UTRECHT UNIVERSITY

Department of Physics

Theoretical Physics master thesis

D-brane gauge theories with spontaneous supersymmetry braking through freely acting orbifolds

First examiner:

Stefan Vandoren

Second examiner:

Thomas Grimm

Candidate:

Hugo Calvo Castro

In cooperation with:

George Gkountoumis

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Abstract

In the context of String Theory, freely acting orbifolds have proven to be an effective method of spontaneously breaking supersymmetry (cite). The effects on the spectrum of the closed string in type IIB String Theory have been studied in detail in (cite), and this thesis aims to explore the effects of the SUSY breaking in the open string spectrum. Here we first show how the open string spectrum is affected in general by the orbifold action, and we calculate the full orbifold projection on a specific example of D1/D5 brane system. This system is closely linked to black hole solutions of the low energy supergravity, and in the last section we give predictions as to how the orbifold projection acts on the low energy worldvolume CFT and thus the black hole theormodynamics in the system with broken supersymmetry.

Contents

1. Introduction

Physics aims to describe the dynamics between all the fundamental constutuents of nature. In the one hand, we can use Quantum Field Theory to describe Particle Physics, and in the other we can use General Relativity to describe astronomical interactions. These two theories are fundamentally different in the sense that the first is a quantum theory, while the second one is not, and the most naive attempts to convert it to quantum language fail fundamentally.

String theory is a paradigm change to the way Particle Physics is built, in the sense that now the fundamental objects are no longer point-like, but extended one dimensional *strings*. Among an impressive list of results that were derived not long after String Theory was invented, the most notable one might be that this fully quantum theory is a theory of gravity. Thus, being a promising candidate for a unifying theory of physics.

One of the issues of String Theory is that in order to have a consistent theory (no tachyons) we need to add supersymmetry in the sense of fermionic excitations of the string. It turns out that the low energy effective theory of this system is Super Gravity (SUGRA), which is the supersymmetric extension of Einstein's General Relativity. But, as we all know, supersymmetry is not actually a low energy symmetry of nature in our universe.

At this point, we can look for ways of breaking the supersymmetry of String Theory. The one considered for this thesis is compactification by freely acting orbifolds. In essence, there is a discrete symmetry in the compact dimensions that gets quotiented away, projecting a part of the spectrum that has a nontrivial group charge.

String Theories in orbifolded backgrounds have been studied extensively (cite), with a focus on the closed string spectrum and the low energy SUGRA (cite). It was discovered that the orbifold projection can be regarded as a

Higgs-like mechanism for the charged fields.

In this thesis we will focus on the open string spectrum, which has not yet beef fully understood in orbifold backgrounds. A full description of the spectrum will be given in a general orbifold for some specific examples, namely the D1/D5 system.

The main goal is to calculate the central charge of the effective CFT in the infrared (IR) of this D1/D5 system, that is dual to a certain black hole solution of the corresponding SUGRA. This process is still not well understood but a prediction can be made based on the projections of the spectrum.

1.1 Outline

This thesis will be organized as follows. In Chapter 2 we will briefly describe general aspects of String Theory relevant for delevoping the later calculations. In Chapter 3 we will describe the massless spectrum of type IIB String Theory from a group theoretical point of view. In Chapter 4 we will use the group theoretical description to understand how the orbifold modifies the spectrum and thus breaks supersymmetry.

Lastly, in Chapters 5 and 6 we will give a dynamical description to the spectrum found in previous chapters, with the goal of calculating thermodynamic quantities of the black hole that describes the D1/D5 system in the orbifold background.

1.2 Conventions

2. Preliminaries

In this chapter we will present some basic concepts necessary to later build

2.1 Type IIB string theory

2.2 Orbifolds

2.2.1 D-branes

2.3 Supersymmetry

3. Open string spectrum

In this chapter we will describe the spectrum of D-brane systems in the context of type IIB String Theory. We start by discussing single brane spectrums, and then move on to general brane configurations, to conclude with the main example of this thesis, the D1/D5 brane system.

