Supersymmetry

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Abstract : *This article deals with the introduction of supersymmetry as the latest and most emerging burning issue for the explanation of nature including elementary particles as well as the universe. Supersymmetry is a conjectured symmetry of space and time. It has been a very popular idea among theoretical physicists. It is nearly an article of faith among elementary-particle physicists that the four fundamental physical forces in nature ultimately derive from a single force. For years scientists have tried to construct a Grand Unified Theory showing this basic unity. Physicists have already unified the electron-magnetic and weak forces in an 'electroweak' theory, and recent work has focused on trying to include the strong force. Gravity is much harder to handle, but work continues on that, as well. In the world of everyday experience, the strengths of the forces are very different, leading physicists to conclude that their convergence could occur only at very high energies, such as those existing in the earliest moments of the universe, just after the Big Bang.*

Keywords: standard model, grand unified theories, theory of everything, superpartner, higgs boson, neutrino oscillation.

1. INTRODUCTION

What is the world made of? What are the most fundamental constituents of matter? We still do not have anything that could be a final answer, but we have come a long way.

Elementary particles are those microscopic elementary constituents out of which all matter in this universe are considered to be made of. In the ancient time water, fire, air and earth were assumed to be basic elements of the universe. According to Hindu Philosophy also water, fire, air, sky and earth are considered as basic constituents of the universe. At the beginning only electron, proton and neutron were considered to be elementary particles or the most fundamental particles. Fundamental particles are the smallest things in the universe and the universe is the biggest thing itself on the large scale. Fundamental particles are not permanent entities; they can be created and destroyed. The development of high energy particle accelerators and associated detectors has been crucial in our understanding of particles. We can classify particles and their interactions in several ways in terms of conservation laws and symmetries, some of which are absolute and others of which are obeyed only in certain kinds of interactions.

Between 1961 and 1967, Sheldon Glashow, Abdus Salam and Steven Weinberg developed a theory that unifies the weak and electromagnetic forces. The basic idea is that the mass difference between photons having zero mass and the weak bosons makes the electromagnetic and weak interactions behave quite differently at low energies. However, at sufficiently high energies the distinction disappears and the two merge into a single interaction. This prediction was verified experimentally in 1983 by two experimental groups working at the proton- antiproton collider at European organization for nuclear research (CERN). The weak bosons were found, again with the help provided by the theoretical descriptions. Their observed masses agreed with the predictions of the electroweak theory as the convergence of theory and experiment. The electroweak theory and quantum chromodynamics (QCD) form the backbone of the standard model. The standard model does not attempt to explain gravitation, although a theoretical particle known as graviton would help to explain it. It can not explain the observed amount of dark matter and dark energy.

2. FUNDAMENTAL FORCES AND INTERACTIONS

There are only four types of forces or interactions in the nature. All the other forces can be expressed in terms of these forces. These forces together account all the phenomena microscopic as well as macroscopic occurring in the universe. These forces are as follows:

2.1 Strong Force

This force acts between hadrons or quarks. It is always attractive and the strongest force in nature. It is mediated by mesons or gluons. This force is charge and mass independent and saturative. Its range is very small. It is responsible for the stability of nucleus.

2.2 Electromagnetic Force

The force which acts in between all charged particles is called an electromagnetic force. It is infinite range force. It is stronger than gravitational but weaker than strong force. It is independent of mass, colour etc. It is attractive for unlike charges and repulsive for like charges. It is mediated by photon. It is responsible for the stability of atoms, binding atoms in matter and chemical reaction.

2.3 Gravitational force

This force acts between the particles having mass. It is always attractive. Its range is infinite. It is inverse square force and is independent with colour, charge etc. It is the weakest force in nature. It is mediated by graviton. It is responsible for the stability of universe.

2.4 Weak force

This force acts between leptons and hadrons. It has shortest range. It is stronger than gravitational force but weaker than electromagnetic and strong force. Mediators of this force are intermediate bosons. This force is responsible for beta decay.

The standard model includes three families of particles. The first family includes six types of leptons which have no strong interactions. The second family includes six types of quarks (upquark, downquark, strangequark, bottomquark, topquark & charmquark) from which all hadrons are made. The third family includes the particles that mediate the various interactions. These mediators are gluons for the strong interaction among quarks, photons for the electromagnetic interaction, the boson particles for the weak interaction and the gravitons for the gravitational interaction.

