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The fate of the type I non-BPS D7-brane

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Abstract

We describe the fate of the Type I non-BPS D7-brane, which is tachyonic but carries a non-trivial K-theory $\mathbf{Z_2}$ charge. It decays to topologically non-trivial gauge field configurations on the background D9-branes. In the uncompactified theory the decay proceeds to infinity, while with a transverse torus the decay reaches a final state, a toron gauge configuration with vanishing Chern classes but non-trivial $\mathbf{Z_2}$ charge. A similar behaviour is obtained for the type I non-BPS D8-brane, and other related systems. We construct explicit examples of type IIB orientifolds with non-BPS D7-branes, which are hence non-supersymmetric, but for which supersymmetry is restored upon condensation of the tachyon.

We also report on the interesting structure of non-BPS states of type IIA theory in the presence of an O6-plane, their M-theory lifts, the relation between string theory K-theory and M-theory cohomology, and its interplay with NS-NS charged objects. We discuss several new effects, including: i) transmutation between NS-NS and RR torsion charges, ii) non-BPS states classified by K-theory but not by cohomology in string theory, but whose lift to M-theory is cohomological.

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1 Introduction

Type I string theory contains certain D-branes with conserved K-theory charges, but which are nevertheless tachyonic. Specifically, type I non-BPS $\widehat{\text{D7}}$- and $\widehat{\text{D8}}$-branes [1] carry non-trivial K-theory $\mathbf{Z_2}$ charges, but contain world-volume tachyons arising from strings stretching between the non-BPS brane and the background D9-branes [1]. Given their non-trivial conserved charges, such states must decay not to the vacuum, but to some other state with their same quantum numbers. In this note we give a detailed picture of this decay, intending to clarify some confusion in the literature. We would like to mention however that some of the points have been anticipated in [2, 3].

Intuitively, one expects these branes to decay to gauge field configurations on the D9-brane world-volume, associated to topologically non-trivial bundles in the correct K-theory class. In fact, in Section 2 we argue that the $\widehat{\text{D7}}$-brane in the uncompactified theory is unstable against dissolving as a monopole-antimonopole pair in the D9-brane gauge group. The tachyon has a runaway behaviour and does not reach a minimum for any finite characteristic size of the gauge field lump. Hence the decay continues to infinity, leading to an infinitely extended and diluted gauge configuration. If the space transverse to the $\widehat{\text{D7}}$-brane is compactified on a two-torus, the decay reaches a final state, which we characterize in detail as a $\mathbf{Z_2}$ toron of $SO(32)$ gauge theory. We also describe a T-dual picture in which the decay process is very intuitive, and corresponds to recombining intersecting D-branes into smooth ones, in the spirit of e.g. [4, 5].

In Section 3 we analyze the decay of the $\widehat{\text{D8}}$-brane, whose story is similar. It decays to a 'kink' configuration in the D9-brane gauge group, which in a non-compact setup does not reach any final state but becomes infinitely extended and diluted. In compact space it reaches a final state described by a $\mathbf{Z_2}$ Wilson line on the D9-branes. In Section 4 we describe related systems of D-branes and O-planes.

In Section 5 we extend on an independent topic, originally motivated by the above systems. We consider the system of an O6-plane with no overlapping D6-branes. By the previous analysis this theory contains stable non-BPS $\widehat{\text{D4}}$- and $\widehat{\text{D5}}$-branes, carrying $\mathbf{Z_2}$ charges. In discussing the M-theory lift of these and other stable non-BPS states in the configuration, we find multiple interesting issues concerning the nature of NS-NS and RR charges in the IIA theory, and its M-theory origin. In particular, we find that certain non-BPS states carrying torsion NS-NS and RR charges are topologically equivalent once lifted to M-theory. We also find non-BPS states in IIA theory whose charge is classified by K-theory but not by cohomology, but whose M-theory lift corresponds

[1]We use a bar to denote antibranes, and a hat to denote non-BPS branes

to M-branes wrapped on torsion cohomology cycles in the Atiyah-Hitchin manifold. This result is relevant in understanding the appearance of K-theory in string theory as derived from M-theory, and we explain why it suggests an extension of those in [6]. This section is self-contained, and the reader interested only in these aspects is adviced to proceed directly to it.

Finally, in the appendix we construct an explicit type IIB orientifold with $\widehat{\text{D7}}$-branes, where a proper understanding of the tachyon is quite essential, since supersymmetry is restored upon condensation of the $\widehat{\text{D7}}$-brane tachyon.

2 The fate of the type I non-BPS D7-brane

2.1 Construction

As described in [7], the type I non-BPS $\widehat{\text{D7}}$-brane is constructed as a pair of one D7- and one $\overline{\text{D7}}$-brane in type IIB, exchanged by the action of world-sheet parity Ω. In the world-volume of the $7\overline{7}$ pair, before the Ω projection, the 8d spectrum is as follows: In the 77 sector we have a $U(1)$ gauge boson, one complex scalar, and fermions in the $4+\overline{4}$ of the $SO(6)$ Lorentz little group; the $\overline{77}$ sector leads to an analogous piece; the $7\overline{7}+\overline{7}7$ sector provides one complex tachyon and two fermions in the $4+\overline{4}$, all with with $U(1)^2$ charge $(+1,-1)$. The Ω action exchanges the 77 and $\overline{77}$ sectors, leaving a group $U(1)$, a complex scalar and vector-like fermions, and maps the $7\overline{7}+\overline{7}7$ to itself, projecting out the tachyon and keeping just one set of fermions.

