D0-branes in SO(32)×SO(32) open type 0 string theory

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Abstract

We construct D0-branes in SO(32)×SO(32) open type 0 string theory using the same method as the one used to construct non-BPS D0-brane in type I string theory. It was conjectured that this theory is S-dual to bosonic string theory compactified on SO(32) lattice, which has SO(32)×SO(32) spinor states as excited states of fundamental string. One of these states seems to correspond to the D0-brane, and by the requirement that other states which do not have corresponding states must be removed, we can determine the way of truncation of the spectrum. This result supports the conjecture.

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Correspondence of SO(32) spinor states is an evidence for the S-duality between type I and Heterotic SO(32) string theories. Heterotic SO(32) theory has SO(32) spinor states as the first excited states of fundamental string. These are the lightest of the states which have SO(32) spinor charge and therefore cannot decay and must exist in strong coupling regime, which is described by type I string theory. Their type I counterpart is non-BPS D0-brane [1].

Let us consider analogous correspondence in type 0 string theory. It was proposed that SO(32) × SO(32) open type 0 string theory [2, 3] (we will abbreviate it as open type 0 theory) is S-dual to bosonic string theory compactified on SO(32) lattice [3]. In this bosonic string theory fundamental string has the following worldsheet matter content:

\[ X^\mu(z), \tilde{X}^\mu(\bar{z}), \lambda^A(z), \tilde{\lambda}^A(\bar{z}), \mu = 0, \ldots, 9, \quad A, \tilde{A} = 1, \ldots, 32. \]  

(1)

Here \( A \) is the index of fundamental representation of one SO(32), while \( \tilde{A} \) is that of the other SO(32). The lightest states which have SO(32) × SO(32) spinor charge are

\[ \lambda^{A_1} \lambda^{B_1} \lambda^{C_1} \lambda^{D_1} |0\rangle_R |\tilde{a}\rangle_L, \quad \alpha^{\mu_1} \lambda^{A_2} \lambda^{B_2} |0\rangle_R |\tilde{a}\rangle_L, \quad \alpha^{-1}_{-1} \lambda^{A_3} \lambda^{B_3} |0\rangle_R |\tilde{a}\rangle_L, \quad \alpha^{-1}_{-2} |0\rangle_R |\tilde{a}\rangle_L, \]

\[ \tilde{\lambda}^{A_1} \tilde{\lambda}^{B_1} \tilde{\lambda}^{C_1} \tilde{\lambda}^{D_1} |a\rangle_R |0\rangle_L, \quad \tilde{\alpha}^{\mu_1} \tilde{\lambda}^{A_2} \tilde{\lambda}^{B_2} |a\rangle_R |0\rangle_L, \quad \tilde{\alpha}^{-1}_{-1} \tilde{\lambda}^{A_3} \tilde{\lambda}^{B_3} |a\rangle_R |0\rangle_L, \quad \tilde{\alpha}^{-1}_{-2} |a\rangle_R |0\rangle_L, \]

(2)

\[ |a\rangle_R |\tilde{a}\rangle_L, \quad |\tilde{a}\rangle_R |\tilde{a}\rangle_L, \quad |\tilde{a}\rangle_R |a\rangle_L, \quad |a\rangle_R |a\rangle_L, \]

(3)

where \( a \) and \( \tilde{a} \) are spinor indices of one SO(32) and the other SO(32) respectively. Here we do not consider the truncation of spectrum required by modular invariance, etc. We will return to this point later.

In this paper we construct the type 0 counterpart to these states using the same method as the one used to construct non-BPS D0-brane in type I string theory. As we will see, the states corresponding to (3) can be found by this method, but the states corresponding to (2) and (3) are not found. This fact suggests what truncation we should adopt. The result is in accord with the proposal in ref. [3].

