Symmetry Breaking and the Structure Formation of the Expanded Early Universe

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Abstract: The experiment performed in recent past using Large Hadron Collider and its planning for further development is highly promising in astroparticle research. As the temperature fell below a critical value with the expansion of the early universe, an invisible force field called the 'Higgs field' came into play throughout the cosmos in addition to 'Higgs boson'. The paper highlights the major epochs and the related main events linked to the formation of the universe and which in turn is associated with the Higgs boson particle.

Keywords: Large Hadron Collider; astroparticle; Higgs field; Early universe

I. INTRODUCTION

Unlike an expanding universe whose distances between galaxies is increasing all the time, the early universe in the past must have been much denser and the galaxies much closer together [1, 2]. Einstein's equations reveal how the expansions run its course with the properties of the cosmos contains. In realistic models the picture emerges suggest that not only of a universe with closely-packed galaxy but in the more extreme situation it may so happen that in the distant past, the universe did not even consist of galaxies. All its matter was so hot and so much under pressure those atomic nuclei and electrons even were unable to form atoms thus suggesting a universe full of hot plasma. The big bang models predict a definite starting point for the existence of our universe a bizarre initial state of infinite density. Everything in the Universe is found to be made from twelve basic building blocks which are known as fundamental particles, governed by four fundamental forces. Our understanding of how these twelve fundamental particles and three of the forces are related to each other is encapsulated in the Standard Model of particles and forces which has become established as a well-tested physics theory. A Higgs boson is a representation of the Higgs field, which extends throughout space and gives mass to all other particles. At the instant of the big bang a state of symmetry was there that lasted for no time and was broken immediately. Particles of matter called fermions emerged from energy, mass and energy being interchangeable, including quarks and electrons that would much later form atoms. Along with these, came force-carrying particles named bosons. Using the concepts of a Higgs field and Higgs boson, the Standard Model successfully explains why quarks, protons, electrons, photons, and other particles have specific masses. However, the Standard Model was unable to predict the mass of the Higgs itself which can only be obtained from experiment [3]. The recent experiment [4] using Large Hadron Collider (LHC) and its planning for further development in near future is highly encouraging, particularly to the scientists engaged in astroparticle research concerning symmetry breaking and the structure formation of the expanded early universe from the very moment of its birth. It is the purpose of the paper to highlight the major epochs and the related main events linked to the formation of the universe and in turn associated with the Higgs boson particle.

II. TERMINOLOGIES

The "*force carriers*" are particles whose movements are seen as familiar forces such as those behind electricity and light (electromagnetism) and radioactive decay (the weak nuclear force).

Quarks combine together for making, for example, the proton and neutron which make up the nuclei of atoms.

Leptons come in charged and uncharged forms; electrons - the most familiar charged lepton, the uncharged leptons are neutrinos, which rarely interact with matter.

The *Standard Model* is the set of ingredients - elementary particles - required to make up the world.

The *Higgs Boson* came about as although the Standard Model holds together neatly, nothing requires the particles to have mass; for a fuller theory, the Higgs - or something else - must fill in that gap.

The *Standard Model and Higgs Boson*: In the Standard Model of particle physics, the Higgs boson (Higgs particle) is a hypothetical elementary particle. The Higgs boson and the associated Higgs field explain the origin of the mass of elementary particles. Higgs field fills all space and the mass of all massive elementary particles is created from the energy of the interaction of that particular particle The Higgs boson was predicted to be highly massive and to have no charge and no intrinsic spin. It was also expected to be unstable, decaying almost immediately after its creation [5].