Hence the type I $\widehat{\text{D7}}$-brane would appear to be tachyon-free. However, RR tadpole cancellation in type I requires the presence of a background of 32 D9-branes, the role of which for the stability of the $\widehat{\text{D7}}$-brane was noticed in [1] (see also [8]). In fact, the $79+97$ sector gives a complex tachyon field, and one chiral fermion, while the $\overline{7}9+9\overline{7}$ sector gives their Ω image.

Despite the instability associated to this tachyon, the D7-brane is unable to decay to the vacuum. This follows from the fact that it carries a $\mathbf{Z_2}$ charge corresponding to the non-trivial K-theory class x in $\mathbf{KO}(\mathbf{S}^2)=\mathbf{Z_2}$. In fact, as proposed in [7] and checked in [9], the $\mathbf{Z_2}$ charge can be detected by a -1 sign picked up by a $\widehat{\text{D0}}$-brane probe moving around the $\widehat{\text{D7}}$-brane in the transverse two-plane. Since the $\widehat{\text{D0}}$-brane transforms as a $SO(32)$ spinor [10], this implies that the K-theory class associated to the $\widehat{\text{D7}}$-brane corresponds to a topologically non-trivial bundle with asymptotic monodromy in the non-trivial element of $\Pi_1(SO(32))=\mathbf{Z_2}$. This property in fact characterizes the non-trivial class x in $\mathbf{KO}(\mathbf{S}^2)=\mathbf{Z_2}$

A different way to detect the $\mathbf{Z_2}$ charge of the $\widehat{\rm D7}$-brane is to introduce a D5-brane probe intersecting the $\widehat{\rm D7}$-brane over a four-dimensional space [11]. The intersection leads to a single four-dimensional Weyl fermion doublet of the D5-brane $SU(2)$ gauge group. The $\mathbf{Z_2}$ global gauge anomaly [12] from this 4d fermion is a reflection of the non-trivial $\mathbf{Z_2}$ charge of the $\widehat{\rm D7}$-brane [2]. In fact, the appearance of such fermion implies that the K-theory class of the $\widehat{\rm D7}$-brane corresponds to a bundle with an odd number of fermion zero modes of the (real) Dirac operator. By the index theorem [14], this characterizes the K-theory class of the $\widehat{\rm D7}$-brane as the non-trivial class x in $\mathbf{KO}(\mathbf{S}^2) = \mathbf{Z_2}$.

Hence the type I $\widehat{\rm D7}$-brane carries a topological charge, endowing it with quantum numbers different from those of the vacuum, to which it cannot decay. It must instead decay to some state carrying the same $\mathbf{Z_2}$ (and no other) charge. Since, from the viewpoint of the parent type IIB theory, the tachyon triggering the decay arises from open strings stretching between the D9- and D7-branes (the $\overline{7}9{+}9\overline{7}$ sector giving merely its Ω image), one is led to suspect that the decay will be roughly speaking a Ω-invariant version of the much studied tachyon condensation in the Dp-D$(p+2)$ system (see e.g. [15]). In fact, our analysis below will make this analogy quite precise, and establish that the $\widehat{\rm D7}$-brane dissolves as a non-trivial gauge field configuration on the D9-brane gauge group. Much as in the Dp-D$(p+2)$ system, for non-compact transverse space the tachyon condensation does not reach an endpoint and leads to infinitely extended and diluted gauge configurations. For compact transverse space, however, the tachyon reaches a minimum and the condensation reaches an endpoint configuration.

2.2 The non-compact case

We have argued that the $\widehat{\rm D7}$-brane is unstable against decay to a topologically non-trivial gauge bundle on the D9-branes, characterized by the K-theory class x associated to the $\widehat{\rm D7}$-brane $\mathbf{Z_2}$ charge. Indeed, it is easy to describe $SO(32)$ gauge configurations on $\mathbf{R^2}$ carrying such charge. Before going into details, let us emphasize that such configurations are however not solutions of the equations of motion. A scaling argument [7] shows that any such lump configuration can lower its energy by increasing its characteristic size. Hence, the gauge field lumps tend dynamically to become infinitely

[2] In the non-compact context, this anomaly is presumably cancelled by a (K-theoretic) anomaly inflow mechanism, implicit in [13]. Hence there is no inconsistency in the configuration, corresponding to the fact that D-brane charge need not cancel in non-compact space.

extended and diluted [3]. However, it is interesting to explore the properties of the topological class of such configurations.

In order to describe a simple example, let us split the group $SO(32)$ as $SO(30) \times SO(2)$, and embed a non-trivial gauge background on the $SO(2)$ factor, of the form

$$F = f(x_1, x_2) \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \tag{2.1}$$

Here $f(x_1, x_2)$ is a function with compact support in a subset Σ or $\mathbf{R^2}$.

