String Compactification with magnetic fluxes

- In this talk — we discuss how — by turning on gauge fluxes
- — which couple to the endpoints of open strings
- one can obtain stabilization of – closed string moduli
- This is done by analyzing — supersymmetry constraints – and — RR tadpole conditions
- – stabilization of complex and Kahler moduli — studied in a T^6/Z_2 orientifold
- based on work with – I. Antoniadis and T. Maillard, hep-th/0505260.
- also, with S. Mukhopadhyay and K. Ray (in preparation)
- to elaborate – $D3$-branes normally used – in this compactification – replaced by $D9$'s – with magnetic fluxes along six compactified directions
- we show – this is a consistent compactification – in the process the moduli are fixed.

Plan

- short introduction
- Analyze Supersymmetry of the brane – on magnetized tori – in some detail
- Present solutions of the supersymmetry conditions
- Discuss tadpole cancellation conditions
- some explicit models

a short introduction

- Discussions on moduli stabilization in IIB string theory – one generally uses — closed string 3-form fluxes – along the six compactified directions.
- The fluxes generate a potential in four dimensions — a potential for the geocentric moduli —-as well as the axion-dilaton fields —- and lead to their stabilization – upon minimization
- In the implementation process – there are restrictions:
- The primitivity condition – $J \wedge G = 0$: (J – Kahler form, G: (imaginary self-dual (2, 1) - form flux) – can fix some of the Kahler moduli as well – but never all.
- In fact – this condition is trivial for CY's
- In the present talk – we discuss a different procedure for stabilizing the moduli
- This is achieved – by turning on fluxes of the worldvolume gauge fields on the brane
- and demanding that the magnetic field that is turned on preserves $N = 1$ supersymmetry after compactification to four dimensions.

magnetic field

- Another reason – D-branes with fluxes – generally introduced – is to obtain stabilized models – with chiral fermions
- The spectrum – Landau energy levels – harmonic oscillator term + a term proportional to spin – (oscillator frequency given by the magnetic field) –
- interplay between the two terms leaves one chirality of fermion massless, — the other becomes massive – but pairs up with the opposite chirality from a massive level (process repeats at all levels).
- In string theory – work of Bachas, 1995, Blumenhagen, Gorlich, Kors, Lust: 2000, Blumehagen, Lust and Taylor: 2003, Cascalas and Uranga: 2003 etc.
- known that – by turning on constant fluxes - one generates non-commutativity – such magnetized tori – also known as –noncommutative tori
- Now – start discussion of supersymmetry property of the magnetized branes.

Part-I: Supersymmetry

- Start with the string action. The worldsheet action, in NSR formulation is given by:

(1) $$S = I_0 + I_1 + I_2$$

(2) $$I_0 = -\frac{1}{4\pi\alpha'} \int d\tau \int_0^\pi d\sigma \left(\partial_a X^\mu \partial^a X_\mu - i\bar{\psi}^\mu \rho^a \partial_a \psi_\mu\right)$$

(3) $$I_1 = -\int d\tau \left(q_L F_{ij}[X^i \partial_\tau X^j - \frac{i}{2}\bar{\psi}^i \rho^0 \psi_j]\right)_{\sigma=0}$$

(4) $$I_2 = -\int d\tau \left(q_R F_{ij}[X^i \partial_\tau X^j - \frac{i}{2}\bar{\psi}^i \rho^0 \psi_j]\right)_{\sigma=\pi}$$

- ρ^a: Dirac matrices on the worldsheet, one also sets: $\alpha' = \frac{1}{2}$. Also: $i, j = 4, 5, ..., 9$

