Closed strings from nothing

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We study the physics of open strings in bosonic and type II string theories in the presence of unstable D-branes. When the potential energy of the open string tachyon is at its minimum, Sen has argued that only closed strings remain in the perturbative spectrum. We explore the scenario of Yi and of Bergman, Hori and Yi, who argue that the open string degrees of freedom are strongly coupled and disappear through confinement. We discuss arguments using open string field theory and worldsheet boundary RG flows, which seem to indicate otherwise. We then describe a solitonic excitation of the open string tachyon and gauge field with the charge and tension of a fundamental closed string. This requires a double scaling limit where the tachyon is taken to its minimal value and the electric field is taken to its maximum value. The resulting flux tube has an unconstrained spatial profile; and for large fundamental string charge, it appears to have light, weakly coupled open strings living in the core. We argue that the flux tube acquires a size or order $\alpha'$ through sigma model and string coupling effects; and we argue that confinement effects make the light degrees of freedom heavy and strongly interacting.

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1. Introduction

The known nonperturbative definitions of string- and M-theory vacua [1,2] are remarkable yet conceptually deficient. They provide unitary, holographic descriptions of quantum gravity; but locality is not manifest even at macroscopic scales. Any sort of background independence is also completely obscure. Experience tells us that the world is local down to microscopic scales. Certainly the systems described in [1,2] describe local spacetime physics; however, such physics is hard to extract from the field theoretic ”boundary” variables used. It seems plausible that there should be another set of manifestly local ”bulk” variables. Holography could then arise via the fixing of some large gauge symmetry of the theory [3]. Such a description would be a major step towards understanding holography in more general backgrounds.

A natural candidate for such a theory is string field theory; it is local down to the string scale, and it has a large gauge symmetry. However, closed string field theory, the natural guess for a theory of quantum gravity, does not seem to be complete as it stands. The state of the art [4] is an “effective” theory, defined perturbatively; vertices must be added at every order in $g_s$, and large regions of the moduli space of string diagrams are integrated over in the construction of these vertices. ¹ There is no simple explanation within closed string field theory of the rapid divergence of closed string perturbation theory [6]; the effect must be contained in the new vertices. The physical D-branes which this divergence signals must be added to the theory by hand.

Open string field theory is in better shape. Bosonic open string field theory (and the NS sector of open superstring field theory) has a classical Lagrangian which can be written in closed form, and which generates all perturbative diagrams [7,8,9,10]. Closed strings appear in intermediate channels of open string diagrams [11], and the open string theory covers the moduli space of closed string diagrams with at least one hole [8]. Perturbation theory diverges no more rapidly than field theory; again, this reflects the existence of D-branes, which contribute effects of order $e^{-1/g_s^{open}}$ to scattering amplitudes.

It remains to find D-branes as open string field theory excitations, and to find a description of closed string theories in the absence of D-branes. The study of unstable D-branes, pioneered and largely carried out by A. Sen and his collaborators, provides an attractive answer for type II and bosonic string theories. Begin with unstable D-branes or D-brane-anti-D-brane pairs, filling all of space. These will contain open-string tachyons;

¹ c.f. [5] for discussion of this issue with further references.
the endpoint of tachyon condensation is the perturbative closed-string vacuum (up to closed-string tachyons) \[12,13,14,15,16\]. D-branes appear as configurations of the open-string tachyon field in the closed string vacuum; the open string vacuum remains at the core of the D-brane \[17,18,19\]. Such configurations have also been found using the tachyon potential calculated in open bosonic string field theory \[20,21,22,23\].

We would therefore like to describe type II string theory via open string field theory living on \(N\) unstable D9-branes of type IIA, or on \(N\) \(D9 - \bar{D}9\)-brane pairs in type IIB \[24,25\] (possibly as \(N \rightarrow \infty\) \[25\]). This raises a number of questions, particularly: what are the dynamics of open strings in the closed string vacuum? How do closed strings emerge as weakly coupled excitations? How can the closed string gauge invariance (in particular diffeomorphism invariance) be made manifest?

