From Particles to Strings

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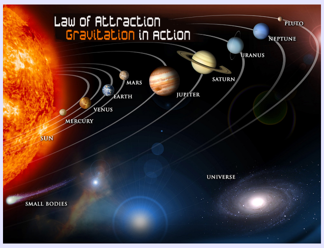
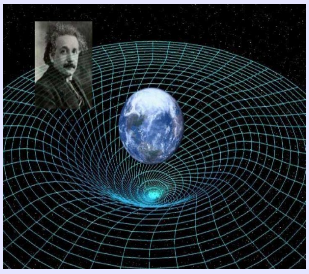
What is Gravity?

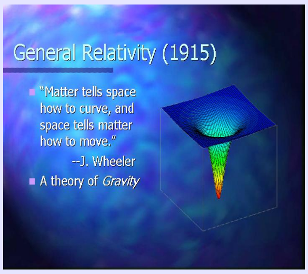
In 1686, Isaac Newton gave the law of universal gravitation that states that any two bodies in the universe attract each other with a force directly proportional to the product of their masses and inversely proportional to the square of the distance between them.



According to this law signal can propagate through space with infinite speed (**Action at a Distance**). But, afterwards, it was shown by **James Clerk Maxwell** in formulating **classical electrodynamics** that signal has a limiting velocity. **Albert Einstein** in 1905 proposed **Special Theory of Relativity** that states that **velocity of light is the same in all inertial frames** (3×10^8 mt/sec). Special relativity also invoked the concept of four dimensional space-time, treating both space and time on equal footing.

In 1915 Einsteing gifted the world the **'Theory of General Relativity'**. This is time to change the notion of Gravity! It is not to be thought of as a force acting between two bodies anymore but rather to be thought of as the effect of curvature of space-time. Yes! Space-time is curved due to matter around us.





Quantum Mechanics

The elementary particles in our universe are microscopic and they do not follow the laws of Newtonian Mechanics. **To describe the physics at such small length scales (atomic and subatomic) we need Quantum Mechanics**.

The Standard Model

Matter is made of atoms, which in turn are made of three basic components: electrons , neutrons and protons. Neutrons and protons together form nucleus and the electrons move around the nucleus inside the atom. The electron is a fundamental particle, but neutrons and protons are not! They are made of smaller particles, known as **quarks**, which are elementary. There are six types of quarks in nature named **Up, Down, Charm, Strange, Top and Bottom.**. The antiparticles (having same mass as particles but opposite quantum numbers) of the quarks exist in nature. They are called **Anti-quarks**.

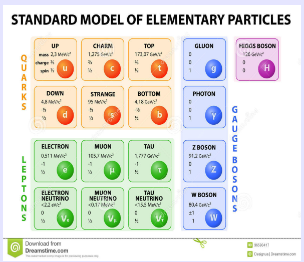


Table S4.2 The Four Forces

Force	Relative Strength Within Nucleus*	Relative Strength Beyond Nucleus	Exchange Particles	Major Role
Strong	100	0	Gluons	Holding nuclei together
Electromagnetic	1	1	Photons	Chemistry and biology
Weak	10^{-5}	0	Weak bosons	Nuclear reactions
Gravity	10^{-43}	10^{-43}	Gravitons	Large-scale structure

* The force laws for the strong and weak forces are more complex than the inverse square laws for the electromagnetic force and gravity; hence the numbers given for the strong and weak forces are very rough.

There are four fundamental forces in our universe: gravity, electromagnetism, weak and strong nuclear forces. Some fundamental particles act as carriers of these forces.(For example photon, a particle of light is the mediator of electromagnetic force). Similarly carrier/mediator of gravity is graviton. Strong force is mediated by eight particles, named gluons, and the weak force is mediated by three particles, W^+, W^- and Z bosons. All the fundamental particles that have been discovered (except Graviton, which has not been seen in experiments yet) obey the rules of Quantum Mechanics and Special Theory of Relativity and these particles are described in a framework known as **Quantum Field theory.** The Standard Model describes the elementary particles and all the forces (except Gravity) of nature using the formalism of Quantum Field theory.

If one tries to include the effects of Gravity in the Standard Model, then the theory loses all its predictability! Also, recent experiments show that the neutrinos have very tiny mass, but Standard Model consider them to be massless. So, there is need to go beyond Standard Model.

What is String Theory?

String theory attempts to provide a complete theoretical description of our universe, unifying the forces of nature, including gravity in a quantum mechanical framework.
In String Theory at the fundamental level, matter does not consist of point particles but rather of tiny loops of strings. There are two types of strings: closed strings and open strings. So, strings are all around us (our clothes are made of strings)! From this picture, the theory of Gravity, electromagnetism, strong and weak interactions can emerge eventually.

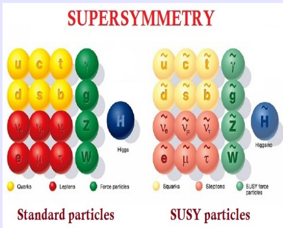
String theory arises as the low energy limit of an yet not fully understood theory called the M theory, where the fundamental objects are membranes.

The Standard Model particles are supposed to be described by string theory as different vibrational modes of the String. String theory can predict some gross features of Standard Model but yet it can not identify the standard model particles uniquely, neither it can yet exactly describe the parameters of the standard model.

Low energy limit of String Theory gives rise to general relativity.

Features of String Theory

- **Supersymmetry:** If String theory has to describe our real world it needs Supersymmetry. Supersymmetry (SUSY) is a proposed enhanced spacetime symmetry. SUSY requires a partner particle for each particle in the Standard Model.



The SUSY particles are yet undiscovered in **Large Hadron Collider (LHC)** experiments at **CERN, Geneva** (the most energetic particle accelerator in the world, providing enerrgy $\sim$ 7 TeV). So, it is believed that **SUSY is broken in nature** and the superpartners of the Standard Model particles must be heavier than the LHC maximum energy scale.

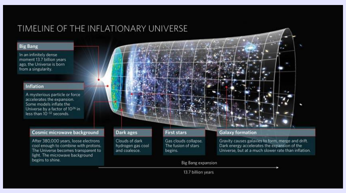
- **Black Holes:** String theory can describe certain black holes. **Black hole (BH)** is a region of spacetime that exhibits such a strong gravitational pull towards its center that no particle or radiation can escape from it. The boundary of the region from which no escape is possible is called the **event horizon.**

In many ways a BH acts like an ideal blackbody as it absorbs everything. However, **In 1974, Stephen Hawking argued that event horizons of black holes emit radiation, with the same spectrum as a black body of temperature inversely proportional to its mass due to quantum effects near the horizon.**

- **Extra Dimensions:** String theory needs spacetime dimensions higher than four. **Superstring theory requires ten spacetime dimensions.**
- **Other Universes:** String theory allows for the existence of other universes besides our universe.

Cosmology

In 1929, observations of distant galaxies showed that the light from those galaxies behaved as if they were going away from us. We know that the universe is expanding and has a finite age of approximately 14.5 billion years from these observations.



The Big Bang: Universe was extremely hot and point-like during its inception. Due to a huge explosion in a very short time the universe started to expand. The explosion is known as the **Big Bang**.

Cosmological predictions from String Theory:

Most of the mass in our universe is in the form of dark matter. **One candidate of dark matter is WIMP(Weakly Interacting Massive Particle).** A strong candidate for the WIMP , called neutralino comes from supersymmetry. As string theory requires SUSY , so it can also address for the mysteries of dark matter.