Open type 0 theory is constructed from type 0B theory by \( \Omega \) projection, where \( \Omega \) is the worldsheet parity inversion, analogously to the construction of type I theory from type IIB theory [3]. Type 0B theory has two types of RR fields and therefore has two types of D-branes. We denote their RR charges by \((q, \bar{q})\). Boundary states of these branes are [3, 4]

\[ |Dp; q, \bar{q}\rangle_0 = \frac{1}{\sqrt{2}} \left( |Dp\rangle_{NS+NS+} + q\bar{q} |Dp\rangle_{NS-NS-} + q |Dp\rangle_{R+R+} + \bar{q} |Dp\rangle_{R-R-} \right), \]  

(5)
with
\[ |Dp\rangle_{NS\pm NS\pm} = \frac{1}{2} (|Dp, +\rangle_{NS} \mp |Dp, -\rangle_{NS}), \]  \hspace{1cm} (6)
\[ |Dp\rangle_{R\pm R\pm} = \frac{1}{2} (|Dp, +\rangle_{R} \pm |Dp, -\rangle_{R}). \]  \hspace{1cm} (7)

Boundary states of type IIB branes are
\[ |Dp; q\rangle_{II} = |Dp\rangle_{NS} + q |Dp\rangle_{R}. \]  \hspace{1cm} (8)

For the definition of $|Dp, \pm\rangle_{NS}$ and $|Dp, \pm\rangle_{R}$, and other notation about boundary states we adopt those of ref. [6].

Strings stretched between ($q, \bar{q}$) brane and ($\pm q, \mp \bar{q}$) brane belong to $\frac{1}{2}(1 \pm (-1)^F)_{NS}$ sector only, and strings between ($q, \bar{q}$) brane and ($\pm q, \mp \bar{q}$) brane belong to $\frac{1}{2}(1 - q(-1)^F)_{R}$ sector only [3, 5]. Open type 0 theory have 32 D9-branes and 32 anti D9-branes of one type for tadpole cancellation. We choose $(1, 1)$ and $(-1, -1)$ as these D9-branes. In this theory we can construct two types of D0-branes respectively from $(1, 1)$ D1-brane$\sim(-1, -1)$ D1-brane system, and $(1, -1)$ D1-brane$\sim(-1, 1)$ D1-brane system, in the same way to construct type I non-BPS D0-brane from D1-brane-anti D1-brane system (for details see ref. [1]):

1. Wrap the D1-branes around a compact direction with radius $R_c = \sqrt{\frac{2}{\alpha'}}$ and put a $Z_2$ Wilson line on one of the D1-branes.

2. Define new worldsheet variables $\phi_R(z), \phi_L(\bar{z}), \phi'_R(z), \phi'_L(\bar{z}), \xi(z), \bar{\xi}(\bar{z})$, $\eta(z)$, and $\bar{\eta}(\bar{z})$:
\[ X(z, \bar{z}) = X_R(z) + X_L(\bar{z}), \]  \hspace{1cm} (9)
\[ \exp(i\sqrt{\frac{2}{\alpha'}}X_R) = \frac{1}{\sqrt{2}}(\xi + i\eta), \]  \hspace{1cm} (10)
\[ \exp(i\sqrt{\frac{2}{\alpha'}}X_L) = \frac{1}{\sqrt{2}}(\bar{\xi} + i\bar{\eta}), \]  \hspace{1cm} (11)
\[ \exp(i\sqrt{\frac{2}{\alpha'}}\phi'_R) = \frac{1}{\sqrt{2}}(\eta + i\psi), \]  \hspace{1cm} (12)
\[ \exp(i\sqrt{\frac{2}{\alpha'}}\phi'_L) = \frac{1}{\sqrt{2}}(\bar{\eta} + i\bar{\psi}). \]

3. Give vev to the tachyon field, i.e. put the Wilson line $\exp(i \oint dz \frac{1}{2\sqrt{2\alpha'}} \partial \phi \sigma_1)$ along $\phi$.

4. Decompactify the compact direction. $\phi'_D(z, \bar{z}) = \phi'_R(z) - \phi'_L(\bar{z})$, $\xi$ and $\bar{\xi}$ are the variables for this direction with Dirichlet boundary condition.

The only difference between type I D0-brane and type 0 D0-branes in this construction is that type 0 D0-branes do not have R sector strings. We can also construct boundary states of type 0 D0-branes following ref. [3]:

\[ 2 \]
1. Introduce $|B, \pm\rangle_{NS}$ and $|B, \pm\rangle_R$ for describing D1-brane and anti D1-brane with a $\mathbb{Z}_2$ Wilson line wrapped around a compact direction with radius $R_c$:

$$|B, \pm\rangle_{NS} = |D1, \pm\rangle_{NS} + |\bar{D}1', \pm\rangle_{NS},$$

$$|B, \pm\rangle_R = |D1, \pm\rangle_R - |\bar{D}1', \pm\rangle_R,$$

where $\bar{D}1'$ means the anti D1-brane with the $\mathbb{Z}_2$ Wilson line.

