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Nuclear Physics B 906 (2016) 194–210

NUCLEAR PHYSICS B

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Branes at angles from worldvolume actions

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Received 30 November 2015; accepted 22 February 2016

Available online 2 March 2016

Editor: Stephan Stieberger

Abstract

We investigate possible stable configurations of two arbitrary branes at general angles using the dynamics of DBI + WZ action. The analysis naturally reveals two types of solutions which we identify as the "marginal" and "non-marginal" configurations. We characterize possible configurations of a pair of identical or non-identical branes in either of these two classes by specifying their proper intersection rules and allowed intersection angles. We also perform a partial analysis of configurations with multiple angles of a system of asymptotically flat curved branes.

1. Introduction and summary

Brane configurations consisting of intersecting BPS branes [1,2] have been the cornerstone of many recent developments and applications of string theory. Beside their role in studying black hole solutions in string theory [3], they have been of importance in providing a new perspective on supersymmetric gauge theories [4]. Phenomenologically, stable or unstable configurations of intersecting branes are of interest both for model building in particle physics [5] and for a realization of inflationary models in cosmology [6].

Configurations of intersecting BPS branes at arbitrary angles have been studied both in view of their supersymmetry properties and in terms of their interactions in string theory [7–11]. At low energies, a brane configuration is described by a classical supergravity solution with suitable isometries that encodes the physical information regarding pairwise brane intersec-

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http://dx.doi.org/10.1016/j.nuclphysb.2016.02.026

tions [1,2]. Using this approach, several orthogonal brane configurations [12,14–17] as well as the non-orthogonal ones [19–25] made up of branes at arbitrary angles have been constructed. Brane intersections (or bound states) naturally fall in either of the two categories termed as the "marginal" and "non-marginal" configurations [12–14], depending on whether or not they remain stable for arbitrary separation of the constituent branes. In the search for general supergravity solutions corresponding to orthogonal marginal intersections of branes of arbitrary dimensions, one finds a set of consistency conditions that determine dimensions of the pairwise intersections in terms of the branes dimensions and couplings in the problem [15,25]. These relations give the "intersection rules" [15–17] of the brane system which determine the allowable intersections in a given model of supergravity. It turns out that these relations have physical interpretations in terms of the no-force conditions between pairs of p-branes [12,25].

Non-orthogonal BPS brane configurations at more general angles were first explored in Ref. [7] using both supersymmetry and worldsheet techniques. They found that generally two BPS D$(p+n)$-branes sharing p of their dimensions form a BPS configuration, if they are rotated into each other by an $SU(n)$ ($\subset SO(2n)$) rotation. Shortly afterwards, examples of supergravity solutions describing D$(p+2)$-branes at $SU(2)$ angles were explicitly constructed [19]. It turns out that in this case solutions describe marginal configurations. These are in contrast to another type of solutions, found later in [20], describing a configuration of NS5-branes at $Sp(2)$ angles, which indeed belongs to the non-marginal category. Except for these two main examples, and those related to them by dualities and some generalizations [21–24], no other solutions for branes at general angles are known. In particular, there have been no solutions that describe multi-angle intersections of a pair of identical[1] branes at $SU(n)$ angles for $n \geq 3$, or those for a pair of non-identical branes at angles other than $0, \pi/2$. Since the $SU(n)$ condition [7] is a result of the asymptotic Killing spinor equation for flat geometries of the spacetime and the branes, one is tempted to guess that such intersections may be formed between pairs of locally curved but asymptotically flat p-branes.

The purpose of this paper is to study the problem of branes at angles from the different point of view of brane's worldvolume (DBI + WZ) action. This has the advantage of directly determining allowable (i.e. stable equilibrium) configurations of branes by giving the full set of consistency conditions for the corresponding supergravity solutions without actually solving the field equations. This will give the allowed number of dimensions shared by the two branes and their possible angles of intersection. Further, it has the capability of determining the marginal or non-marginal nature of a bound state of branes, while predicting the flat or curved profile of the individual branes in the equilibrium configuration. To use this method in full generality, one should in principle take into account the coupling of each of the branes to the supergravity background due to all of the branes including that of each brane itself. For a configuration of flat BPS branes in equilibrium, however, one can use the simplification due to the fact that the individual branes are already kept in balance by their self-interaction forces. So, in effect, any of the branes in the system can be treated as a probe in the supergravity background produced *only* by the rest of the branes. In this paper we will apply this sort of probe analysis to pairwise brane intersections in models of supergravity with a metric, one (or no) dilaton field and appropriate p-form gauge fields. For simplicity and uniformity of the formulation, we will ignore the possibility of

[1] In this paper we will refer to two branes as being "identical" if they carry the same type of form-field charges, and as the "non-identical" on the contrary.