Non-perturbative Transitions among Intersecting Brane Vacua

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Summary

- Introduction and Overview
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- Field Theory Solutions of the D5 vs Magnetized D9 Transition
- Conclusions

Introduction and Overview

- Type I string theory with D9/D5 branes
  - D5 branes can be described as zero-size gauge instantons on the worldvolume of D9 branes
  - Instanton size related to vev of D9-D5 states
  - It is possible connect orientifold vacua with D9 and D5 branes to string vacua with internal magnetic fluxes
  - D5 branes are converted into magnetic flux on the D9 branes (brane transmutation)
  - This phenomenon is T-dual to brane recombination in the intersecting brane picture
  - In the low-energy limit this can be captured by a Higgs mechanism. Scalars living at the intersection of branes condense. The condensate interpolates between zero-size instantons and constant *non-Abelian* magnetic field ("fat" instanton)

[E. Witten "Small instantons in string theory", Nucl.Phys. B460 (1996)]

Introduction and Overview

- Present work
  - Possbile non-perturbative transitions among different orientifold vacua.
  - Low-energy field equations for the Abelian theory living on a D9 brane, we show that an *Abelian* constant magnetic field is generated which is related to the constant zero-mode of the Laplacian on a compact space.
  - The Abelian magnetic field is T-dual to the supersymmetric angle configuration in toroidal intersecting-brane models.
  - We extend the analysis of non-perturbative transitions to the class of non-supersymmetric vacua with Brane Supersymmetry Breaking.
  - We study specific examples based on the $\mathbb{T}^4/\mathbb{Z}_2$ in Type IIB and $\mathbb{T}^6/\mathbb{Z}_2 \times \mathbb{Z}_2$ with discrete torsion in Type IIA.
  - All string vacua, in a given orientifold construction, live in the same moduli space and are connected to one another by the process of brane recombination.

Brane Recombination and Higgs Effect

- Type IIB theory with intersecting D7 branes compactified on $\mathbb{T}^4/\mathbb{Z}_2$ with the orientifold projection $\tilde{\Omega} = \Omega(-1)^{F_L}\mathcal{R}$ yields six-dimensional supersymmetric vacua.
  - The branes wrap two-cycles $\Pi_a \in H_2(\mathbb{T}^4/\mathbb{Z}_2) =$ bulk cycles $\oplus$ exceptional cycles.
  - The invariant combination $\Pi_a + \tilde{\Omega}\Pi_a \equiv \Pi_a + \Pi_{\bar{a}}$ only wraps bulk cycles (perturbative description, the twisted tadpoles are identically vanishing).
  - Conservation of RR charges $N_c(\Pi_c + \Pi_{\bar{c}}) = N_a(\Pi_a + \Pi_{\bar{a}}) + N_b(\Pi_b + \Pi_{\bar{b}})$

$$N_c m_c^1 m_c^2 = N_a m_a^1 m_a^2 + N_b m_b^1 m_b^2 \, , \qquad N_c n_c^1 n_c^2 = N_a n_a^1 n_a^2 + N_b n_b^1 n_b^2$$

  - Example: $U(16) \times U(16)$ vacuum with $\Pi_{D7} \sim (1,0;1,0)$, $\Pi_{D7'} \sim (0,1;0,1)$ and massless spectrum consisting of hypermultiplets in $2 \times [(120,1) + (1,120)]$ and $(16,16)$
  - Recombining all branes yields $U(16)$ with $\Pi_r \sim (1,1;1,1)$ and massless spectrum consisting of four hypermultiplets in 120.
  - A Higgs effect involving a vev of the bifundamental $(16,16)$ representation describes this recombination at the field theory (massless) level.

Brane Recombination and Higgs Effect

- Type IIB theory with intersecting D7 branes compactified on $\mathbb{T}^4/\mathbb{Z}_2$ with the orientifold projection $\hat{\Omega} = \tilde{\Omega}\sigma$ yields six-dimensional BSB vacua.
  - One of the (two) $O7$ planes will be exotic (positive NSNS tension and RR charge).
  - The invariant combination $\Pi_a + \Pi_{\bar{a}} = 2c_a^1\pi_1 + 2c_a^2\pi_2 + 2\sum_{x,y}\epsilon_a^{xy}\mathbf{e}_{xy}$ (additional tadpoles for the twisted RR forms).
  - Conservation of RR charges

$$(\Pi_a+\Pi_{\bar{a}})+(\Pi_b+\Pi_{\bar{b}}) = (m_a^1m_a^2+m_b^1m_b^2)\pi_1+(n_a^1n_a^2+n_b^1n_b^2)\pi_2+2\sum_{x,y}(\epsilon_a^{xy}+\epsilon_b^{xy})\mathbf{e}_{xy}$$

  - Example: $SO(16)^2 \times USp(16)^2$ vacuum with $\Pi_{D7}^{\pm} \sim (1,0;1,0)$, $\Pi_{D7'}^{\pm} \sim (0,1;0,1)$.
  - Recombining all branes yields a two stack model $U(8) \times U(8)$ with opposite twisted charges$\Pi_r^{\pm} \sim (1,1;1,1)$ and massless spectrum consisting of four hypermultiplets in 120.
  - Higgs mechanism: extra states need to get a mass in order to reproduce the correct massless spectrum. Necessary third order Yukawa couplings and fourth-order scalar couplings exist.