We will attack these questions by studying electric flux tubes with closed string charge as the tachyon condenses, as in \[26,27,22,28,29\]. In section 2 we argue, following previous work, that that the open strings in the closed string vacuum are strongly coupled, at least in variables natural to world sheet conformal field theory. We will begin with a selective survey of the literature surrounding this issue. In particular our claim appears to contradict the worldsheet analysis of \[30,31,32\], and we discuss a resolution of this contradiction by pointing out order of limits implicit in various approaches. We will also address the rather different picture emerging from numerical calculations in the level truncation scheme \[33\] and discuss the possible relationship via nonlinear, nonlocal, field redefinitions. Our conclusion is that, at least in the variables natural to world sheet conformal field theory, the open strings should disappear through a confinement of the \(U(1)\) gauge field on the unstable D-brane (or the diagonal \(U(1)\) gauge field on a \(D - \bar{D}\) pair) under which the string endpoints are charged; this picture was developed initially by P. Yi and his collaborators \[26,27\]. In section 3 we study solutions of the tachyon-Born-Infeld action proposed in \[13,34,31,35\], and find a solution with the charge and tension of a macroscopic closed string. In this solution the the electric field must be scaled to its critical value (as in refs. \[36,37\]), and the profile appears completely unconstrained. We study the physics of this solution in Sec. 4, first discussing effects by which the flux tube may be localized, and next addressing the open string dynamics in the core of this flux tube. It appears that if the closed string charge is large, then the open strings in the core are light and weakly coupled. We argue that if the flux tubes are indeed localized, this will not be the case. The picture we arrive at is that closed strings are a collective excitation in a strongly-coupled open string background, following the scenario developed in \[26,27\].
2. The fate of open strings, or the dynamics of nothing

“I ask for nothing, Master.”
“And you shall receive it – in abundance.”
– The Rocky Horror Picture Show

2.1. Arguments for strongly coupled open strings

Let us begin with an unstable Dp-brane in type II or bosonic string theory. The perturbative spectrum of open strings ending on the brane will include a tachyon, a $U(1)$ gauge field, massless scalars describing the transverse fluctuations of the Dp-brane, and a tower of massive open string modes. The unstable brane decays by condensation of the tachyon; at the minimum of the tachyon potential, the theory has only closed strings as perturbative excitations [12,13,14,15,16].

How do the open strings disappear as perturbative excitations? Sen [13] argued that the Lagrangian for open string modes vanishes at the endpoint of tachyon condensation, i.e.

$$L = f(\phi) \tilde{L}(\{\Psi\})$$ (2.1)

where $\phi$ is the tachyon, $f(\phi)$ vanishes at the minimum of the tachyon potential, and $\Psi$ represents the open string modes. In particular, worldsheet RG flow arguments [30], and calculations [34,31,35] using the background-independent string field theory proposed in [38], show that the action for the $U(1)$ gauge field with slowly varying field strength $F$ is as proposed in [13]:

$$S = \int d^{p+1}x \frac{V(\phi)}{g_s} \sqrt{-\det (g_{\mu\nu} - F_{\mu\nu})} ,$$ (2.2)

where $V(\phi)/g_s$ is the potential energy for the tachyon and $V(\phi) = 0$ in the closed string vacuum.

A related phenomenon is discussed in [39]. A nontrivial maximal rank, constant NS-NS B-field in Euclidean space leads to a gauged $U(\infty)$ symmetry. The authors of [39] propose that the endpoint of tachyon condensation in this background is the “nothing state” for which the $U(\infty)$ symmetry is restored (the background is gauge-invariant). This symmetry forbids a nonvanishing gauge kinetic term. We adopt their coinage for our title.

A vanishing kinetic term generally signifies strong coupling; there is little cost in action for wild fluctuations over short distances in space. Said another way, we can rescale the fields to maintain a nonvanishing kinetic term, but then the interaction terms will