D-brane supersymmetry

- discussion on supersymmetry below following:
Berkooz, Douglas, Leigh 1996, Balasubramanian, Leigh 1996, Witten 2000, Marino, Minnasian, Moore, Strominger 1999
- Now we start to discuss the supersymmetry of D-branes. For a non-magnetized Dp-brane, the supersymmetry conditions are:
$\epsilon_L = \Gamma_0 \Gamma_1 ... \Gamma_p \epsilon_R$
where ϵ_L and ϵ_R are two spinors, both of +ve chirality in ten-dimensions – one coming from the left-sector of string theory and another from the right sector
- Next question — what is the supersymmetry preserved by a magnetized Dp-brane.
- First consider fluxes turned on along T^2 only
- On a two dimensional torus F_{ij} has only a single nonzero component identified with $F_{ij} = H\epsilon_{ij}$
- To understand supersymmetry — we study the boundary conditions
- For worldsheet fermions ψ, we recall, before the magnetic field – turned on $\psi_L = \psi_R|_{\sigma=0}$.

spinor transformation

- However — now one has – by defining $b = \pi q_L H$:
  $\psi_R = \frac{1+ib}{1-ib}\psi_L|_{\sigma=0}$
- then by using the relation: $b = tan\theta$ – one obtains
  $\psi_R = e^{2i\theta}\psi_L|$
- or in real notation the boundary condition of worldsheet fermions changes to:
  $\psi^4_R = cos2\theta\psi^4_L - sin2\theta\psi^5_L|$
  $\psi^5_R = cos2\theta\psi^5_L - sin2\theta\psi^4_L|$
- In other words, there is a rotation in the left-sector in directions ψ^4_L and ψ^5_L, with respect to the non-magnetized case.
- simply note that for the rotation of vectors by an angle 2θ, as above, in $X^4 - X^5$ space – spinors transformation by:
  $\epsilon_L \longrightarrow e^{\theta\gamma^{45}}\epsilon_L$

supersymmetry of the brane

- As a result, in general the D-brane supersymmetry condition now has a form
  $\epsilon_L = \Gamma_0\Gamma_1...\Gamma_p\rho(F)\epsilon_R$
  with $\rho(F)$ giving the rotation of the spinors.
- For magnetic fields which can be of block diagonal form along three T^2's of the compactified six dimensional space, we have: $\rho \equiv e^{\theta_1\gamma^{12}+\theta_2\gamma^{34}+\theta_3\gamma^{56}}$
- We will come back to a general form of ρ little later. At the moment – let us analyze some simple cases.
- The question relevant to us: When a magnetized D-brane, say $D5$, $D7$ or $D9$ will have the same supersymmetry as that of the $D3$ brane.
- This is because – we are studying T^6/Z_2 orientifold model where we necessarily have the $O3$ planes – having same susy property – as D3's.
- first example (D5-D3): without magnetic field
  Susy of the $D3$: $\epsilon_L = \Gamma_0...\Gamma_3\epsilon_R$
  susy of $D5$: $\epsilon_L = \Gamma_0...\Gamma_5\epsilon_R$
- Both can be consistent only if $\Gamma_4\Gamma_5\epsilon_R = \epsilon_R$
- This is not possible as Γ_{45} has only imaginary eigen values. In this case, the situation does not change much in the presence of magnetic field

D3-D5/D3-D7

- In the case of magnetic field – condition translates into;
- $\Gamma^{45}.e^{\theta\Gamma^{45}}$ – having e.values ± 1
- for this to happen, $\theta = \pm\frac{\pi}{2}$
- However from the relation $b = tan\theta$ – we learn that —this corresponds to infinite magnetic field.
- In other words the range of θ is restricted from $-\pi/2 < \theta < \pi/2$
- On the other hand — it is possible for a magnetized $D7$ to preserve the same supersymmetry — as that of an ordinary $D3$
- for this to happen – we obtain a condition – exactly in the same way : $\pm\theta_1 \pm \theta_2 = 0$
- where θ_1 and θ_2 – the spinor rotations – associated with magnetic fields — in directions, x^4, x^5 and x^6, x^7, the directions that are — transverse to the $D3$, but are —the longitudinal directions of $D7$.
- Note also the relation: $b_i = tan\theta_i$ between the magnetic field and the spinor rotation angle θ

self-duality

- This implies – for a $D7$ compactification on T^4 – the magnetic fields have to satisfy a relation
- $b_1 = \pm b_2$,
- or written in a covariant notation:
- $F_{ij} = \pm \epsilon_{ijkl} F_{kl}$
- In other words, the magnetic fields are either self-dual or anti-self dual – instanton configurations in 4d (Euclidean gauge theory).
- This equation – written in a complex coordinate: $z^i = x^i + iy^i$, $i = 1, 2$
- a notation we will use below, by identifying directions x^4, x^6, x^8 with x^i's and directions x^5, x^7, x^9 with y^i's (for $i = 1, 2, 3$).
- In this complex notation: the self-duality condition becomes
- $F_{(2,0)} = 0$
- for T^6 – we have a similar equation – which we will use for the moduli stabilization.