III. SYMMETRY BREAKING AND EXPANSION OF THE EARLY UNIVERSE

Since, the Big Bang, the Universe has largely changed a great deal in the 13.7 billion years but interestingly the basic building blocks of everything from microbes to galaxies were signed, sealed and delivered in the first few millionths of a second. During this period the fundamental quarks became locked up within the protons and neutrons to form atomic nuclei. They remain, stuck together by the carrier particles of the strong force called gluons. This force being very strong, experiments have not been able to dislodge individual quarks or gluons out of protons, neutrons or other composite particles. The universe was dominated by radiation though there was some matters which were infinitesimal compared to the amount of radiation [6]. This radiation was in the form of photons as well as neutrinos and anti-neutrinos. The matter present was in the form of electrons, positrons and a very small concentration, about 1 part per billion, of protons and neutrons. Due to extremely high temperature and density, all acted like particles and thus colliding into each other. In the early universe no physical "walls" were present to contain these objects but owing to large number of rapid collisions temporary walls of the universe were formed. At the very start of the universe, due to the high energy density, the collisions between particles happened so rapidly that the proton- and neutron-creating reactions balanced each other and the relative number of protons and neutrons were equal which was broken almost immediately. Neutron being slightly heavier than a proton, it requires a little more energy to change a proton into a neutron than vice versa. As the energy density was decreasing with the expansion of the universe, there was less energy available for each collision. As a matter of fact, this started to tip the balance in favor of the proton-forming reactions which leads to an increase in the number of protons compared to neutrons [7, 8].

With further collisions, the size of the universe was increasing and due to this expansion the density of energy was diminished as it was spread out over a larger volume causing a decrease in the temperature of the universe which is still continuing. These collisions had three contributions: (i) the universe reached a condition of thermal equilibrium, (ii) the constant annihilation and re-creation of electrons and positrons, and (iii) the conversion between protons and neutrons. These three contributions have illustrated in Fig. 1(a), (b) and (c) respectively.

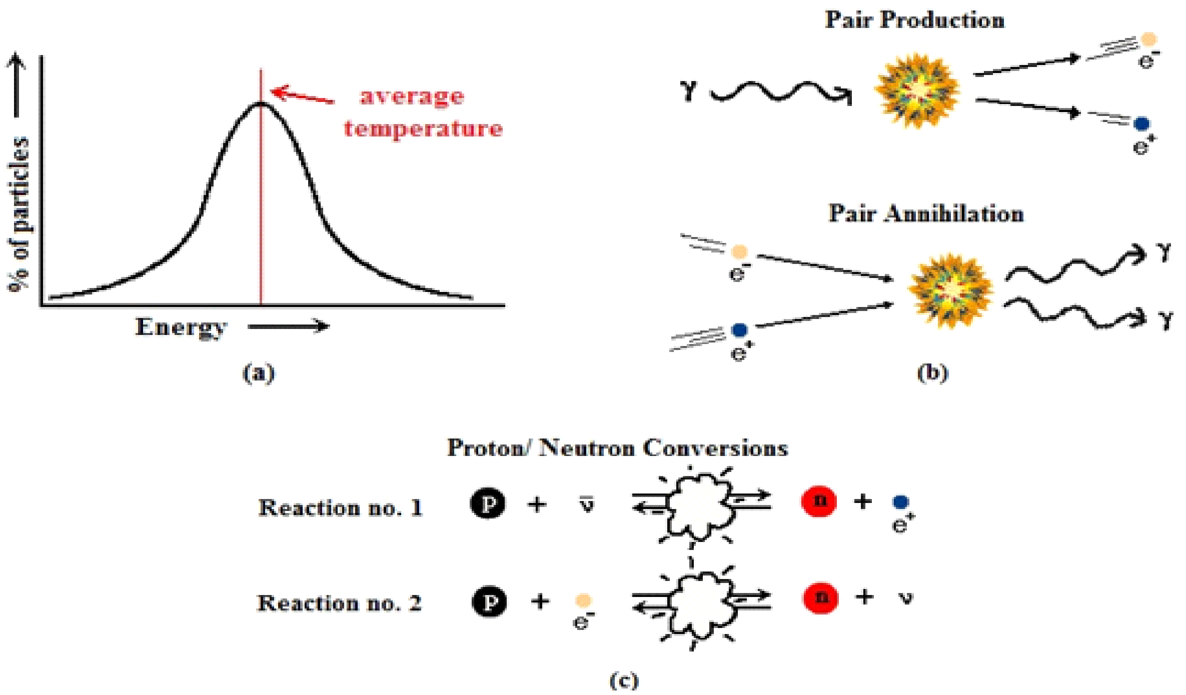

Figure 1: The collisions illustrating three contributions: (a) the universe attained a condition of thermal equilibrium, (b) the constant annihilation and re-creation of electrons and positrons, and (c) the conversion between protons and neutrons.

