An Observable Stringy Effect from the Sky?

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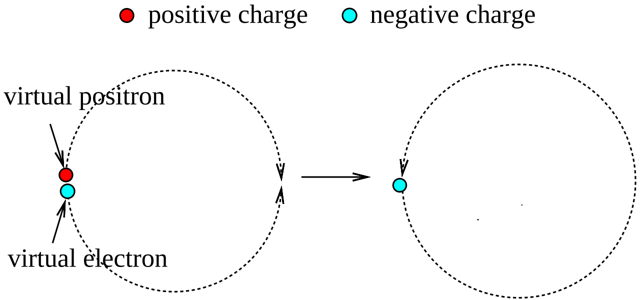
Outline

- Motivation
- String theory: A lightening review
- The open string pair production rate calculations
- The production rate enhancement by a magnetic flux
- Discussion and Summary

Vacuum polarization

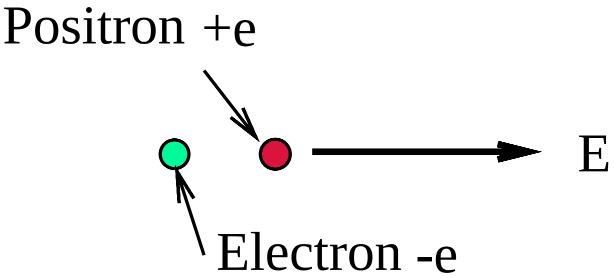
VACUUM FLUCTUATION!

An anti-charge moving forward in time equivalent to a charge moving backward in time



Vacuum polarization

Applying a constant electric field to QED vacuum, there is certain probability to create real electron and positron pairs from the vacuum fluctuation, called Schwinger pair production.



Stringy process

- Does there exist an analogous process in string theory?
- If so, can it have observational consequences?
- Then what are the possible implications?

A lightening review

WHY QUANTUM GRAVITY ?

A few examples:

- Understand our Universe at $\sim 10^{-43}$ second,
- Understand the black hole singularity,
- Understand physics at a distance $\sim 10^{-35}$ meter,
- Explore the possible unification of matter and interactions.

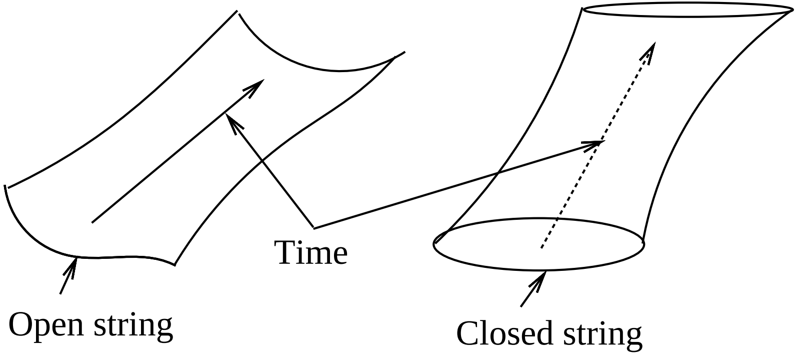
A lightening review

WHY STRING THEORY ?

- The unsuccessful description of Quantum Field Theory to gravity at its quantum region implies that the fundamental building blocks can no longer be taken as zero-size geometric points at a distance $\sim 10^{-35}$ m,
- The only known consistent theory which is capable to quantize gravity is string theory. In other words, String theory is an attempt to quantize gravity and to unify the gravity with the other three known interactions.

A lightening review

A string can either be an open interval or a circle, sweeping out a $(1+1)$-dimensional sheet or cylinder when it moves through spacetime:



A lightening review

The basic idea in string theory is:

different elementary particles observed in nature

$\Longleftrightarrow$

different vibrational modes of a one-dimensional string.

In other words, instead of having different kinds of elementary particles, we have only one kind of string, and the differences in the observed properties of elementary particles are due to the different quantum states of this string.

A lightening review

As a good quantum gravity and unified theory,

- Quantum string theory does not suffer from any ultraviolet divergence,
- Spectrum of a string theory contains a particle which has all the properties of a graviton— the mediator of gravitational interaction,
- The spectrum contains also particles which have all the properties of gauge bosons— the mediators of gauge interactions.