$D9$ on T^6

- This is the case which will be of most interest to us, — as mentioned
- Let us review the situation again, starting with the non-magnetized case. — We have the $D3$ brane supersymmetry:
  $\epsilon_L = \Gamma_0 \Gamma_1 ... \Gamma_3 \epsilon_R$
- and the $D9$-brane supersymmetry: $\epsilon_L = \Gamma_0 \Gamma_1 ... \Gamma_9 \epsilon_R$
- For both of these to be consistent, one will have to have: $\Gamma_4 ... \Gamma_9 \epsilon_R = \epsilon_R$ which is not possible, as $\Gamma_4 ... \Gamma_9$ has only imaginary eigen value.
- So, no $D9$ can be put together with $D3$ to produce a supersymmetric system.

$D9$ on T^6 with magnetic field

- The situation changes when magnetic fields are turned on along the compactified directions of $D9$
- As a result, the supersymmetry condition now becomes
  $\Gamma_4 ... \Gamma_9 e^{\theta_1 \Gamma^{45} + \theta_2 \Gamma^{67} + \theta_3 \Gamma^{89}} \epsilon_R = \epsilon_R$
- and leads to the condition: $\pm\theta_1 \pm \theta_2 \pm \theta_3 = \frac{\pi}{2}$
  where – of course – we have turned on magnetic field components only along three factorized T^2's.

spinor rotation matrix

- We now obtain supersymmetry condition – for a general (constant) magnetic flux on T^6. – For this we write down the spinor rotation matrix for a general background metric and gauge flux
- First – restricting to the – internal six dimensional space – with a metric $g_{ij} = \delta_{ij}$ – we can write –
$\rho(F) = \frac{1}{\sqrt{det(1+F)}} EXP. \left[-\frac{1}{2} F_{ij} \Gamma^{ij}\right]$
- where notation: 'Exp.' – stands for an exponential expansion – with complete antisymmetrization – in indices of F_{ij}. As a result, the expansion is always finite.
- Now we discuss the general situation with the $D9$ branes. The condition we analyze is:

$$\Gamma^{4..9} \frac{1}{\sqrt{det(1+F)}} EXP(-\frac{1}{2} F_{ij} \Gamma^{ij}) \epsilon_R = \epsilon_R \qquad (5)$$

- also for general G – we make a change –
$\frac{1}{\sqrt{det(1+F)}} \rightarrow \frac{\sqrt{detG}}{\sqrt{det(G+F)}}$

covariant form

- The supersymmetry is written as:

$$\frac{1}{\sqrt{det(1+F)}}\Gamma^{4..9}\left(1 - F_{ij}\Gamma^{ij} + \frac{1}{2}F_{[ij}F_{kl]}\Gamma^{ijkl} - \frac{1}{3!}F_{[ij}F_{kl}F_{mn]}\ \Gamma^{ijklmn}\right)\epsilon_R = \epsilon_R \tag{6}$$

- Moreover, this eqn. can be written in a covariant form (not keepng track of factors) as:

$$\frac{\sqrt{detG}}{\sqrt{det(1+F)}}\left(\epsilon^{ijklmn}\Gamma^{ijklmn} + \epsilon^{ijklmn}F_{ij}\Gamma^{klmn} + \frac{1}{2}\epsilon^{ijklmn}F_{[ij}F_{kl]}\Gamma^{mn} + \frac{1}{3!}\epsilon^{ijklmn}F_{[ij}F_{kl}F_{mn]}\ \Gamma^{ijklmn}\right)\epsilon_R = \epsilon_R \tag{7}$$

