Introduction

Why this text?

Long ago, I set myself the goal of understanding gravity. What holds us to the earth? Holds moon in its orbit? Creates black holes?

It's an essential mystery. Modern physics makes clear that one, perhaps the, remaining great question is the relation between general relativity, Einstein's theory of gravity, and quantum mechanics, our basis for understanding the particles and forces. The two theories are oil and water, but you can't explain our universe without the both of them. You can't describe the extremes of gravity without quantum mechanics, and you can't understand the particles and forces without including gravity.

As a high school teacher of math and science, I've come to appreciate the imagination and energy of high school students. They can do a whole lot more than we usually expect of them. I think they can do string theory, at least the basics.

So here I am trying to weave the tapestry of models that represent our universe. The latest and best threads in that tapestry appear to be strings.

I owe this endeavor to two marvelous resources. I am summarizing the ideas put forth by Leonard Susskind in his lecture series, *String Theory*, included in his extraordinary exposition of modern physics, *The Theoretical Minimum*. I also rely on the text by Barton Zwiebach, *A First Course in String Theory* (Zwiebach, 2009). Both those professors address an advanced college audience; I have distilled the essentials to make the ideas and the math accessible to high school students with a background in physics and calculus. I am not likely to add any new ideas herein, but in some instances I provide a different perspective. I suspect there are mistakes in my presentation, and I take full responsibility for them. I hope that alert readers will inform me of any errors in the logic.

String theory is not a single theory. It is many theories. Nor is it complete – far from it. It is a work in progress. By "string theory" I include the basic ideas of strings, their morphology and dynamics, and the extensions of the theory to branes and M-theory.

Is string theory the fundamental theory of our universe (and of the multiverse)? Is it the end of the long search for a theory of everything, a model that will tie together all the loose ends of general relativity and quantum mechanics? As we will see, the very term "fundamental theory" may be a will o' the wisp. When we try to squeeze down the strings for closer inspection, they push back out in new forms. Physicists have not yet formulated a complete string model for the universe, no string model that pops out all the known particles and forces. But there are tantalizing clues that we're on the right track and more clues that ours is only one among other universes built on other string models.

We will look first at string basics. What is a string? How can we describe it? How can we measure its motion and energy? Then we shall introduce the dualities, the complementary

pictures by which we can describe string dynamics, including branes. With the basics in hand, we shall explore the accomplishments of string theory, including string models of black holes, the strong nuclear force, solid state physics, and the multiverse.

I have chunked the text into bite-size chapters. Each chapter addresses one particular aspect of the string model. The mathematics assumes familiarity with integral and differential calculus. It would be helpful for the reader to have some familiarity, also, with Lagrangian mechanics, the principle of least action, and core concepts of quantum mechanics, but I try to summarize the essentials as they are needed. Mathematical logic is color coded, so the reader can follow the ingredients of a model from start to finish.

I hope you enjoy the notion that these tiny, wiggling strings are tying together so many disparate branches of physics. It appears that the multiverse is string.

References

Susskind, Leonard. 2010-2013. The theoretical minimum. Lecture series sponsored by the Continuing Education Program at Stanford University.

Zwiebach, Barton. 2009. A first course in string theory, 2e. Cambridge University Press.

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