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Theme: Some Models Beyond the Standard Model and the Problem of Electroweak Baryogenesis.

Abstract

For a long time, physicists have tried to explain cosmic phenomena by asking the following question:

Has our universe changed over time? That is, are the main ingredients of the primordial universe the same as in the current universe? the answer to this major question is related to two branches of physics, cosmology and particle physics. The most common cosmological model is the standard Big-Bang cosmology model which assumes three basic principles:

1) The validity of the cosmological principle which says that the universe is homogeneous and isotropic and that the laws of physics are the same at all points.
2) The laws of physics are time invariant.
3) The current universe is in expansion and it was created at a precise moment in the past by an immense explosion (the Big Bang).

Big Bang theory provides explanations for many current observations of our universe such as the abundance of elements through primordial nucleosynthesis and predicts the cosmic microwave background (CMB), but it does not answer the question of why our universe seems to be totally dominated by matter and contains very few baryons compared to the number of photons, the baryonic density is of the order of 10^{-10}, explaining low baryonic density or understanding the origin of baryonic asymmetry is one of the current challenges of cosmology and particle physics.

Each particle is associated with an antiparticle that differs only by the sign of the charge, except for neutral particles, the antiparticle can be identical to the particle, the laws which govern the fundamental interactions do not distinguish between particle-antiparticle, we can think then that they were produced in equal quantities at the beginning of the universe, in other words the primordial universe was symmetric. The various direct and indirect observations have not proved the existence of antimatter in our current universe, it contains only matter and most of the current theorists are looking for mechanisms that can generate a surplus of particles (baryons).

According to the Big Bang theory, the early universe was symmetric and the baryonic number was conserved, this universe expands, cools and its density decreases until its temperature reaches a specific value at which different symmetries are broken and the thermal equilibrium is broken, the generation of baryonic number becomes possible at this time, in other words, depends on the breaking and conservation of the baryonic number in the interactions of elementary particles.

Thus, it is obvious that such a baryonic asymmetry must be accompanied by a mechanism called baryogenesis which is the most promising scenario for the generation of baryonic number and must fulfill the three conditions formulated by Andrei Sakharov in 1967:

1) There must be a fundamental process causing the violation of the baryonic number.
2) This process should violate C and CP.
3) Process must be out of thermal equilibrium.

For the first condition if the number of baryons is conserved, that is, it is zero at the beginning and will remain so forever, but if it is not subject to any conservation law then it is violated at the equilibrium state, for the second condition, the violation of C and CP ensures the preeminence of matter over antimatter since the conservation of C and CP would lead to the creation of the same quantity (matter-antimatter), it should be noted that if the two other conditions are satisfied no net baryon charge is generated.

As we have seen previously at thermal equilibrium, the process that creates an excess of baryons is cancelled by the reverse process in order to preserve the excess baryons that are the results of the violation of C and CP, this process must come out of the thermal equilibrium.

Kuz'min, Rubakov and Shaposhnikov proposed that baryonic asymmetry could be generated at temperatures of the TeV order based on the electroweak theory (EW) which contains all the necessary ingredients of baryogenesis: C and CP symmetry violation, baryonic number is violated due to the chiral anomalies and the breaking of the thermal equilibrium during the electroweak phase transition of the first order which corresponds to the passage from an unbroken to a broken symmetry. Despite this, the calculated value of the asymmetry is too low and the theory has two major problems:

∗ CP violation is insufficient because, in the electroweak theory, the only source of CP violation is the complex phase of the Cabbibo-Kobayashi-Maskawa matrix (CKM) and its value is too small to account for the observed baryonic asymmetry.

∗ The first-order electroweak phase transition: to create the necessary thermal disequilibrium the transition must be first-order, but in the case of the standard model (SM) the electroweak baryogenesis (EWBG) related to the Higgs boson mass which must take the value $m_H \leq 70$ GeV this is in contradiction with the current experimental value which is about 125 GeV then the transition would typically be second-order and much smoother.

The efficiency of the electroweak baryogenesis is evoked only in the vicinity of the phase transition temperature (critical temperature T_c), for this reason it can be said that the electroweak baryogenesis is dominated by the first-order phase transition, which is based on the estimation of the height of the barrier separating the region of space where the symmetry is broken and the region where it is not, and thus it determines the strength of the phase transition.

The purpose of this work is to study the problem of the electroweak baryogenesis at low energy by the electroweak phase transition and we also explained the baryogenesis by sphalerons of the three models: the economical 331 model with right handed neutrinos (331 RHN), the minimal 331 model with only two Higgs triplets (RM331) and the compact 341 model.

We have seen that currently in the framework of the SM that the baryogenesis scenarios with the phase transition cannot be realized and the main reason for the failure of the EWBG in this model is the weakness of the phase transition, also the SM has several open questions that have not been answered at this level, this is what has pushed physicists to propose models beyond the SM. While we study the particle spectrum of the three models mentioned above, these models contain all particles that have heavy masses compared to ordinary particle masses, whereas the two models (331 RHN, RM331) are based on the same gauge groups or in other words the spontaneous symmetry breaking occurs in two steps of phase transition, the first one at the TeV scale and the second one is the same of the SM at the GeV scale. Nevertheless, the spontaneous symmetry breaking of the 341 model takes place in three steps and we have three VeVs, the first two on the TeV scale and the last $\upsilon_{\rho=}246$ GeV (of the SM).

Through the expression of the effective potential which is a function of particle masses and temperature, we found that the electroweak phase transition for each step (of the three models) is satisfied when the condition $(2E/\lambda)$ is fulfilled. In addition we discussed the problem of baryogenesis by the sphaleron approach where we calculated the sphaleron rate (Γ) and compared it to the Hubble constant (H) which describes the expansion of our universe at the temperatures T. We then saw that there are two ways to calculate the sphaleron rate, the first is the static approximation, it is noted that this approach cannot give consistent results for the ratio (Γ/H) in the case of $T<T_c$, on the other hand the second thin-wall approximation does.

Lastly, we were able to understand and explain how the electroweak baryogenesis occurs and that it is related to the electroweak phase transition, the latter must be strong and first order to achieve the third Sakharov condition.

Keywords:

Baryogenesis, electroweak phase transition, beyond standard model, sphaleron and the baryon violation.