Quarks are the smallest building blocks of matter. They are the fundamental constituents of all the hadrons. They have fractional electric charges. They never exist alone in nature. They are always found in combination with other quarks or antiquarks in larger particle of matter. Without quarks there would be no atoms and without atoms matter would not exist as we know it.

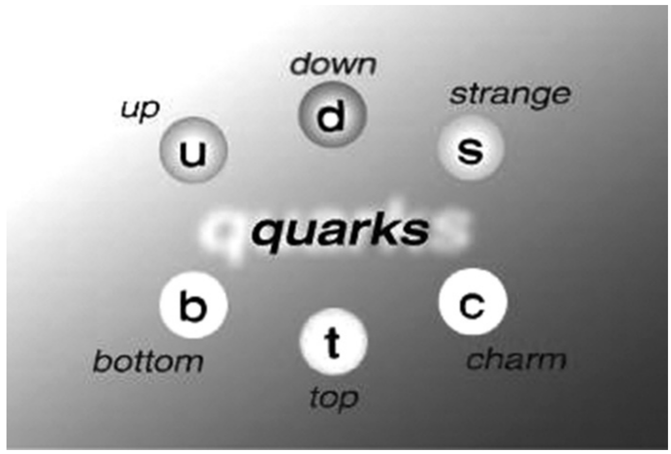

Fig.1 Six types of quarks

Theoretical physicists have long dreamed of combining all the interactions of nature into a single unified theory. As a first step, Einstein spent much of his later life trying to develop a field theory that would unify gravitational and electromagnetism. He was only partly successful.

3. DIFFERENT MODELS, THEORIES AND HIGGS BOSON

It is well known that particles are of two types- fermions whose spins are odd multiples of half, and bosons which have zero or integral spin. Fermions obey the Pauli's Exclusion Principle that states that two of them cannot occupy the same physical state simultaneously. The formulation of Quantum Chromodynamics (QCD) gives the introduction of the concept of color. Quarks can be of colors red, green and blue and antiquarks of antired, antigreen and antiblue. According to Quantum Chromodynamics, all combinations of quarks must contain mixture of these imaginary colors that cancel out one another with the resulting particle having no net color. The development of the theory of Quantum Chromodynamics (QCD) describes how gluons interact among themselves and with the quarks.

A remaining difficulty in the electroweak theory is that photons are massless but the weak bosons are very massive. To account for the broken symmetry among these interactions mediators, a particle called the Higgs boson has been proposed. Its mass is very small but to produce it in the laboratory may require a much greater available energy.

At sufficiently high energies the strong interaction and the electroweak interaction have a convergence similar to that between the electromagnetic and weak interactions. If so, they can be unified to give a comprehensive theory of strong, weak and electromagnetic radiations. Such schemes called Grand Unified Theories (GUTs) lean heavily on symmetry considerations. Some Grand Unified Theories (GUTs) also predict the existence of magnetic monopoles. At present there is no confirmed experimental evidence that magnetic monopoles exist, but the search goes on.

Higgs boson plays a unique role in the standard model by explaining why the other elementary particles except the photon and gluon are massive. Higgs bosons will explain why the photon has no mass, while bosons are very heavy. Higgs particle is a massive particle and also decays immediately. Only a very high energy particle accelerator can observe and record it.

A number of extensions of the standard model have been proposed by physicists. The most studied of these is the Minimal Supersymmetric Standard Model (MSSM). It requires that all standard model particles are accompanied by a supersymmetric partner particle which has a spin differing by half a unit. The electron with spin half has a partner particle with spin zero. The lightest of these supersymmetric partner particles constitutes a perfect candidate for dark matter. It yields the correct amount of dark matter in the universe as measured in astrophysical experiments.

According to Minimal Supersymmetric Standard Model (MSSM), the collision of two protons at sufficiently high energies should produce either two gluinos (the supersymmetric partner of the gluon) or scalar quarks (called squarks), the supersymmetric partners of the quarks. The gluinos and squarks then decay to lighter supersymmetric particles and quarks.

