Contents

Chapter 1

Type IIA generalities

The are six main types of strings theories: a bosonic string theory and five supersymmetric string theories, the latter include both bosons and fermions. In this thesis we will only work with the supersymmetric type IIA theory.

TIIA spectrum

Type IIA string theory requires ten space-time dimensions to be consistent. Furthermore, it has a 10-dimensional supersymmetry with 32 supercharges, which corresponds to $\mathcal{N} = (1, 1)$. The flat 10-dimensional space-time bosonic spectrum of type IIA can be classified according to the boundary conditions of the strings, whether we consider Ramond (R) or Neveu–Schwarz (NS) conditions. In the NS-NS sector, we have the dilaton ϕ, a two-form B_2 and a graviton $G_{\mu\nu}$, while in the R-R sector we have the 1- and 3-forms c_1, c_3. The fermions, which belong to the NS-R and R-NS sectors, are two opposite-chirality gravitinos ψ and two opposite-chirality dilatinos λ.

The D-brane

A generalization of strings are Dp-branes, which are p-dimensional extended objects. Thus, a D1-brane would correspond to a string, a D2-brane would be a membrane and so on. The existence of Dp-branes can be motivated, in the weak coupling limit, as objects where open strings end, so they are a way to impose Dirichlet boundary conditions on open strings. In fact, D-branes should be though as new non-perturbative states in their own right.

Might remove last line. More subtle than this. In perturbative regime branes are fully described in terms of strings. f-strings, T and S dualities lead to a more democratic formulation in non-perturbative regime.

We can study the dynamics of a Dp-branes in terms of the dynamics of open strings with endpoints attached to the Dp-brane. Let us consider the open string excitations of a Dp-brane, the latter spanning $p+1$ dimensions and transverse to $d-p-1$ dimensions. The presence of the Dp-brane breaks the ten-dimensional Poincaré invariance of the theory, because particles propagate on the $(p+1)$-dimensional volume of the Dp-brane only. This implies that massless particles must transform under irreducible representations of $SO(p-2)$, instead of $SO(d-2)$. The massless spectrum in $(p+1)$ dimensions of the open string theory is composed by a gauge boson A^μ ($\mu = 0, \ldots, p$) (corresponding to transverse oscillations to the brane), $9-p$ real scalars ϕ^i (corresponding to longitudinal oscillations to the brane) and some fermions λ_a. This particle content can be arranged into a vector supermultiplet of $U(1)$ with 16 supersymmetries in $(p+1)$ dimensions. Thus, a Dp-brane reduces the degree of supersymmetry of the type IIA theory by half.

In order to find out the action of a Dp-brane we must realize that it corresponds to the $(p+1)$-dimensional effective action of the massless open string excitations of the Dp-brane. As an illustration of this, a Dp-brane breaks the translational symmetry of the vacuum, which allows us to conclude that the ϕ^i scalar fields are the Goldstone bosons associated to the broken symmetry. The vev of these scalar fields determine the position of the Dp-brane in the transverse space, and the fluctuations of the scalar fields determine the evolution of the Dp-brane wordlvolume W_{p+1} (the worldline of a particle generalization to the case of branes). The resulting action of the bosonic sector of the Dp-brane is the sum of a Dirac-Born-Infeld term S_{DBI} and a Chern-Simons term S_{CS}.

The DBI term carries the information of how a Dp-brane interacts with the NSNS fields. It takes the form

$$S_{DBI} = -\frac{\alpha'^{-(p+1)/2}}{(2\pi)^p} \int_{W_{p+1}} d^{p+1}x f(\phi^i, A^\mu, G_{\mu\nu}, B_2, \phi) \tag{1.1}$$

where the precise expression of f is unimportant for the purposes of this work.

What is the background here and what is dynamical? BG: closed string fields and Dynamical: open string fields?

