

# More meta-stable brane configurations without D6-branes

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## Abstract

We describe the intersecting brane configurations, consisting of NS-branes, D4-branes (and anti-D4-branes), in type IIA string theory corresponding to the meta-stable nonsupersymmetric vacua of  $\mathcal{N} = 1$   $SU(N_c) \times SU(N'_c) \times SU(N''_c)$  gauge theory with bifundamentals. By adding the orientifold 4-plane to these brane configurations, we also discuss the meta-stable brane configurations for other gauge theory with bifundamentals. Furthermore, we study the intersecting brane configurations corresponding to the nonsupersymmetric meta-stable vacua of other gauge theory with bifundamentals, by adding the orientifold 6-plane. © 2007 Elsevier B.V. All rights reserved.

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## 1. Introduction

In the standard type IIA brane configuration, the quark masses correspond to the relative displacement of the D6-branes (0123789) and D4-branes (01236) along the 45 directions geometrically. Then the eigenvalues of quark mass matrix correspond to the positions of D6-branes in 45 directions. See the review paper [1] for the gauge theory and the brane dynamics. The Seiberg duality in the classical brane picture can be accomplished by exchanging the locations of the NS5-brane (012345) and NS5'-brane (012389) along  $x^6$  direction each other.

The geometric misalignment of D4-branes connecting both NS5'-brane and D6-branes in the magnetic brane configuration can be interpreted as a nontrivial F-term condition in the gauge

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theory with massive flavors. Then the F-term equations can be partially cancelled by both recombination of flavor-D4-branes with the color-D4-branes and then movement of those D4-branes into the 45 directions. This phenomenon in magnetic brane configuration corresponds to the fact that some entries in the magnetic dual quarks acquire nonzero vacuum expectation values to minimize the F-term in the dual gauge theory side. Moreover, the remaining flavor-D4-branes that do not move to 45 directions, connecting to NS5'-brane, can move along 89 directions freely since D6-branes and NS5'-brane are parallel and this geometric freedom of meson field corresponds to the classical pseudomoduli space of nonsupersymmetric vacua of the gauge theory.

On the other hand, it is known that the NS-brane configuration in type IIA string theory, where there exist only two types of NS5-brane and NS5'-brane, preserves  $\mathcal{N} = 2$  supersymmetry in four dimensions [1]. The geometry [2] of the coincident NS5-branes is characterized by the metric, the dilaton, and the field strength and is useful to construct the DBI action for D4-branes. In order to break the supersymmetry, one adds D4-branes and anti-D4-branes [3]. By adding D4-branes suspending between the NS5-brane and the NS5'-brane, and anti-D4-branes ( $\overline{D4}$ -branes) suspending between the NS5-brane and the other NS5'-brane, the supersymmetry of this system is broken [3]. The low energy dynamics can be described by the gauge theory on the D4-branes. The brane configuration corresponding to the electric theory with vanishing mass for the bifundamentals consists of the left NS5'-brane, the middle NS5-brane and the right NS5'-brane and two sets of D4-branes suspended between two NS5'-branes. The gauge group is a product of two unitary gauge groups and there exist bifundamentals. For the nonvanishing mass for these bifundamentals, the relative displacement between the two NS5'-branes along the 45 directions occurs. By taking the Seiberg dual for one of two gauge group factors with nonvanishing masses for the bifundamentals, the magnetic dual theory has a cubic superpotential between the dual quarks and a meson which is nothing but a quadratic term of bifundamentals in an electric theory. Also the linear term in a meson appears in this magnetic superpotential. Then the F-term equation for this meson field leads to the supersymmetry breaking. One finds that supersymmetry is broken classically but is restored quantum mechanically. It turns out the classical nonsupersymmetric vacuum becomes long-lived state [3].

As the distance between the two NS5'-branes along the 45 directions becomes zero, this brane configuration with D4- and  $\overline{D4}$ -branes can decay and the geometric misalignment between flavor-D4-branes arises, as before. Due to the presence of NS5-brane in this system, there exists an attractive force between the tilted D4-branes and NS5-brane. The explicit and careful computation of DBI action for these D4-branes in the background created by NS5-brane has been done by the work of [3] and this effect of the gravitational attraction leads to a curve for tilted D4-branes rather than a straight line. Then for small displacement of two NS5'-branes, the ground state is given by this “curved” brane configuration. As this displacement between two NS5'-branes is increased, the ground state brane configuration is given by “straight” brane configuration. The meta-stable vacua of [4] arise in some region of parameter space. In this description, the dual quarks are represented by the bifundamentals of product gauge group and the mass term is encoded by the relative displacement of two NS5'-branes in 45 directions, as we mentioned before. Note that there exist no D6-branes in this brane configuration.<sup>1</sup> When one of the NS5'-branes goes to infinity along the  $x^6$  direction, then the corresponding gauge group becomes a global symmetry and the theory leads to a standard  $\mathcal{N} = 1$  SQCD with fundamentals. In other regions,

<sup>1</sup> A replacement of D6-branes with NS5'-brane corresponds to the gauging of the flavor group (global symmetry) of the gauge theory realized on the D4-branes and this replacement might be useful to construct the phenomenological model building.

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