On the basis of above findings and discussions, it is understood that it took about half a century from the discovery of strangeness to the discovery of standard model for quarks and leptons and their interactions. Physicists continue to conduct experiments to discover whether new data will dispute their findings and to learn more about new theories including supersymmetry.

The ultimate dream of physicists is to unify all four fundamental interactions, adding gravitation to the strong and electroweak interactions that are included in Grand Unified Theories. Such a unified theory is called a Theory of Everything (TOE). It turns out that an essential ingredient of such theories is a space- time continuum with more than four dimensions.

The standard model of particle physics describes the elementary particles and the forces that act between them. According to this model the matter building blocks contain the quarks and leptons which include the electron. So, it is the most precise and successful theory ever developed. The only missing building block of the model is the Higgs particle which is needed to give mass to all other elementary particles. Despite its success, it can not be the ultimate theory because it can not explain dark matter.

4. NEUTRINO OSCILLATION

Neutrino oscillations are a peculiar quantum mechanical effect, for which it is hard to find a good macroscopic analogy, as it has to do with the wave-particle duality of fundamental matter. In standard model, the neutrinos have zero mass. Nonzero values are controversial because experiments to determine masses of neutrino are difficult both to perform and to analyse. In most grand unified theories the neutrinos must have nonzero masses. If neutrinos have mass then transitions called neutrino oscillations can occur in which one type of neutrino (electron neutrino, muon neutrino or tau neutrino) changes into another type. The existence of neutrino oscillations gives the first evidence for exciting new physics beyond that predicted by the standard model.

A long-standing mystery about the sun has been cleared up by the discovery of neutrino oscillations. Physicists provide the resolution of this mystery in 2002 by detecting neutrinos of all three flavors (electron neutrino, muon neutrino and tau neutrino) in Sudbury Neutrino Observatory. According to the explanation the sun is producing electron neutrinos at the rate predicted by theory, but that two-thirds of these electron neutrinos are transformed into muon neutrinos or tau neutrinos during their flight from sun's core to a detector on earth.

5. SUPERSYMMETRY

Another ingredient of many theories is supersymmetry which gives every boson and fermion a superpartner of the other spin type. For example, the proposed supersymmetric partener of the spin half electron is a spin zero particle called the selectron and that of the spin one photon is a spin half photino. Within a few years, new data from the Large Hadron Collider (LHC) and other proposed accelerators will help us decide whether these theories have merit or whether nature is even more exotic than we imagine.

An automatic consequence of having this symmetry in nature is that every type of particle has one or more superpartners—other types of particles that share many of the same properties, but differ in a crucial way. If a particle is a fermion, its super partner is a boson. If a particle is a boson, its super-partner is a fermion. If supersymmetry were a symmetry of nature, every type of elementary particle that we know in nature would have to have partners we have not discovered yet. Since there are many particles known, that would mean we have a lot of work left to do. Einstein's theory of relativity does a beautiful job of describing and predicting many aspect of our world. His theory consists of a set of equations that obey a certain set of symmetries. It was proven mathematically that supersymmetry is the only symmetry that can be added to the symmetries of Einstein's theory without making the resulting equations inconsistent with the world we live in. In this sense supersymmetry is very special.