A lightening review

THE FIRST SUPERSTRING REVOLUTION (84-85)

Such Quantum String Theories Exist Indeed!

However, there are also several problems, for examples:

- String theory is consistent only in $(1 + 9)$-dimensional spacetime instead of the $(1 + 3)$-dimensional spacetime in which we seem to live,
- Instead of a single consistent string theory, there are five consistent string theories in $(1 + 9)$-dimensions. They are called Type IIA, Type IIB, Type I, SO(32) heterotic, and $E_8 \times E_8$ heterotic string theories. On the other hand it is desirable that we have a single theory, as there is only one nature which string theory attempts to describe.

A lightening review

THE SECOND SUPERSTRING REVOLUTION
(94-PRESENT)

Such a single so-called M-theory Exists Indeed!

Its existence is based on the following:

- Non-perturbatively, string theories contain not only the one-dimensional strings but also the other higher-dimensional objects, called p-branes, $p = 0, 1, 2 \cdots, 9$. Each of these p-branes is a soliton with respect to the strings, whose dynamics can be ignored in the weak string coupling limit.

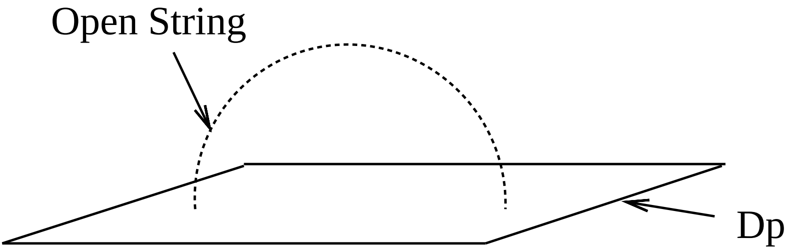
- There are also various duality relations, called S, T and U dualities. For example, the well-known AdS/CFT is a S-duality.

A lightening review

Among these p-branes, there is one particular useful type called D_p branes. As non-perturbative objects, their dynamics can be studied by a perturbative open string description!

A D_p brane

- can have two equivalent descriptions, one by a closed string and the other by an open string,

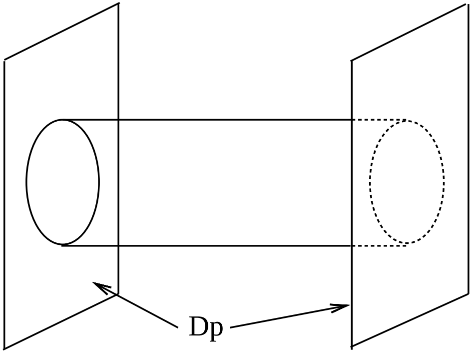


A lightening review

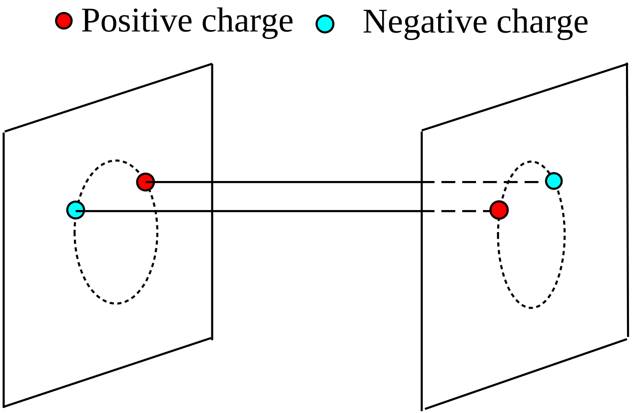
- is a non-perturbative object of string theory $(T_p \sim 1/g_s)$, but a fundamental building block of string/M-theory,
- is the so-called 1/2-BPS object, therefore stable,
- has spatial dimensionality $p = 0, 1, 2, \cdots, 9$
- each carries a mass (due to its tension) and a so-called R-R charge

A lightening review

As such, the net static force between two Dp branes is zero!