If we expand the DBI action in powers of α', we obtain the Yang-Mills term

$$S_{YM} = \frac{\alpha'^{-(p-3)/2}}{4g_s(2\pi)^{p-2}} \int d^{p+1}x\sqrt{-g}\,\mathrm{Tr}\,F_{\mu\nu}F^{\mu\nu} \tag{1.2}$$

which allows us to identify the Yang-Mills coupling as

$$g_{YM}^2 = g_s\alpha'^{(p-3)/2}(2\pi)^{p-2} \tag{1.3}$$

The Chern-Simons term is topological in nature and describes how Dp-branes interact with RR-fields.

Anything more to add?

Multiple D-branes

It is convenient to generalize the single Dp-brane configuration to N parallel Dp-branes. In order to determine the spectrum of a stack of Dp-branes, we consider open strings with endpoints attached to either a single brane or two of them.

In the case of N coincident Dp-branes, all configurations lead to massless states, so the gauge symmetry is increased from $U(1)$ to $U(N)$. The massless spectrum is composed of $(p-1)$-dimensional $U(n)$ gauge bosons, $(9-p)$ real scalars in the adjoint representation and several fermions in the adjoint representation.

If all branes are separated from each other, strings that stretch from a brane to itself correspond to massless gauge bosons that belong to $U(1)^N$. In contrast, strings that stretch from one brane A to another brane B lead to massive particles whose masses increases with the distance between branes. The lightest of these particles have opposite have charge $(1,-1)$ under $U(1)_A \times U(1)_B$. Since Type IIA strings carry an orientation, string that stretch from B to A would have opposite charges.

Let us now suppose Dp-branes which are not parallel, so they can intersect each other. This situation is relevant because in the case of D6-branes, it leads to 4-dimensional chiral fermions. We are interested in describing the open string spectrum of two stacks of D6-branes that intersect over a 4-dimensional subspace of their volumes.

Strings that stretch from a coincident stack of N D6-branes to itself lead to 7-dimensional $U(N)$ gauge bosons, three real adjoint scalars and their fermion superpartners.

String that stretch from a stack of N_1 D6-branes to another stack of N_2 D6-branes are localized at the intersection, in order to minimize their energy. They lead to a 4-dimensional fermion charged in the $(\mathbf{N_1}, \mathbf{N_2})$ of $U(N_1) \times U(N_2)$ or its conjugate, depending on the orientation of the intersection.

Not all geometric configurations preserve supersymmetry. Let us decompose space-time as $M_4 \times \mathbb{R}^2 \times \mathbb{R}^2 \times \mathbb{R}^2$. The D6-branes span all M_4 and a line in each $\mathbb{R}^2$ plane, such that the angle between two stacks is given by θ_i for each plane. It can be shown that the condition $\theta_1 \pm \theta_2 \pm \theta_3 = 0(\mathrm{mod} 2\pi)$ implies $\mathcal{N} = 1$ supersymmetry in 4 dimensions, provided that no angle vanishes. If some of the angles vanish, the supersymmetry would we enhanced.

The reason we have used D6-branes and no other dimension of Dp-branes is that they would not lead to chiral fermions in 4 dimensions. Intuitively, two D6-branes allow to define an orientation in the transverse 6-dimensional space, which would not be possible with two other type of Dp-branes.

So have we seen that no Calabi-Yau is needed to obtain 4d chiral fermions if we consider a theory with intersecting D6-branes? Of course, we still would have to cancel RR charges in some way.

Add tadpole cancellation here?

SUGRA

The low-energy theory of the ten-dimensional type IIA string theory is type IIA SUGRA. The spectrum of Type IIA SUGRA has as elementary fermions, which belong to the massless spectrum (NS-R and R-NS) of type IIA theory, two Majorana-Weyl gravitinos of the same chirality ψ^a_M and two dilatinos λ^a.

Isn't the spectrum the same as the high-energy TIIA? Might not need to mention SUGRA here then.

Bibliography

How should I cite?