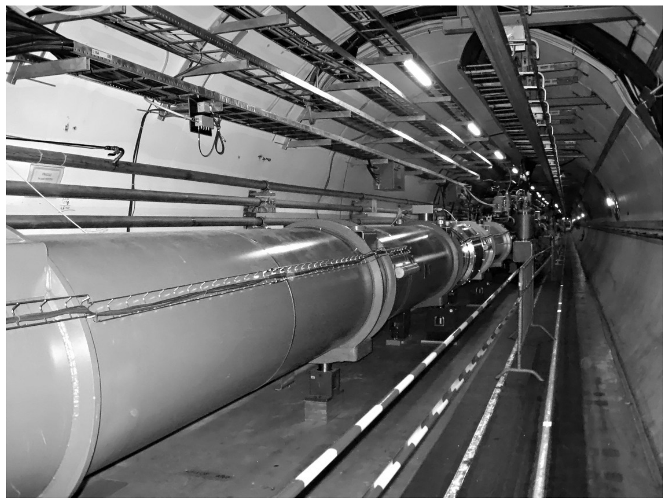

Fig. 2 Linear Hadron Collider

Efforts to demonstrate convergence by extrapolating existing experimental data were unavailing until 1991, when Ugo Amaldi of the European Laboratory for Particle Physics (CERN) near Geneva, Switzerland, and Wim de Boer and Hermann Fürstenau of the University of Karlsruhe in Germany published an intriguing analysis based on experimental results from the Large Electron Positron accelerator at CERN. These results included the most accurate measurements so far of the strengths of electromagnetic, weak, and strong forces at the energy of the accelerator, which was 90 gigaelectron volts (GeV) for these experiments. (A gigaelectron volt is equal to 1 billion electron volts.) The new analysis showed more convincingly than ever that the strengths of the forces do not converge within existing theories. The physicists then showed that with the addition of 'supersymmetry,' an extensively studied candidate for the next generation of elementary-particle theories, the energy dependence of the strengths of the three forces changed in such a way that the forces would in fact converge at the incredibly high energy of 10^{16} GeV.

Although this energy is far beyond the reach of any conceivable accelerator, it is still possible to test for unification of the forces by detecting new elementary particles predicted by supersymmetry, which requires that all the known particles have twins. For example, an electron would be accompanied by a selectron which is a spin zero particle. Amaldi and his colleagues suggested that the masses of the supersymmetry particles required for the convergence to occur were in the range from 100 to 10,000 GeV. The lower half of this mass range nicely matches that of the Superconducting Super Collider (SSC) under development in Texas as well as the proposed Large Hadron Collider (LHC) at CERN.

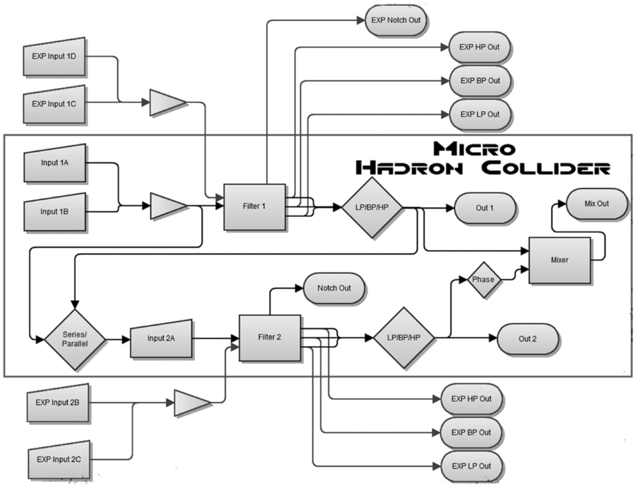

Fig. 3 Micro Hadron Collider

The Large Hadron Collider (LHC) was built by European organization for nuclear research (CERN) and was officially inaugurated in 21st October 2008. The biggest and most expensive research in the human history, in the field of particle physics have started in research named Linear Hadron Collider (LHC). LHC is the world's large and highest energy particle accelerator. It has become the most expensive scientific experiment with budget of 9 billion US dollars. Finding of Higgs is one of the main objectives for the LHC. LHC will also help to resolve the problems like what is the origin of mass? why do some particles have no mass at all? why gravity is weak force than other three fundamental forces?

6. CONCLUSION

Particle physics is not finished yet. Physicists still seek evidence of physics beyond the standard model and supersymmetry. They look for new particles both on earth and throughout the cosmos.Supersymmetry is the latest and most extensive search for the evidence which explains dark matter and unifies three of the fundamental forces correctly. But no particles predicted by supersymmetry have been found. So, the theory of supersymmetry is likely more complicated than many had hoped. The results of other theories do not exclude supersymmetric theories. So, supersymmetry remains as one of the hot candidates for the very much needed extension of the standard model, physicists may have to accept that it is not realized in its simplest forms. The search for supersymmetric particles at the Large Hadron Collider (LHC) has just begun. To draw a clearer picture, many more proton-proton collisions will need to be studied. Right now, the field of elementary particle physics is in one of its most exciting phases in history.

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