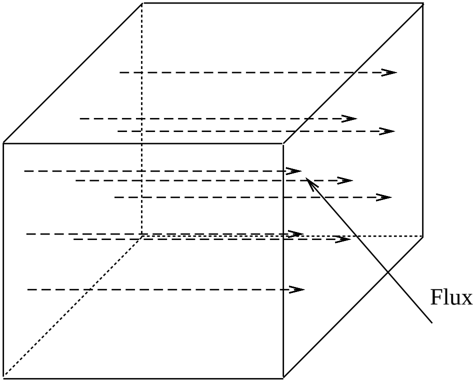


A lightening review



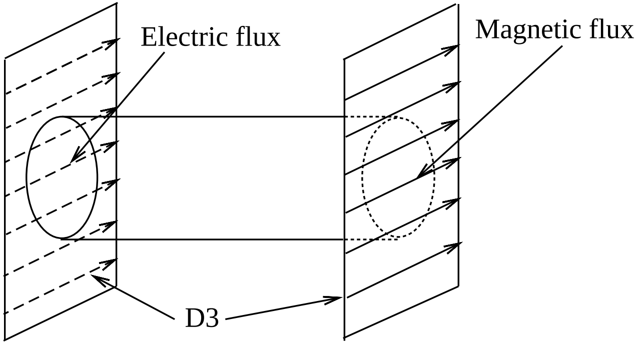
The brane interaction

Consider a particular D3 brane, relevant to our own world, carrying a flux, electric or magnetic,



The brane interaction

The static force between two D3 brane, with one carrying an electric flux and the other a magnetic flux, is now non-zero,



The brane interaction

We choose the electric flux $\hat{F}'$ in one D3 brane and the magnetic flux on the other, respectively, as

$$\hat{F}' = \begin{pmatrix} 0 & -f' & 0 & 0 \\ f' & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}, \qquad \hat{F} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -f \\ 0 & 0 & f & 0 \end{pmatrix}. \quad (3.1)$$

The brane interaction

The closed string tree-level cylinder or the open string one-loop annulus amplitude per unit 3-brane worldvolume can be calculated, following PRD79:126002(2009)& JHEP09(2009)93, to be

$$\begin{aligned}\Gamma &= \frac{4\,n'n\,\tanh\pi\nu'\,\tan\pi\nu}{(8\pi^2\alpha')^2}\int_0^\infty \frac{dt}{t}\,e^{-\frac{Y^2 t}{2\pi\alpha'}} \\ &\times\frac{(\cos\pi\nu' t-\cosh\pi\nu t)^2}{\sin(\pi\nu' t)\sinh(\pi\nu t)} \\ &\times\prod_{n=1}^{\infty}\frac{1}{(1-|z|^{2n})^4(1-e^{2\pi\nu t}|z|^{2n})(1-e^{-2\pi\nu t}|z|^{2n})} \\ &\times\frac{\prod_{j=1}^{2}(1-e^{\pi(i\nu'+(-)^j\nu)t}|z|^{2n})^2(1-e^{-\pi(i\nu'+(-)^j\nu)t}|z|^{2n})^2}{1-2|z|^{2n}\cos 2\pi\nu' t+|z|^{4n}}\end{aligned} \tag{3.2}$$

The brane interaction

In the above, we have $|z| = e^{-\pi t} < 1$, $2\pi\alpha' = 1/T$ with T the string tension and

$$\tanh \pi\nu' = |f'|, \quad \tan \pi\nu = |f| \tag{3.3}$$

where $0 < \nu' < \infty$ for an electric flux $0 < |f'| < 1$, and for a magnetic flux $0 < \nu < 1/2$ since $0 < |f| < \infty$.