3.1 Dp-Dp spectrum

Consider a single D9-brane. This equates to considering Neumann boundary conditions in all directions of a string. The NS vacuum is a scalar $|0\rangle$, while the R sector is a spinor $|a\rangle$, given by $SO(2)$ eigenvalues s_0, s_1, s_2, s_3, s_4. The massless spectrum can be found from the mass formula $\alpha' M^2 = N + 1/2$. This leads to the modes $b^{\mu}_{-1/2}|0\rangle$ and $|a\rangle$.

The representation theory of the massless spectrum turns out to be straight forward. There is a vector and a fermion in D = 10, composed by $b^{\mu}_{-1/2}|0\rangle$ and $|a\rangle$ respectively.

To obtain the spectrum of an arbitrary Dp-brane we can perform dimensional reduction over the D9 spectrum we already constructed. By dimensional reduction we mean splitting the D9 symmetry group $SO(1,9)$ into the transverse and world-volume symmetry groups of the lower dimensional Dp-brane, namely, $SO(1,p) \times SO(9-p)$.

Starting with a vector in the $\mathbf{10}$ of $SO(1,9)$, it decomposes into a $(\mathbf{p}, \mathbf{1}) \oplus (\mathbf{1}, \mathbf{9} - \mathbf{p})$ of $SO(1,p) \times SO(9-p)$. The original R vacua was a Majorana-Weyl spinor of $SO(1,9)$, and depending on p it will decompose into the corresponding irreducible spinors of $SO(1,p) \times SO(9-p)$. The dimensional reduction of spinors is discussed in detail in A.

This is already the full spectrum of a single Dp-brane. Extending it to a stack of Q_p Dp-branes adds a Chan-Paton factor to both string ends, which labels the adjoint representation of $U(Q_p)$.

We can count on-shell degrees of freedom to make sure the spectrum is supersymmetric. For a explicit example, we can consider a single D5-brane. By on-shell we refer to adopting light-cone gauge, meaning that $SO(1,5) \to SO(4)$, effectively identifying 2 degrees of freedom for the vector, and specifying a s_0 eigenvalue for the spinor.

$$
\begin{aligned}
(\mathbf{6},\mathbf{1}) &\to (\mathbf{4},\mathbf{1} \\
(\mathbf{1},\mathbf{4}) &\to (\mathbf{1},\mathbf{4}) \\
(\mathbf{4}_s,\mathbf{2}_s) &\to (\mathbf{2}_s,\mathbf{2}_s) \\
(\mathbf{4}_c,\mathbf{2}_c) &\to (\mathbf{2}_c,\mathbf{2}_c)
\end{aligned}
$$

Now if we count degrees of freedom in the right side, we find that there are 8 matching bosonic and fermionic degrees of freedom, meaning that there can be 8 on-shell supercharges in the theory. A general discussion can be made for any p to find the same 8 possible on-shell supercharges.

3.2 Dp-D(p+4) spectrum

3.3 D1/D5 spectrum

4. Orbifolds

4.1 Orbifold compactification

4.2 Orbifold group action on the spectrum

Representations of the rotation group -> action by the orbifold group (discrete SO(4) rotations). So non-trivial charges.

5. D-brane gauge theories

5.1 Gauge theory on a single brane and dimensional reduction

5.2 Gauge theory of the D1/D5 system

5.3 Coulomb and Higgs branch

6. Infrared limit and Black Hole thermodynamics

6.1 IR SCFT = black hole theormodynamics

6.2 Predictions of IR limit in orbifold context

7. Conclusions

Appendices

A. Spinors in various dimensions

A.1 Weyl Spinors in $D = 2, 4, 6, 8, 10$

A.2 Majorana condition

A.3 Table of irreducible spinors in even dimensions