A Beginner's Guide to String Theory

What is String Theory?

We are taught in school that the universe is most fundamentally described by little particles, which exist at some precise point in space. We have all these atoms made up of neutrons and protons, with some electrons whizzing around. And you may even have heard that these neutrons and protons are made up of smaller things, called quarks. Oh and then there's photons. And neutrinos. And gluons. And now the Higgs boson. Getting a bit silly isn't it? The issue is, it's not just silly - it's also just plain wrong. While these descriptions hold up in every day life, these models - which come under the banner of *particle physics* - break down as soon as we stop describing a cup of tea and start describing something more exciting, like a star or a black hole. The problem here, really, is that we don't know how to include *gravity* in the Standard Model.

The idea of string theory is contained completely in the name. It says: where we've been going wrong with *particle* physics is the 'particle' bit. Perhaps the most fundamental objects in our universe are not particles, but instead little loops of *string*. Loops so tiny that from our big, lumbering perspective they just look like particles. In this description, what we think of as an electron is just that string wobbling in a particular way, whereas to get a quark we just need to wobble it a different way. If particle physics was silly, this is *really* silly - but amazingly, it works. We can find all the complexity contained in the 17 different particles of particle physics by considering the wobble of just a single string. Not only that - we find gravity too! In this project, we will uncover the first steps of how this description comes about.

Outline of the project

The aim of the first part of this project is to build up an elementary knowledge of how a piece of string floating in space would wobble around. We will use this as a springboard to learn a selection of essential bits of mathematics. We will first look at the *wave equation*. This is an equation that governs how a string vibrates. In looking at this, we will learn about derivatives, changing variables, and we will in the end solve a simple partial differential equation

We will then further explore the form of the solutions to the wave equation. We will learn about periodic functions, and our journey will be simplified when we learn about the famous Euler identity, $e^{i\pi} + 1 = 0$, and the world of complex numbers that comes with it.

With our solutions to the wave equation in hand, we will draw some plots and get a firm grasp of what these solutions actually look like.

Once happy with these solutions, we'll take a bit of a jump. After all when we zoom out we're supposed to be able to think of these little loops of string as particles. So, we'll work to understand how the string's wobble is interpreted as its *mass* when we zoom out and look at it like a particle. In this way, we'll be able to work out how many particles of different masses String Theory predicts. We'll also have a look at how some kind of particle interaction like pair creation is understood in term of *string interactions*. The final task of the project will be to show that our universe is not really 4-dimensional at all - it's 26-dimensional! Or maybe 10. Or is it 11?

Suggested skills

Although we will make good use of derivatives and complex numbers, the necessary information for these topics will be provided as part of the project, rather than assumed. The remainder of the project will involve some fiddly algebra, but nothing a committed student with an interest in physics can't handle.