We should require proper Dirac quantization for fields in the adjoint of $SO(32)$. This representation decomposes as $\mathbf{496} = \mathbf{435}_0 + \mathbf{30}_{+1} + \mathbf{30}_{-1} + \mathbf{1}_0$, with subindices denoting the $SO(2)$ charge. Hence, Dirac quantization for this representation requires the integral of f to be 2π times an integer. Choosing the minimum Dirac quantum

$$\int_\Sigma f(x_1, x_2) dx_1 dx_2 = 2\pi, \tag{2.2}$$

quantization is obeyed for the $SO(32)$ adjoint, but not for the $SO(32)$ spinor representation. Fields in this representation carry charge $q = \pm 1/2$ under the $SO(2)$ subgroup, hence their asymptotic holonomy is

$$\exp(q \oint_{\partial\Sigma} A) = \exp(q \int_\Sigma F) = \exp(q\, 2\pi i \sigma_2) = -\mathbf{1}_2 \tag{2.3}$$

Hence $\widehat{\mathrm{D0}}$-branes pick up a -1 phase in going around the gauge field lump (2.1), which therefore carries the correct K-theory $\mathbf{Z_2}$ charge. Notice that, regarding the $SO(2)$ subgroup as arising from two D9-branes (related by Ω), the above gauge background can be seen as a unit Dirac monopole in one D9-brane (we denote it $\mathrm{D9}_+$) and an antimonopole in another ($\mathrm{D9}_-$), both being exchanged by Ω.

It is also easy to detect the $\mathbf{Z_2}$ topological charge by introducing a D5-brane probe, spanning the directions x^1, x^2. The 4d Weyl fermions in doublets of the D5-brane $SU(2)$ arise from zero modes in the Kaluza-Klein reduction of the 6d fermions in the 59+95 sector, in the presence of the gauge field background. Clearly, strings stretched between D5-branes and the 30 D9-branes with no gauge flux lead to no contribution to the 4d global gauge anomaly. However, fermions zero modes arise from strings stretched between the D5-branes and the $\mathrm{D9}_+$-brane (while strings stretched between the D5- and the $\mathrm{D9}_-$-brane are merely their Ω image). The number of fermion zero modes is given by the index of the (complex) Dirac operator coupled to the monopole

[3]The absence of a tachyon vacuum manifold allows to avoid the argument in [8]. For more detailed discussion of the relation, in this example, between the classification of states by K-theory classes vs. homotopy classes of the vacuum manifold, see [3].

background. By the index theorem, this number is 1 for the minimum quantum (2.2), reproducing the correct 4d Weyl fermion global anomaly. The above discussion can be regarded as a rudimentary computation of the mod two index of the real Dirac operator of the $SO(32)$ gauge configuration.

Notice that for any such configuration, strings stretched between the 30 D9-branes with no background, and the $D9_+$- or the $D9_-$-brane lead to additional tachyons, whose condensation would further break the gauge group. Such strings behave as charged particles in a magnetic field, and so are localized in $\mathbf{R^2}$. The negative squared masses of the tachyons are related to the gauge field strength at such points. Hence, as the flux becomes more dilute the masses get less and less tachyonic. This argument also supports that the system become more and more stable as the gauge lump expands.

2.3 Toroidal transverse space

The situation would be better understood by taking the space transverse to the $\widehat{\rm D7}$-brane to be a $\mathbf{T}^2$, since the size of the gauge field lump would have an upper bound, and we may expect a well-defined final state. Notice that there is a subtlety in trying to do so: As discussed in [11], consistency of the configuration requires cancellation of the K-theory $\mathbf{Z_2}$ charge in the compact space, so we have to include at least two $\widehat{\rm D7}$-branes. The total configuration hence has the same quantum numbers as the vacuum, to which it could annihilate. However, for our present purposes we may consider one of the $\widehat{\rm D7}$-branes as spectator, and ignore it in the analysis of the decay of the other. We will be interested in describing the decay in this setup [4].

2.3.1 A T-dual picture

One advantage in making the transverse space compact is the possibility of using T-dual pictures to describe the decay process. Considering for simplicity a square two-torus, and vanishing NS-NS B-field, we may T-dualize along one direction in the torus to get type I' theory, as depicted in Fig 1. The O9-plane becomes two O8-planes, and the D9-branes become D8-branes, all depicted horizontally in the picture. The type IIB D7-$\overline{\rm D7}$ pair becomes a pair of oppositely oriented vertical D8-branes, which are exchanged by

[4] A more suitable system to address the compact setup would be the (isomorphic in other respects) decay of a non-BPS D$(p-2)$-brane in the presence of Dp-branes on top of an Op-plane, See section 4. The existence of this non-BPS brane, its non-trivial $\mathbf{Z_2}$ charge, and its tachyon in the p-$(p-2)$ sector, are shown in the same way as for the $\widehat{\rm D7}$-brane. For lower p we may consistently compactify without bothering about tadpole cancellation conditions.