- Then using property of spinors: $\Gamma_{m\bar{n}}\epsilon = iJ_{m\bar{n}}\epsilon$ etc., (with J: Kahler form) where ϵ is the covariantly constant spinor on the particular space one is talking about. In our case they are ϵ_L and ϵ_R, or more precisely their decompositions in terms of a 4d and a 6d spinor.

constraint on Kahler moduli

- One obtains:

$$\frac{\sqrt{detG}}{\sqrt{det(G+F)}}[-iJ\wedge J\wedge J - J\wedge J\wedge F + iJ\wedge F\wedge F + F\wedge F\wedge F] = V_6 \quad (8)$$

where V_6 is the six dimensional volume element. It comes in the process of changing the equation in components to that in terms of Kahler form.

- in writing this form – a number of terms are dropped – only $F_{i\bar{j}}$ (in complex notation) – are kept. This amounts to using – (a condition mentioned earlier):

$$F_{(2,0)} = 0 \quad (9)$$

- In a compact form one finally writes:

$$(iJ+F)^3 = e^{i\theta}\frac{\sqrt{(G+F)}}{\sqrt{detG}}V_6 \quad (10)$$

supersymmetry: final form

- for us: $\theta = 0$, corresponding to $D3$ brane supersymmetry. on the other hand: $\theta = \frac{\pi}{2}$ if one wants a $D9$ brane supersymmetry.
- These two cases will correspond to IIB on $T^6/\Omega(-)^{F_L}R$, with $R : (X^5, .., X^9) \to -(X^5, .., X^9)$ or IIB/Ω on T^6
- one can similarly analyze other situations. Condition we have derived – can also be written as:

$$e^{-i\theta}(iJ+F)^3 = \frac{\sqrt(G+F)}{\sqrt{detG}}V_6 \tag{11}$$

- which further implies, (since RHS is a real quantity): $Im[e^{-i\theta}(iJ+F)^3] = 0$
- In our case, as $\theta = 0$, we therefore have: $J \wedge J \wedge J - J \wedge F \wedge F = 0$
- the real part of the above condition:

$$Re[e^{-i\theta}(iJ+F)^3] = \frac{\sqrt(G+F)}{\sqrt{detG}}V_6 \tag{12}$$

positivity

- which also implies:

(13)
$$\int Re[e^{-i\theta}(iJ+F)^3] = \int \sqrt(G+F)$$

can also be verified. We have already done this for the 2×2 case.

- Now since BI action:

$$V_{DBI} = \frac{\mu_9}{g_s}\int_{M_10}\sqrt(G+F) = \frac{\mu_9}{g_s}\int_{T^6}\sqrt(G+F)\int_{M^4}\sqrt{g}$$
$$= \frac{\mu_9}{g_s}\int_{T^6} Re[e^{-i\theta}(iJ+F)^3]\int_{M^4}\sqrt{g}$$

(14)

- This implies a condition:

(15)
$$Re[e^{-i\theta}(iJ+F)^3] > 0$$

positivity

- condition can be seen from the requirement of the right sign for KE of the 4d gauge field. For $\theta = 0$ we then obtain:

(16) $$F \wedge F \wedge F - J \wedge J \wedge F > 0$$

summary: part-I

- To summarize: the key supersymmetry conditions for us are:

(17) $$F_{(2,0)} = 0$$

(18) $$J \wedge J \wedge J - J \wedge F \wedge F = 0$$

(19) $$F \wedge F \wedge F - J \wedge J \wedge F > 0$$

- Above discussion: following Marino, Minasian, Moore, Strominger: hep-th/0011206