As electrons and positrons were annihilated, the radiation that formed was stretched due to the growing universe. This caused a reduction of energy carried by the photons below the level which would allow them to convert back into electrons and positrons. Up to this time i.e. just over three minutes past the beginning, there had been no nucleosynthesis. For forming atomic nuclei, the nucleons must be able to collide and stick together. The main reaction in the early universe was the collision of a proton and a neutron to form a deuterium nucleus. Since the beginning of the universe the collisions between protons and neutrons had been happening continuously. But their energies were too high to allow them to stick together for forming deuterium nuclei as illustrated in Fig. 2.

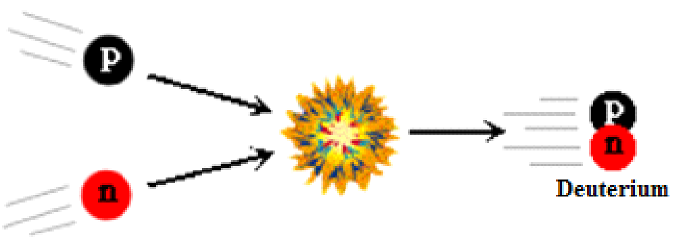

Figure 2: Collision of a proton and a neutron to form a deuterium nucleus

In the early universe, once the deuterium "bottleneck" was cleared, the newly formed deuterium could undergo further nuclear reactions producing Helium by two different means. In the first type of reaction the deuterium nucleus collides with a proton to form He-3 and then a neutron to form He-4 (Fig. 3).

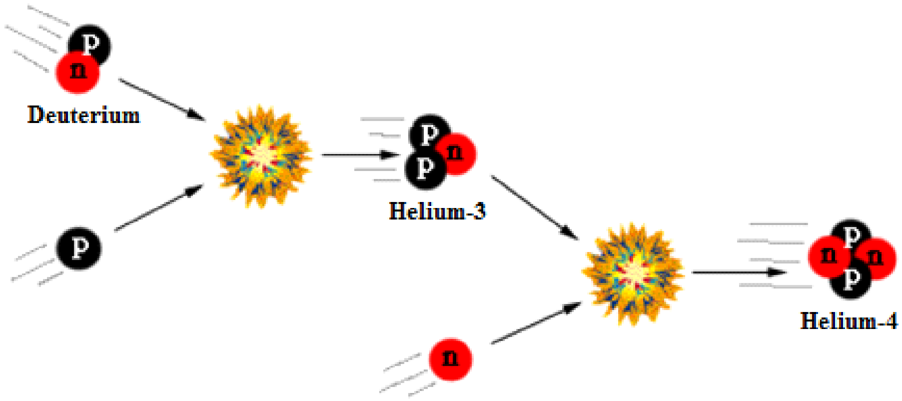

Figure 3: Deuterium nucleus collides with a proton to form He-3 and then to form He-4

In the second type of reaction the deuterium collides first with a neutron to form H-3, commonly called tritium, and then with a proton to form He-4 (Fig. 4).

At the time when nucleosynthesis started, the relative abundance of protons to neutrons was 13% neutrons and 87% protons and subsequently all the neutrons present were incorporated into He nuclei. After the use of all the neutrons the remaining protons remained as hydrogen nuclei. Thus after the completion of the first wave of nucleosynthesis the universe consisted of roughly 25% He and 75% H by weight. A graphical summation of nucleosynthesis in the early universe is presented in Fig. 5 showing the relative abundances of different nuclei along the Y-axis during the first three hours of creation. The X-axis has been labeled using both time (top) and the equivalent temperature (bottom). In the figure a dashed line has been drawn at the 1% abundance level; anything below this line would indicate less than 1% of the total mass present.

