S-duality

T-duality makes us confront the question, which is the “real” string? The Kaluza-Klein string, spiraling around a torus? Or the wound string, wrapped on the torus? Change the dimension of the torus, and the two swap properties.

Now we bump into another puzzlement. What is “fundamental.” What is the world “really” made of? What are the bricks that build the edifice? What is the mortar that holds it together? A second duality, S-duality, tells us that the “fundamental” particles themselves morph back and forth, like actors in a play changing costumes to assume different roles.

Key to S-duality is the coupling constant, g . It’s not constant. It is a function of position, and we are interested in knowing what happens to string interactions when we dial its strength up or down.

g measures the probability that strings will interact. How likely is it that string ends will join if they bump into each other? How likely is it that a closed string will open up? A large value of g makes it more likely that these interactions will occur. Small g makes it less likely.

The best known coupling constant is α , the interaction parameter for electromagnetism. Its value is about $1/_{137}$. That is, roughly speaking, about once in every 137 electron-photon collisions, the electron will scatter (absorb and re-emit) the photon. Doesn’t happen very often. If α was larger, the electromagnetic force would be a whole lot stronger than it is. (Still, it’s about forty powers of ten stronger than gravity. Think how small must be the value of the coupling constant for gravity!)

Now imagine “tuning” α . Theorists posit two “fundamental” particles in electromagnetism, the electron and the magnetic monopole. The electron has a tiny mass. The monopole is heavy. If we “dial up” the value of α , the electron becomes more massive and the monopole gets lighter. They exchange properties!

Here’s why. The electron is surrounded by a cloud of virtual particles – photons, loops (of electron-positron pairs), propagators, and interactions between them (governed by α). Turn up α and the cloud gets thicker – more loops and propagators and interactions between them. Increasing alpha is like dialing up the energy density in the vicinity of the electron. More energy, more mass. It begins to look like a monopole.

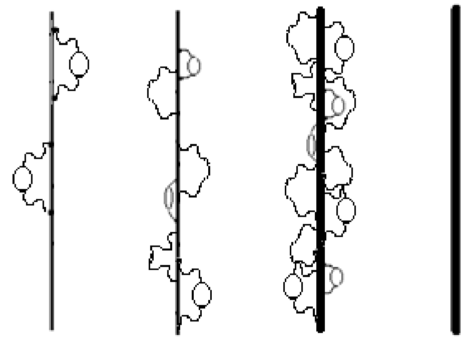

Figure 24.1. Electron on the left at low value of α , therefore few virtual interactions. α increases left to right, facilitating more virtual interactions. Magnetic monopole on right at limit of large α .

Same deal between strings and branes. Tuning the string coupling constant, g , converts strings into branes and vice versa. Most obvious, similar to back-and-forth electron-to-monopole, is the relation between an open string and the D1-brane. At normal $g \ll 1$, the D1-brane has more structure and is more massive than the string. Dial up g and the string develops more structure, the D1-brane less, because as g increases, segments of the string fuse and break away as loops and those loops interact. Some rejoin the original string, so the region around the string boils with activity. Meanwhile, strings that were attached to the D1-brane boil away. The brane is stripped of its string fuzz. It shrinks. The brane begins to look more and more like a string, the string more like a D1-brane.

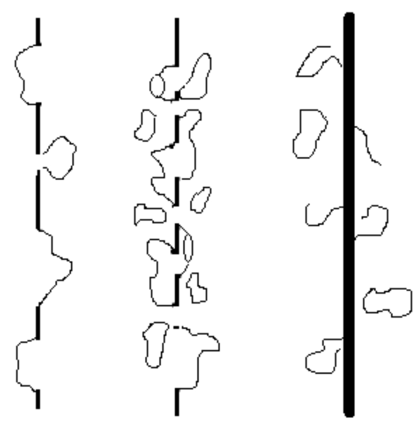

Figure 24.2. As g increases, left to right, string transforms into D1 brane, and vice versa.

This is S-duality. Increasing g turns strings into D1-branes and branes into strings. Same kind of thing happens at higher dimensions. We'll look at a couple further examples.

Consider strings on a compactified space, for example 3d compactified to 2d. Increase g and the string stretches into a membrane with added mass.

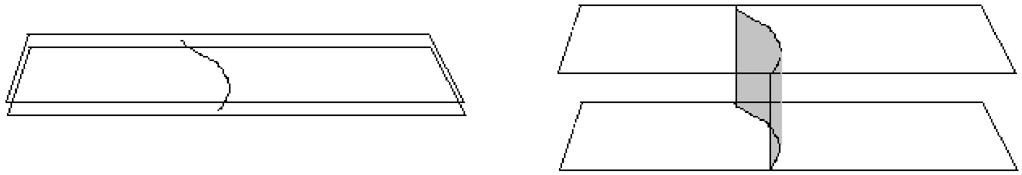

Figure 24.3. String in 2d (left) transforms to brane in 3d (right).

Upward through the dimensions: to physicists like us living in a familiar 3d brane, D1 and fundamental strings stuck to the brane look like monopoles and electrons, respectively.

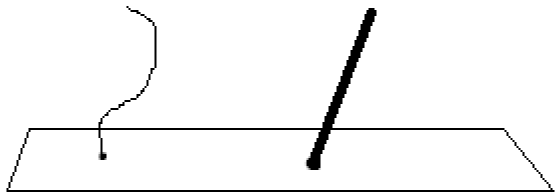

Figure 24.4. Projection of our familiar 3D brane onto 2D. String/electron on left, D1/monopole on the right.

Finally (for our discussion here – there are many other regions to explore) compactified dimensions provide another model relating D1 and fundamental strings. Suppose variations in g cause variations in the scale along axes of compactified dimensions. Then a brane stretched in the wider x, y plane might be dual to a brane stretched in the narrower y, z plane. The one might be the fundamental string, and the other could be D1.

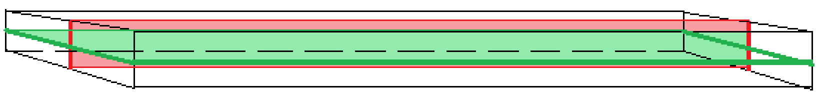

Figure 24.5. Dual (green and red) branes.

And the payoff (well, one among many). Scale up to the 10 dimensions of string theory. Increase g and the string theory becomes an 11-dimensional theory of gravity. The mathematics of the one theory can be used to describe phenomena in the other. In some circumstances, the calculations are easier in 11d supergravity. In others, the calculations simplify in 10d superstring. A physicist can choose one or the other, whichever is most convenient to study the physics.

Return to Table of Contents