2. Rewrite these boundary states in terms of the new variables $\phi(z), \tilde{\phi}(\tilde{z}), \xi(z), \tilde{\xi}(\tilde{z}), \eta(z),$ and $\tilde{\eta}(\tilde{z})$:

$$X(z, \tilde{z}) = \frac{1}{2} (X_R(z) + X_L(\tilde{z})),
\exp(i\sqrt{\frac{1}{2\alpha'}X_R} = \frac{1}{\sqrt{2}}(\eta + i\xi),
\exp(i\sqrt{\frac{1}{2\alpha'}X_L} = \frac{1}{\sqrt{2}}(\tilde{\eta} + i\tilde{\xi}),
\exp(i\sqrt{\frac{1}{2\alpha'}\phi_R} = \frac{1}{\sqrt{2}}(\xi + i\psi),
\exp(i\sqrt{\frac{1}{2\alpha'}\phi_L} = \frac{1}{\sqrt{2}}(\tilde{\xi} + i\tilde{\psi}),$$

$$|B, \pm\rangle_{NS/R} = \frac{1}{4\pi\alpha'g_s\sqrt{2\pi R_c}} \exp[-\sum_{n>0} \frac{1}{n} \alpha_n \hat{S}_n(1)\tilde{\alpha}_n] \exp[\pm i \sum_{n>0} \psi_n \hat{S}_n^{(1)}\tilde{\psi}_n]
\times \exp[-\sum_{n>0} \phi_n \hat{\phi}_n] \exp[\pm i \sum_{n>0} \eta_n \tilde{\eta}_n] |D1, \pm\rangle_{NS/R}
\times 2\delta^{(8)}(q^i) \prod_{i=0,2,\ldots,9} |k^i = 0\rangle \sum_{w_\phi = \text{even/odd}} |0, w_\phi\rangle.$$

3. Put the Wilson line $\exp(i \oint dz \frac{1}{2\sqrt{2\alpha'}} \partial \phi \sigma_1)$ along $\phi$:

$$|B, \pm\rangle_{NS} \rightarrow \frac{1}{4\pi\alpha'g_s\sqrt{2\pi R_c}} \exp[-\sum_{n>0} \frac{1}{n} \alpha_n \hat{S}_n(1)\tilde{\alpha}_n] \exp[\pm i \sum_{n>0} \psi_n \hat{S}_n^{(1)}\tilde{\psi}_n]
\times \exp[-\sum_{n>0} \phi_n \hat{\phi}_n] \exp[\pm i \sum_{n>0} \eta_n \tilde{\eta}_n] |0\rangle_{NS}
\times 2\delta^{(8)}(q^i) \prod_{i=0,2,\ldots,9} |k^i = 0\rangle \sum_{w_\phi} (-1)^{w_\phi} |0, 2w_\phi\rangle,$$

$$|B, \pm\rangle_R \rightarrow 0.$$
Thus we get two types of boundary states as follows:

\[ |D1; q, \bar{q}\rangle_0 + |\bar{D}1'; -q, -\bar{q}\rangle_0 \rightarrow |D0\rangle_{NS+NS+} + q\bar{q} |D0\rangle_{NS-NS-} \equiv |D0; q\bar{q}\rangle_0. \] (23)

The factor $\sqrt{2}$ in (22) means that the tension of these D0-branes $T_0$ is $\sqrt{2}$ times the tension of type 0A D0-brane:

\[ T_0 = \sqrt{2}T_{0A} = T_{IIA} = \frac{1}{\sqrt{\alpha' g_s}}. \] (24)

The rules for computing the spectrum and the interactions of open strings which end on the D0-branes are the same as in ref. [7] except that the strings stretched between the same type (different types) of D0-branes belong to NS (R) sector only. Similarly, strings between $(\pm 1, \pm 1)$ D9-branes and $|D0; +1\rangle_0$ of (23) belong to NS sector only, while strings between $(\pm 1, \pm 1)$ D9-branes and $|D0; -1\rangle_0$ belong to R sector only. The NS sector gives only massive states because its zero point energy is $5/8 > 0$ and the R sector has massless states. The R sector massless states belong to SO(32) fundamental representation corresponding to 32 $(1, 1)$ D9-branes or 32 $(-1, -1)$ D9-branes. The zero modes of these massless states form a Clifford algebra and their quantization gives rise to spinor representation of SO(32) $\times$ SO(32). Therefore $|D0; -1\rangle_0$ corresponds to the state (4). On the other hand, $|D0; +1\rangle_0$ has no SO(32) $\times$ SO(32) charge and does not correspond to any state in (2), (3) and (4).