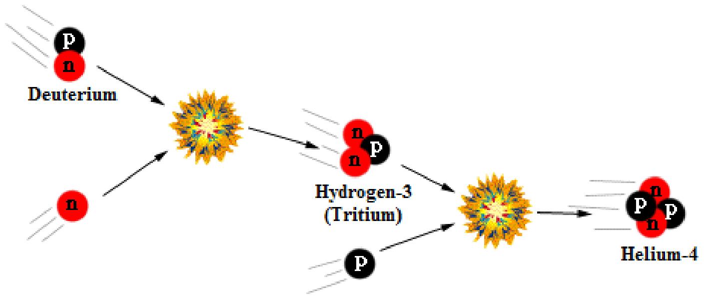

Figure 4: Deuterium collides with a neutron to form H-3 and then with a proton to form He-4

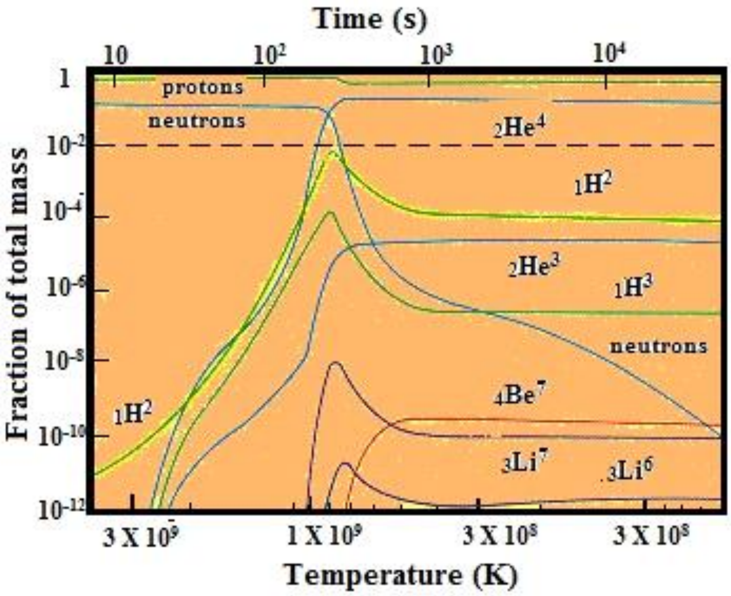

Figure 5: The relative abundances of different nuclei
[http://aether.lbl.gov/www/tour/elements/early/early_a.html]

The curves show that at the higher temperatures only neutrons and protons exist, with there being more protons than neutrons while with the decrease of temperature, there is an increase amount of deuterium and helium nuclei. Below the temperature of 1 billion degrees there is a significant increase in deuterium and helium and a decrease in the abundance of protons and neutrons [9]. This uses up the all the free neutrons and some of the protons causing the neutron line to drop off, and the proton line to dip. The deuterium abundance increases to a point as it is an intermediate to the formation of helium. With its creation, it is immediately consumed completing the process of helium nucleosynthesis. When all the neutrons have been used up, its presence drops off and the final step in the formation of elements was capture of the proper number of free electrons for forming neutral atoms. Remaining electrons still had plenty of energy and took about 700,000 years of cooling until this was able to occur. The captures of electrons for the formation of atoms are responsible for making some significant changes in the universe [10]. The stretched out photon wavelengths are referred to as the Cosmic Microwave Background, the intensity of this background radiation can be measured which closely supports the "Big Bang" theory of the creation of the universe. Major epochs and the related main events in the history of the Universe is presented in table I.

IV. DISCUSSION

A major breakthrough in particle physics came in the 1970s when physicists understood that there are very close ties between the weak force and the electromagnetic force which can be described on the basis of the Standard Model. This ‘unification’ suggests that electricity, magnetism, light and different types of radioactivity are all manifestations of the electroweak force. This unification can work mathematically if the force-carrying particles have no mass but experiments indicate that this is not true. In fact, all particles had no mass just after the Big Bang. As the Universe expanded and the temperature fell below a critical value, an invisible force field called the ‘Higgs field’ came into play throughout the cosmos in addition to ‘Higgs boson’. Any particles that interact with it are given a mass through the Higgs boson [11]. The more they interact; they become more massive, whereas particles that never interact are left with no mass at all.