The open string pair production rate

- This amplitude has an infinite number of simple poles occurring on the positive real t-axis at $t_k = k/\nu'$ with $k = 1, 2, \cdots$.
- Therefore this amplitude has an imaginary part which is given as sum of the residues of these simple poles. It gives the non-perturbative rate of pair production of open strings per unit worldvolume as

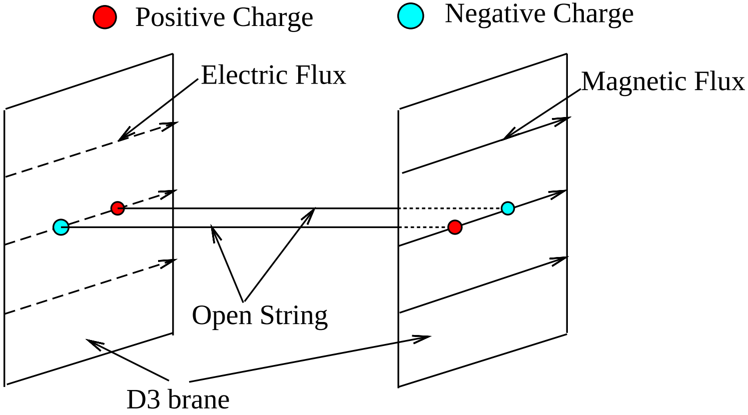
The open string pair production rate

$$
\begin{aligned}
\mathcal{W} \;=\; & \frac{8n'n\tanh\pi\nu'\tan\pi\nu}{\nu'}\sum_{k=1}^{\infty}(-)^{k+1}\left(\frac{\nu'}{8k\pi^2\alpha'}\right)^2 \\
& \times e^{-\frac{kY^2}{2\pi\nu'\alpha'}}\frac{\left[\cosh\frac{k\pi\nu}{\nu'}-(-)^k\right]^2}{\frac{\nu'}{k}\sinh\frac{k\pi\nu}{\nu'}} \\
& \times\prod_{n=1}^{\infty}\frac{\left[1-2(-)^k e^{-\frac{2nk\pi}{\nu'}}\cosh\frac{k\pi\nu}{\nu'}+e^{-\frac{4nk\pi}{\nu'}}\right]^4}{\left[1-e^{-\frac{2nk\pi}{\nu'}}\right]^6\left[1-e^{-\frac{2k\pi}{\nu'}(n-\nu)}\right]\left[1-e^{-\frac{2k\pi}{\nu'}(n+\nu)}\right]},
\end{aligned}
\tag{3.4}
$$

The open string pair production rate

- The rate is highly suppressed by the separation and the integer k and for each given k the corresponding term appears likely enhanced by both ν' and ν.
- The latter is particularly evident for large magnetic flux for which $\nu \to 1/2$ and the front factor $\tan \pi\nu \to \infty$.
- The odd k gives positive contribution while the even k gives negative contribution to the above rate. $k = 1$ term gives the leading positive contribution to the rate.
- The presence of magnetic flux appears to enhance the rate

The open string pair production rate



The rate enhancement

Consider now small fluxes, realistic case!

Let us consider two separate cases for showing the enhancement by the presence of a magnetic flux:

- The rate for small ν' and $\nu = 0$ can be given approximately by the $k = 1$ term as

$$(2\pi\alpha')^2 \mathcal{W}_{\nu=0} \approx 32\pi n' n \left(\frac{\nu'}{4\pi}\right)^2 e^{-\frac{Y^2}{2\pi\nu'\alpha'}} \tag{4.1}$$

Vanishingly small in general!

- Similarly, the rate for small ν' and fixed ν is

$$(2\pi\alpha')^2 \mathcal{W}_{\nu\neq 0} \approx 4\pi n' n \left(\frac{\nu'}{4\pi}\right)^2 e^{-\frac{Y^2}{2\pi\nu'\alpha'}} \frac{e^{\frac{\pi\nu}{\nu'}}}{\nu'} \tan \pi\nu, \tag{4.2}$$

The rate enhancement

The following ratio

$$\frac{\mathcal{W}_{\nu\neq 0}}{\mathcal{W}_{\nu=0}} = \frac{e^{\frac{\pi\nu}{\nu'}}}{8\nu'}\tan\pi\nu \qquad (4.3)$$

gives the rate enhancement of the magnetic flux, which can be very significant!

The rate enhancement

To have a better sense of the enhancement, let us make the following numerical estimations for illustration.