The type 0 states corresponding to the states (2) and (3) are not found. It is impossible to construct the states which have spinor charge of only one SO(32) like the states (2) and (3) by using boundary states. This is because the difference between D9 and anti D9-branes is only the signature of RR part of the boundary states, and it is NSNS part that can be interpreted by modular transformation as R sector of open strings which have massless states with SO(32) charge.

This result suggests what truncation we should adopt. What is given in ref. [3] as a ground of S-duality between open type 0 theory and bosonic string theory on SO(32) lattice is the fact that the worldsheet matter content of fundamental string of bosonic string theory on SO(32) lattice coincides with that of the counterpart of open type 0 theory. But this leaves two possibilities in the choice of truncations in bosonic string theory side:
1. We adopt separative GSO projection \( \frac{1}{2}(1 + (-1)^F)\frac{1}{2}(1 + (-1)^{\tilde{F}}) \), where \( F \) and \( \tilde{F} \) are the number operators of \( \lambda \) and \( \tilde{\lambda} \) respectively.

2. We adopt diagonal GSO projection \( \frac{1}{2}(1 + (-1)^{F+\tilde{F}}) \) and in addition remove NSR and RNS sectors. This removal is necessary for modular invariance of the 1-loop partition function. Indeed the partition function is given by

\[
\frac{1}{2}(1 + (-1)^{F+\tilde{F}})(\text{NSNS} + \text{RR})
\]

\[
= \int \frac{d\tau d\tilde{\tau}}{4\text{Im}\tau} (4\pi^2 \alpha'\text{Im}\tau)^{-\frac{5}{2}} \frac{1}{2} \frac{|\vartheta_{00}(0, \tau)|^{32} + |\vartheta_{01}(0, \tau)|^{32} + |\vartheta_{10}(0, \tau)|^{32}}{|\eta(\tau)|^{48}},
\]

which is modular invariant.

In ref. [3] the latter truncation is adopted. Diagonal GSO projection leaves the charged tachyon \( \lambda_{-\frac{1}{2}} \lambda_{-\frac{1}{2}} |0\rangle_R |0\rangle_L \) which is projected out by separative GSO projection. Condensation of this tachyon breaks some part of the gauge group. This corresponds to condensation of the tachyon from string stretched between D9 and anti D9-branes in open type 0 theory side. In addition since the states (2) and (3) belong to NSR and RNS sector respectively, they are removed only by the latter truncation. Therefore we should adopt the latter truncation. Then the S-duality conjecture in ref. [3] is supported by the agreement on \( \text{SO}(32) \times \text{SO}(32) \) spinor states.

Now we comment on the other branes. Type I string theory has non-BPS \( (-1), 7, 8 \) brane as well as D0-brane [8]. Analogously we can consider \( (-1), 7, 8 \) brane in open type 0 theory. Their boundary states can be constructed following ref. [3]:

\[
|Dp; q\rangle_0 = \frac{\mu_p}{\sqrt{2}} (|Dp\rangle_{\text{NS}+\text{NS}+} + q |Dp\rangle_{\text{NS}+\text{NS}-}),
\]

where \( \mu_p = 2 \) (for \( p = -1, 7 \)), \( \sqrt{2} \) (for \( p = 8 \)). However, as pointed out in ref. [3], because strings stretched between D9-branes and D7 or D8-brane with \( q = 1 \) have tachyon modes, D7 and D8-brane with \( q = 1 \) are unstable. D\((-1)\)-branes break the disconnected components of \( \text{O}(32) \times \text{O}(32) \) [8].

We have considered various branes in the background with tachyons from closed strings and open strings stretched between D9 and anti D9-branes. It is desired to consider these branes in stable background without tachyons.

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