

What is String Theory?

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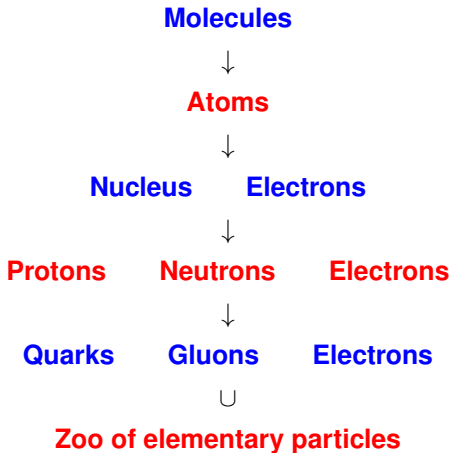
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String theory is an attempt to find a unified theory of the elementary constituents of matter and the forces operating between them

– study of the laws of the universe at small scales of order 10^{-33} cm. going far beyond atoms and nuclei.

Modern understanding of the ultimate constituents of matter



These elementary particles interact via various kinds of forces.

1. Gravitational

2. Electromagnetic

3. Strong

4. Weak

5. Higgs

It turns out that the effect of gravitational force between elementary particles is negligible compared to the other forces.

To see this one can compare the electrostatic force between two protons with the gravitational force between two protons at rest.

Result:

$$\frac{\text{Grav. Force}}{\text{Elec. Force}} = \frac{Gm_p^2/r^2}{e_p^2/r^2} \sim 10^{-36}$$

G: Newton's gravitational constant (6.67×10^{-8} cm³/gm sec²)

m_p: proton mass (1.67×10^{-24} gm)

e_p: proton charge (4.8×10^{-10} e.s.u.)

Similarly all other forces are also much larger than the gravitational force.

There is a mathematical theory, known as the standard model, which describes all the elementary particles and their forces if we leave out gravity.

This theory is based on the principles of quantum mechanics and special theory of relativity.

However the absence of gravity shows that the standard model cannot be the complete description of nature.

Can we modify the standard model so as to include gravity?

The standard model is based on the principles of special theory of relativity and quantum mechanics.

⇒ we need to first make the theory of gravity consistent with the principles of

- 1. special theory of relativity**
- 2. quantum mechanics.**

The first step – making gravity consistent with special theory of relativity – was carried out by Einstein in 1915.

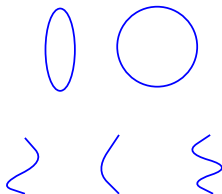
→ **general theory of relativity.**

The second step, – combining this with quantum mechanics – turns out to be extremely difficult.

String theory provides a possible way out of this problem.

Basic postulate of String Theory

Elementary constituents of matter are not zero dimensional point particles but one dimensional strings.



Typical size of a string $\sim 10^{-33}$ cm

This is much smaller than the length scale that can be probed by any present day experiment ($\sim 10^{-17}$ cm.)

Thus to a present day experimentalist the states of the string will appear to be particle like objects.

We need to formulate a theory of strings consistent with the principles of

1. Quantum mechanics.

2. Special theory of relativity.

It turns out that as a consequence of these two requirements strings automatically exert gravitational force on each other.

– string theory is automatically a quantum theory of gravity!

Furthermore the requirement of mathematical consistency completely fixes the underlying laws of string theory.

In other words there is a unique string theory.

This is to be contrasted with the theory of point particles where there are infinite number of consistent theories.

Standard model is one of these consistent theories favoured by experimental results.

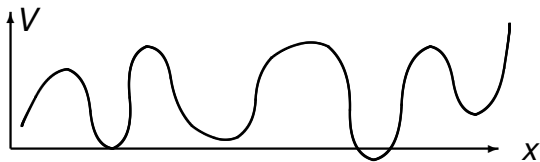
The uniqueness of string theory, and the fact that it incorporates quantum theory of gravity, makes this a strong candidate for the theory that describes the fundamental constituents of matter and their forces.

To confirm this we need to verify that string theory also explains the origin of electromagnetic, strong, weak and Higgs forces.

– not completely straightforward

The difficulty in doing this is related to the existence of string theory landscape which we shall now explain.

An analogy: A particle in a potential



Even though the potential gives the laws of motion completely, the particle may get stuck around different minima depending on the initial condition.

Similarly our universe may get stuck in different phases of string theory.

– landscape of phases of string theory.

For some phases of string theory the environment is very similar to what we observe in nature.

→ has elementary ‘particles’ and forces similar to what we see.

However there are also other phases of string theory which have very different environment.

– even the dimension of space can be different in these phases taking values all the way up to 10 instead of 3.

Is there a phase of string theory that describes exactly the universe in which we live?

We have not yet found one, but the search for such a phase is still on.

This is a very active area of research.

Another area of research involves using the laws of string theory to answer various puzzles that arise when we try to combine gravity and quantum mechanics.

Yet another area of research involves attempts to gain a better understanding of the underlying laws of string theory itself.

I hope that some of you will be participating in this adventure in the near future.