Part-II

- 1. Fixing Complex Structure Moduli
- Ref: hep-th/0505260;
  earlier work: Antoniadis and Maillard: hep-th/0412008 (for type I on T^6).
- We now show how the condition: $F^a_{(2,0)} = 0$, for a set of brane-stacks – denoted by index a – fixes the complex structure moduli
- For this, – first we introduce a set of brane-stacks which have fluxes of various types – meaning – having different components of F turned on, – with different magnitues.
- The brane-stacks are being labeled by an index 'a'
- The complex structure matrix (in this case a 3×3 matrix), appears in this condition through the definition $z^i = x^i + \tau y^i$,

torus : T^6

- the six dimensional torus of for us will be defined by periodic coordinates x^i, y_i $(i = 1, 2, 3)$: $x^i = x^i + 1$, $y_i = y_i + 1$.
- the orientation defined by:
  $\int dx^1 \wedge dy_1 \wedge dx^2 \wedge dy_2 \wedge dx^3 \wedge dy_3 = 1$
- the complex structure can be defined by choosing complex coordinate:
  $z^i = x^i + \tau^{ij} y_j$, with τ^{ij} being 3×3 complex matrix —- implying 9 complex components.

torus – contd.

- one can also define a basis for cohomology $H^3(T^6, Z)$, with a symplectic structure: α_0, α_{ij}, β^0, β^{ij}: $(i, j = 1, 2, 3)$ with: $\alpha_o = dx^1 \wedge dx^2 \wedge dx^3$ etc. $\int_{T^6} \alpha_A \wedge \beta^B = -\delta_A^B$.
- Furthermore $H^3(T^6, Z)$ can be decomposed into (3, 0), (2, 1), (1, 2) and (0, 3) forms. In this decomposition, $\omega = dz^1 \wedge z^2 \wedge dz^3$ is the unique (3, 0) form.
- The complex structure τ is then also identified as a period of Ω and can be identified from a relation:
  $\Omega = \tau^a \alpha_a - \mathcal{G}_b \beta^b$
- in our case, we again get their identification with τ^{ij}'s.
- complex structure and Kahler moduli – also parameterized by the set of $(2, 1)$ (δg_{ij}) and $(1, 1)$ ($\delta g_{i\bar{j}}$) deformations of the metric. In particular, Kahler forms J are given as:
  $J = i\delta g_{i\bar{j}} dz^i \wedge \bar{z}^j$

fixing τ^{ij}'s

- $F_{(2,0)} = 0$ are now used to fix τ^{ij}'s.
- In addition we also use the fact that flux components $F^a_{x^i x^j}$, $F^a_{y^i y^j}$, $F^a_{x^i y^j}$ are rationally quantized:
- $q_a F^a_{ij} \equiv 2\pi p^a_{ij} = 2\pi \frac{m^a_{ij}}{n^a_{ij}}$
- precise form of n^a_{ij} – will be clear later on – using the mapping between the worldvol. to space-time.
- Using the definition of p^a's given here, the complex structure matrix, τ satisfies the equation:
-
$$F^a_{(2,0)} = 0 \to \tau^T p^a_{xx} \tau - \tau^T p^a_{xy} - p^a_{yx} \tau + p^a_{yy} = 0, \tag{20}$$
- Then by specifying p^a_{xx}, p^a_{xy} etc., for set of branes, one aims to fix τ's.

fixing τ's

- one can show that the off-diagonal components of τ can be forced to be zero, by taking appropriate fluxes $p_{x^i y^j}$, $p_{x^i x^j}$ etc.along various brane-stacks:

(21) $$\tau^{12} = \tau^{13} = \tau^{21} = \tau^{23} = \tau^{31} = \tau^{32} = 0\,.$$

- For diagonal components of τ one can obtain:

(22) $$\frac{\tau^{11}}{\tau^{22}} = \frac{p^1_{x^2 y^1}}{p^1_{x^1 y^2}} \equiv K_1, \quad \frac{\tau^{22}}{\tau^{33}} = \frac{p^2_{x^3 y^2}}{p^2_{x^2 y^3}} \equiv K_2, \quad \frac{\tau^{33}}{\tau^{11}} = \frac{p^3_{x^1 y^3}}{p^3_{x^3 y^1}} \equiv K_3,$$

and

$$\tau^{11}\tau^{22} = -\frac{p^4_{y^1 y^2}}{p^4_{x^1 x^2}} \equiv -K_4, \quad \tau^{22}\tau^{33} = -\frac{p^5_{y^2 y^3}}{p^5_{x^2 x^3}} \equiv -K_5, \quad \tau^{33}\tau^{11} = -\frac{p^6_{y^3 y^1}}{p^6_{x^3 x^1}} \equiv -K$$

(23)

- with solution given as:

(24) $$\tau^{11} = i\sqrt{K_1 K_4}, \quad \tau^{22} = i\sqrt{\frac{K_4}{K_1}}, \quad \tau^{33} = i\sqrt{K_1 K_4}K_3.$$

contd.