Field Theory Solutions of the D5 vs Magnetized D9 Transition

- Six-dimensional Super-Yang-Mills theory compactified on a $\mathbb{T}^2$ with A_4, A_5 the components of the gauge field along the two torus ($\Phi = A_5 + iA_4$).
  - The scalar potential for a supersymmetric theory is: $\boxed{V = \frac{1}{2}D^2 + |F|^2}$
  - We parametrize the vev of the 95 multiplets by a localized FI term in the action

$$D = -\frac{1}{2}(\partial\Phi + \bar{\partial}\Phi) + \xi\delta^{(2)}(z)\,, \qquad F = 0$$

  - The equations of motion are: $\boxed{\partial D = \bar{\partial} D = 0}$
  - The solution: $\boxed{\Phi = \xi\,\partial G_2 \qquad D = \frac{\xi}{V}}$
  - Explicitly, making use of the expression of the Green's function, one has

$$\varPhi(z) = -\frac{\alpha\,\theta_1'(z|\tau)}{4\,\theta_1(z|\tau)} - \frac{\pi\alpha\,(z-\bar{z})}{4\,\mathrm{Im}\,\tau}$$

  - The last term in the equation above gives rise to a constant magnetic field.

Field Theory Solutions of the D5 vs Magnetized D9 Transition

- Eight-dimensional super Yang-Mills theory compactified on a $\mathbb{T}^4$ with Φ_1, Φ_2 the complex gauge fields along each of the two-tori.
  - The F and D terms are given by

$$\bar{F} = -\frac{1}{\sqrt{2}}\left(\partial_1 \Phi_2 - \partial_2 \Phi_1\right), \qquad D = -\frac{1}{2}\sum_{i=1}^{2}(\partial_i \bar{\Phi}^i + \bar{\partial}^i \Phi_i) + \xi\, \delta^{(4)}$$

  - Equations of motion: $\boxed{\bar{\partial}^i D - \sqrt{2}\,\epsilon^{ij}\,\partial_j F = 0}$
  - Solutions of the form: $\Phi_1 = k_1\,\partial_1\,G_4\,, \qquad \Phi_2 = k_2\,\partial_2\,G_4$
  - F- and D- terms then become:

$$\bar{F} = 0 \qquad \text{if} \qquad k_1 = k_2 = k$$

$$D = -(F_{45} + F_{67}) = \frac{\xi}{V_4} \qquad \text{with} \qquad k = \xi$$

  - The solution can be written as: $\boxed{A_\mu = M_{\mu\nu}\partial_\nu G_4 = M_{\mu\nu} x_\nu f(r)}$.

$$M_{\mu\nu} = k \begin{pmatrix} 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

Field Theory Solutions of the D5 vs Magnetized D9 Transition

- Dual field strength is: $\tilde{F}_{\mu\nu} = -F_{\mu\nu} - M_{\mu\nu}\Delta G_4$
- Locally

$$G_4 = c_1 + \frac{c_2}{r^2} - \frac{r^2}{4V_4} \;\rightarrow\; A_\mu = -\frac{1}{4}M_{\mu\nu}x_\nu(\frac{1}{V_4} + \frac{8}{r^4})$$

- Instanton number is infinite due to the singularity in the origin $f(r) \sim r^{-4}$.

Field Theory Solutions of the D5 vs Magnetized D9 Transition

- DBI (Dirac-Born-Infeld) corrections

$$\mathcal{L}_{DBI} = \sqrt{\det(g+F)}$$

  - We looked for a correction of the following form: $A_\mu = A_\mu^{(0)} + A_\mu^{(1)}$ with
  $$A_\mu^{(1)} = M_{\mu\nu} x_\nu g(r)$$
  - Expand for small F and keep the first subleading correction. Then the solutions is
  $$A_\mu = M_{\mu\nu} x_\nu (f - V_4^{-1} f^2 + O(V_4^{-2}))$$
  - In agreement with the subleading correction to the profile of a non-commutative $U(1)$ instanton in the singular gauge.
  - Since the solution has a fast variation near the singularity the DBI action is not a good approximation of the string effective action.
  - Higher derivatives change the behavior of the solution near the singularity, leading eventually to a finite instanton charge?

Conclusions

- We have investigated non-perturbative transitions among intersecting branes.
- All string vacua, in a given orientifold, are related to one another by brane recombinations.
- This phenomenon is T-dual to brane transmutation where D5 branes are converted into magnetic flux on the worldvolume of D9 branes.
- Brane recombinations and Higgs effect in vacua with Brane Supersymmetry Breaking ($\mathbb{T}^4/\mathbb{Z}_2$, $\mathbb{T}^6/\mathbb{Z}_2 \times \mathbb{Z}_2$).
- The solution of the equations of an Abelian theory on the D9 brane contained a constant magnetic field related to the constant zero-mode of the Laplacian on a compact space.
- It was singular at the origin and the instanton number was infinte.
- Higher derivative corrections can resolve the singularity at the origin?