type IIA Toroidal Orientifolds

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The standard model of the particle physics (SM) has been confirmed by many experiments and observations. One of the biggest results is the observation of the Higgs particle in the LHC. However, since the SM does not include the quantum gravity, we need a more fundamental theory. Suprstring theory is regarded as such a quantum theory of gravity. If superstring theory gives a quantum mechanical description of the universe, the SM should be interpreted as the low energy effective theory of superstring. In addition, the results of the LHC show that there is no new physics up to a few TeV. It may imply that the SM is valid until very high scale, e.g. the string scale. Thus, it would be important to construct such models that are derived from string theory and can explain the SM consistently.

In this thesis, we investigate inersecting D6-brane models on toroidal orientifold. Using these models, one can easily construct 4-dimensional chiral theories with various gauge symmetries. In Chapter 2, we review intersecting D6-brane models briefly. We show the reason why chiral theory can be constructed as open string massless modes, and we derive some constraints on D-brane models.

In Chapter 3, we construct a new class of intersecting D-brane models compactified on torus, whose massless spectrum is the same as the that of the SM. The $SU(2)$ gauge symmetry in the SM can be realized in two ways in D-brane models: $U(2)$ models and $Sp(2)$ models. Most previous works are investigated in the $U(2)$ model, but we constructed semi-realistic $Sp(2)$ models. As the result, we found that the $Sp(2)$ models can generate large discrete flavor symmetry. We also try to realize the gauge couplings of the SM in our models. In intersecting D-brane models, a gauge coupling is a function of the volume of each D-brane. Thus, it may seem always possible to realize a realistic values by tuning parameters. However, we show that this is not the case in our models, and one cannot

make the string scale arbitrarily low.

Chapter 4 and 5 are devoted to D-brane instantons on torus. The D-brane instanton is a D-brane which is localized in 4-dimensional Minkowski space, but has a finite volume in the compact dimensions. These effects can induce pertrubatively forbidden terms, e.g. neutrino Majorana mass terms and μ-terms of the Higgs fields. First, we study them on a simple torus. where we show that Majorana mass matrices generated by D-brane instantons have Z_3 permutation symmetry. μ-terms also have the permutation symmetry and it may induce an exponential hierarchy in the eigenvalues of the μ-term matrix. However, D-brane instantons on a simple torus have a problem that they may not generate a superpotenatial.

Thus, in Chapter 6, we investigate D-brane instantons wrapping rigid cycles on a $Z_2 \times Z_2$ toroidal orbifold, since such D-brane instantons can contribute to the superpotential naturally. We show that some Majorana mass matrix generated by rigid D-brane instantons on $Z_2 \times Z_2$ toroidal orbifold can have a Z_2 exchanging symmetry. These flavor symmetry may be the origin of the flavor structure of the SM. Approximate Z_2 and Z_3 symmetries are known in the observed neutrino mixing angles. Indeed, we showed that the mixing angles of neutrinos and mass splittings might be realized in a toy model.

Chapter7 is the summary.