- We therefore see that by specifying fluxes, p^a's along a set of brane - stacks, one can fix the complex structure moduli.
- To stabilize the Kahler moduli one makes use of the conditions:

$$J \wedge J \wedge J - J \wedge F^a \wedge F^a = 0 \tag{25}$$

with the constraint:

$$F^a \wedge F^a \wedge F^a - J \wedge J \wedge F^a > 0 \tag{26}$$

where a is denoting the brane-stack.
- Without going into detail, we mention that by specifying fluxes, as mentioned above for the complex-structure stabilization
- One can obtain solution for J's: the off-diagonal Kahler moduli are zero:$J_{i\bar{j}} = 0$ and
- Diagonal components of $J_{i\bar{j}}$ are stabilized to the string scale
- This is possible for many combination of fluxes and branes.
- However, one needs to satisfy an additional constraint for building any model.

Part-III: RR Tadpoles

- Before giving explicit model we discuss the RR-tadpole cancellations
- Constant fluxes generate RR charges, corresponding to lower dimensional branes. Cancellation of all these charges - implies the worldvolume theory free of anomaly.
- The amount of charge that is generated can be seen by looking at the WZ couplings of the brane. The total action is given by

$$I = V_{DBI} + V_{WZ} \tag{27}$$

- We have already looked at V_{DBI}. V_{WZ} has a general form (using that RR forms are even or odd under the orientifolding $\Omega(-)^{F_L}$):

$$V_{WZ} = \mu_9 \sum_a N_a \int_{M^{10}} (C_4 \wedge F^a \wedge F^a \wedge F^a + C_8 \wedge F^a) \tag{28}$$

  N_a's are the number of branes in a stack with fluxes F^a_{ij}.

- implies new contributions to the 3-brane and 7-brane tadpoles.

tadpole

- Using – Jacobi matrix – giving map from the worldvolume – to space-time (Bianchi and Trevigne, 2005): $W_A^i = \frac{\partial X^i}{\partial \sigma_A}$
- The tadpole cancellation conditions are read from:

$$\sum_a N_a W_a F^a \wedge F^a \wedge F^a + N = 16 \tag{29}$$

and

$$\sum_a N_a W_a F^a = 0 \tag{30}$$

where N is the number of ordinary $D3$-branes which one can also put to cancel the 3-brane tadpole and $W_a = detW$, N_a: no. branes in a'th stack.

tadpole-contd.

- We choose the matrix W_A^i to be diagonal:

(31) $$W = diag.(n_1, n_2, n_3; n_1, n_2, n_3)$$

where the first three directions correspond to the x directions and the last three to the y directions.

toy model

- We work with stacks, 1, 1'. 2, 2'.
- 1', 2' defined as: off-diagonal component of fluxes are of opposite sign w.r.t. the branes: 1, 2.
- As a result there are no 7-brane off-diagonal tadpoles left. the diagonal one: computed below
- We make the following choices for brane-1 for n_i's:

(32) $$n_1^{(1)} = 2, \;\; n_2^{(1)} = 1, \;\; n_3^{(1)} = 3, \;\; m_{23}^{(1)} = 1, \;\; m_{x^3y^3}^{(1)} = 1$$

- for brane 1', the sign of the off-diagonal m_{ij} is opposite. For brane-2 we have:

(33) $$n_1^{(2)} = 1, \;\; n_2^{(2)} = 2, \;\; n_3^{(2)} = 1, \;\; m_{13}^{(2)} = 1, \;\; m_{12}^{(2)} = 1, \;\; m_{x^3y^3}^{(2)} = -1$$

tadpole-contd.