Take $\nu' = 0.02$ and $\nu = 0.4$, the enhancement given above is then

$$\frac{e^{\frac{\pi\nu}{\nu'}}}{8\,\nu'}\tan\pi\nu = e^{20\pi}\frac{25\tan 0.4\pi}{4} \sim 3.6\times 10^{28}!!! \qquad (4.4)$$

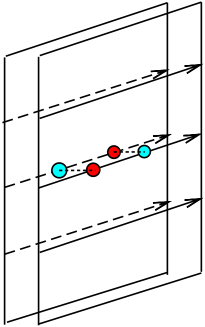
A huge number!

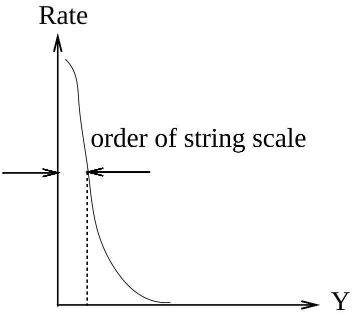
The rate enhancement

We have then

- The above significant enhancement in the presence of a magnetic flux indicates the possibility that the dimensionless rate itself can become significant
- Note that the rate is highly suppressed by the brane separation
- So only at small brane separation $Y = \pi\sqrt{2\nu\alpha'} + \triangle\sqrt{\alpha'}$ with $\triangle \ll \nu'/\sqrt{2\nu}$, this rate can become significant indeed!
- Any brane separation significant away from the above will make the rate vanishingly small

The rate enhancement





The rate enhancement

Given $\nu' = 0.02$ and $\nu = 0.40$, let us estimate the dimensionless rate

$$(2\pi\alpha')^2 \mathcal{W}_{\nu=0.4} \approx n' n \frac{\nu'}{4\pi} \tan 0.4\pi \approx 0.49 \,!!!, \qquad (4.5)$$

where we have taken the brane separation given above and also $n' = n = 10$.

Note that we need to have $p \geq 3$ for this enhancement to occur and the $p = 3$ case gives the largest rate and the rate for $p = 4$ is one order of magnitude smaller and so on.

Summary

- When one flux is electric and the other magnetic, the pair production rate is greatly enhanced by the presence of the magnetic flux and can become significant even for a small electric flux
- This can occur only for $p \geq 3$
- When the brane separation is on the order of string scale, this rate can be very significant, is the largest for $p = 3$ and decreases rapidly with the value of $p > 3$
- For example, the rate of $p = 3$ is larger than that of $p = 4$ by at least one order of magnitude and the rate becomes insignificant for $p > 4$ for reasonable large brane numbers of n', n

Discussion

- If string theory is indeed relevant to our real world, the above pair production should have potentially observational consequences, most likely from the sky
- For example, in quantum gravity stage or even after the reheating epoch or later, the two sets of D_p branes ($p \geq 3$) with one set carrying an electric flux and the other carrying a magnetic flux can experience dynamics by approaching each other to produce highly energetic open string pairs and then annihilate to give rise to other particles such as the high energy photons or other particles. Now one expects the brane numbers of n' and n not to be very large

Discussion

- Also, in the late stage of our Universe, one can take either of the above mentioned sets of D_p branes as a macroscopic object in our Universe for which the brane number should be fairly large. Then when the two objects approach to each other in a small separation, one expects a large number of open string pairs to be produced
- This should be most significant for $p = 3$ and the produced open string pairs are mostly confined along the $p = 3$ brane directions since the rate only becomes significant when the brane separation is very small

Speculation

- If such effects can indeed be observed, it would imply the existence of extra dimensions since we need to have $p \geq 3$ for this process to occur
- It would also imply the selection of three extra large dimensions since the $p = 3$ gives the largest effect and the pair production is mostly confined along the $p = 3$ directions (Does this imply further why our world is $(1 + 3)$-dimensions?)

Speculation

- As mentioned above, when the two sets of D$_p$ branes are taken as macroscopic objects in our Universe, the open string pair production can be very significant in particular for $p = 3$ since now n' and n can be very large. In analogy to the annihilation of electron-positron into photons, we expect the annihilation of large number of open string pairs to produce huge high energy photons in a short time of period. Can this be used to explain the recently observed γ-ray burst?

THANK YOU!