String charge and the fields of extra dimensions

The standard model of particle physics is built from fields and field quanta. In the extra dimensions of string theory we find new fields.

According to the classical picture, fields are the gradients of potentials and charge density determines the divergence of a field.

$$E = \nabla\Phi \tag{23.1}$$

$$\rho = \nabla \cdot E \tag{23.2}$$

Different kinds of charge are associated with the different fields. Familiar electric charge generates the electric field. Mass-energy is a kind of charge that generates the gravitational field. We'll use the old reliable vector potential A^{μ} of electromagnetism to help sniff out new fields in string theory. If we find an analog of A^{μ} in our explorations, we're on the track of a field.

Here's a look ahead. When we analyze the extra dimensions of string theory, we'll find added terms in the metric. The metric describes the geometry of spacetime, and extra dimensions require extra coordinates. We will find that some of those new terms are fields of form A^{μ}. Those new fields have associated particles and charges.

Here's the argument. The metric of familiar 4-dimensional spacetime is $g_{\mu\nu}$. The μ, ν each run over the four dimensions of spacetime. $g_{\mu\nu}$ tells us how clocks speed up or slow down, how meter sticks stretch or contract, as we move along the various spacetime dimensions. It is a measure of the gravitational field. When we add another dimension, we must add two new terms to the metric. (We'll use the torus as our extra dimension.)

$$g_{\mu\nu} \to g_{\mu\nu} + g_{\mu 5} + g_{55} \tag{23.3}$$

g_{55} tells us how the fifth dimension itself changes as we move through it. We can get an impression on the torus.

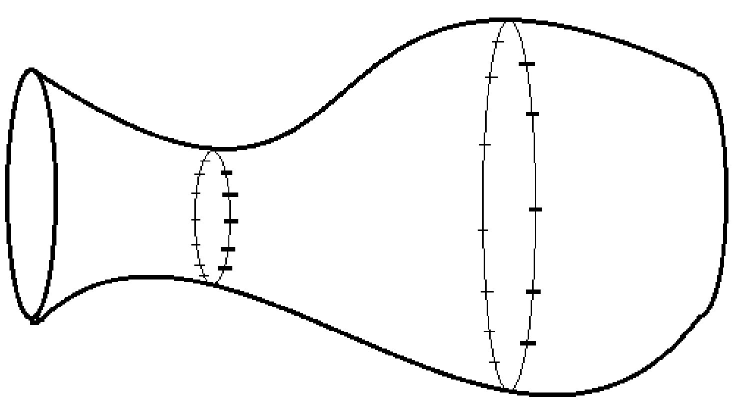

Figure 23.1. Distortions induced by g_{55} projected onto background spacetime. Note σ scale on the two wound strings.

The $g_{\mu 5}$ term has the essential characteristics of a vector potential in the new dimension. It describes how the familiar spacetime metric changes as we move through the 5th dimension. It is analogous to A^{μ}. Looks like a duck, quacks like a duck – it behaves like a new field.

We'll work with closed strings. Where there are new fields there are charges and potentials. We have seen that open strings have an orientation and that the ends of open strings behave like charges. Analogously, closed strings wrapped around the extra dimension also carry charge due to their orientation. Strings with the same orientation repel each other, and strings with opposite orientation attract.

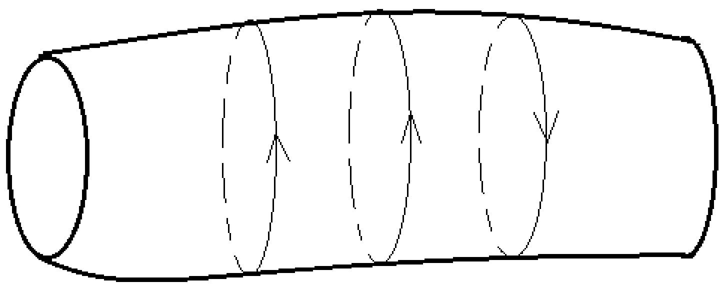

Figure 23.2. Middle string repels string on left, attracts string on right.

Let's see what happens when we tickle that field and disturb it from its ground state. Closed strings must obey the rules of level-matching. To excite the first state above the ground state in the extra dimension, we require equal contributions from L- and R- moving creation operators. Here's the first excited state, resulting from mixed creation operators acting on the ground state:

$$a_1^{\mu}(R)a_1^5(L)|0\rangle \pm a_1^{\mu}(L)a_1^5(R)|0\rangle \tag{23.4}$$

The $+$ gives a graviton. The $-$ produces the axion, a boson that pops up in other field theories, as well.

Success! Well, at least string theory in extra dimensions produces fields and particles familiar in standard quantum field theories. That's encouraging.

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