Table I. Major epochs and the related main events in the history of the Universe

Era	Epoch	Time (after Big Bang)	Density (kg/m^3)	Temp. (K)	Main Events
Radiation Era The radiation era lasted for about 50,000 years	Planck	0s - 10^{-43}s	∞ - 10^{95}	∞ - 10^{32}	First 10^{-43} seconds after the Big Bang. No current theory of physics (quantum gravity) exists.
	GUT (Grand Unified Theory)	10^{-43}s - 10^{-35}s	10^{95} - 10^{75}	10^{32} - 10^{27}	After 10^{-43} seconds, temperature fell to 10^{32} K. Strong, weak, and electromagnetic forces unified.
	Quark	10^{-35}s - 10^{-4}s	10^{75} - 10^{16}	10^{27} - 10^{12}	Creation of protons and neutrons continued for about 10^{-4} seconds. Temperature drops below 10^{13} K, and protons and neutrons are no longer produced in pairs. Strong force frozen out. Heavy and light particles all in thermal equilibrium.
	Lepton	10^{-4}s - 10^{2}s	10^{16} - 10^{4}	10^{12} - 10^{9}	Ends when the universe is about 100 seconds old. During this epoch, the leptons (electrons, neutrinos, and other light particles) are still produced in pairs, because they are light. Ends when temperature drops below 1 billion K.
	Nuclear	10^{2}s - 2×10^{12}s	10^{4} – 6×10^{-16}	10^{9} - 16,000	Deuterium and helium formed by fusion of protons and neutrons during first 1000s.
Matter Era	Atomic	2×10^{12}s - 6×10^{15}s	6×10^{-16} – 10^{-22}	16,000 - 60	Begins about 50,000 years after the Big Bang. Atoms form and remain intact (electrons attached to nuclei). Ends 200,000,000 years after Big Bang.
	Galactic	6×10^{15}s – 10^{17}s	10^{-22} – 2×10^{-25}	60 - 10	Large-scale structure forms; first stars and quasars shine; galaxies form and grow.
	Stellar	10^{17}s - > 3×10^{17}s			Stars continue to form up to today. Extends into the Dark Energy Era.
Dark Energy Era		> 3×10^{17}s - today	3×10^{-27}	3	Approximately 73% of the Universe and associated with the vacuum in space; homogeneously distributed in space and time.

A systematic study of this particle would give an insight into the problem clarifying why particles have certain mass and thus helps to develop subsequent physics. But there is a serious technical problem as we are not yet ascertain the mass of the Higgs boson itself, which makes it more difficult to identify. Physicists have to look for it by systematically searching a range of mass within which it is predicted to exist. The range is accessible using the Large Hadron Collider, which will be improved further to determine and confirm the existence of the Higgs boson.

V. Conclusion

With the possible discovery of the Higgs boson using LHC, there has been much speculation about the consequences of the discovery. But it is true that the Higgs boson is the final building block that has been missing from the Standard Model, to describe the structure of matter in the universe. The Higgs boson combines two forces of nature to reveal that they are different aspects of a more fundamental force. Scientists are attempting to make a unification of the four fundamental forces of nature (the weak force responsible for radioactivity; electromagnetic force; the strong force responsible for the existence of protons and neutrons; and gravitation) that act on the final building block of the associated particles. There are again important questions yet unanswered like what is dark matter, what happened to the missing antimatter, and more. Perhaps it is only a part of a bigger picture that includes new hidden physics concerning the subatomic world or in the dark recesses of the Universe. Further information waiting to get from the analysis of the experimental results obtained from the Large Hadron Collider will definitely provide us more information of these missing pieces.

VI. Acknowledgment

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VII. References

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