- they correspond to flux:

(34) $$p_{23}^{(1)} = \frac{1}{3},\ \ p_{12}^{(2)} = \frac{1}{2},\ \ p_{13}^{(2)} = 1$$

- 7-brane tadpole contributions are:

(35) $$(q^7)_{x^3y^3}^{(1)} + (q^7)_{x^3y^3}^{(1')} = 2(n_1^{(1)}n_2^{(1)})^2 m_{x^3y^3}^{(1)}$$

(36) $$(q^7)_{x^3y^3}^{(2)} + (q^7)_{x^3y^3}^{(2')} = 2(n_1^{(2)}n_2^{(2)})^2 m_{x^3y^3}^{(2)}$$

- We now write down the 3-brane tadpole contribution. First, it is zero for the stacks 1 and 1'. For the stack-2 on the other hand, using the diagonal form of W we get:

tadpole-contd.

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(37)
$$\begin{aligned}(q^3)^{(3)} &= -W_3 p_3^{(3)} (p_{12}^{(3)})^2 \\ &= -(m_{12}^{(3)})^2 m_{x^3 y^3}^{(3)}\end{aligned}$$

- where we have used relations such as:

(38)
$$p_{12} = \frac{m_{12}}{n_1 n_2}$$

- Then using the above results in the 7-brane tadpoles above, we obtain:

(39)
$$(q^7)_{x^3 y^3}^{tot} = 8(m^{(2)}{}_{x^3 y^3} + m^{(3)}{}_{x^3 y^3}) = 0$$

- Also: for the total 3-brane tadpole:

(40)
$$(q^3)_{x^3 y^3}^{tot} = -2.(-1)(m_{12}^{(3)})^2 = 2$$

- we have therefore shown that using branes 1, 1', 2, 2' one can obtain a consistent model with all the 7-brane tadpoles cancelled and 3-brane tadpole = 2.

comments

- However, this model corresponds to the case – when one of the diagonal J: $J_{x^2y^2}$ is negative.
- We then – turn on antisymmetric tensor B: — their values are constrained to be 0 or $\frac{1}{2}$
- We choose: $B_{x^1x^2} = B_{y^1y^2} = \frac{1}{2}$ — and show; $G + B$ is positive definite — implying a well-defined worldsheet theory
- 3-brane tadpoles are to be saturated to 4 rather than 16 (due to the presence of – exotic orientifold planes)
- The model satisfies this condition —
- Several explicit models along this line – constructed with partial moduli stabilizations

contd.

- It is difficult to obtain stabilization in T^6/Z_2 orientifold model without B – as generated 7-brane tadpoles are to cancel among themselves.– consistent with supersymmetry and other requirements — however, no no-go theorem yet.
- In another work in progress, with S. Mukhopadhyay and K. Ray (in progress) – we used non-abelian gauge fluxes
- it seems possible to solve supersymmetry and tadpole cancellation conditions to get all (diagonal) J's positive.

other issues

- RR Moduli: There are 15 RR moduli, 9 of them complexify the Kahler forms to form the chiral multiplet in four dimensions. they are all absorbed by 9 gauge bosons on the branes, as one fixes the Kahler moduli. The remaining 6 RR moduli, together with 6 complex components of the metric, form the complex structure τ which has nine components – and get fixed by the mechanism mentioned.
- large radius: The solution obtained above: all the radii are fixed at the string scale, — as identified in this solution – due to the factorized form – of the solution in products of three T^2's: τ_{ii} are given by the ratio of the radii and J_i by the product.
- however – possible to obtain solution with large radii, by scaling the windings n_i while maintaining the tadpole conditions.

axion-dilaton moduli

- Unlike the stabilization using 3-form fluxes, the axion-dilaton modulus does not appear – when using magnetic fluxes on D-branes
- not surprising – since the string construction and action we are using, does not allow ϕ to vary.

final

- One way to stabilize them – combine this mechanism with the one using close string fluxes
- However, possible(?) to generalize the Dp-Dp' system to the one involving the (p, q) - branes which carry $SL(2, Z)$ S-duality charge – and get constraints on them??