

Review

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Review

Bridging Gaps in the Standard Model

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Abstract: Topological defects such as magnetic monopoles that may have formed during cosmological phase transitions in the early universe. The Kibble mechanisms govern the formation of these defects and their abundance is influenced by the correlation length and the temperature-dependent Higgs mass. The Magnetic monopoles are particularly interesting but their excessive production poses the monopole problem which is a challenge to the standard model. Many solutions including symmetry breaking patterns and thermal pair production have been proposed to mitigate the monopole problem. Detecting monopoles would offer valuable insights into high-energy physics and the early universe. Detection of (even) a single monopole could revolutionize our current knowledge of the universe.

Keywords: monopole problem; Kibble mechanism; topological defects; magnetic monopoles; grand unified theories

1. Introduction:

The hot big bang theory is one of the acceptable explanations of the origin and evolution of our universe. It started from the Planck epoch, at that time our universe was very hot and dense. All of the fundamental forces were unified to a single force and the spacetime was a singularity. As the hot big bang happened, the universe expanded and reached the grand unification epoch. During that epoch the separation of the strong force from weak forces occurred and in

there happened the birth of monopoles [1]. This epoch was followed by the electroweak unification epoch, where the weak and electromagnetic forces were separated from each other, after that the formation of particles.

Occurred called quark epoch which are the building blocks of ordinary matter. After the enough cooling of universe from the quarks epoch, the hadron formation started normally

Called hadron epoch. After that the lepton epoch, the formation of protons, neutrons, and atomic nuclei while electrons, positrons, and neutrinos played critical roles in the evolution of matter [2]. The photon epoch is the last epoch, where the total decoupling of matter and radiation happened. From hot Big Bang until around 380,000 years after big bang, when the universe had cooled enough, the neutral atoms formed, allowing photons to travel freely and giving rise to the cosmic microwave background radiation.

The Hot Big Bang theory successfully explains the evolution and expansion of the early universe; some challenges are faced from the standard model which is not explained very well by it. These challenges include the observed large-scale structures of our universe and the homogenous nature of the cosmic microwave background radiation (CMBR) [3]. To solve these problems the cosmologists searched for explanations, some of them are answered by inflationary theory. To study the early universe and the exploration, we need some new theoretical models for our understanding of the cosmos and those problems which are insoluble mysteries in the standard hot big bang model. The hot big bang theory, which is successful in many aspects, is facing a number of problems [4]. Some of the problems are the horizon problem, flatness problem, and the monopole problem. The horizon problem is that uniformness of the cosmic microwave background radiation across distant regions

that should not have had sufficient time to achieve thermal equilibrium. The flatness problem is related to the overall geometry of universe, as slightly deviations of density from the critical value of density in the early universe, due to which we observe the universe as non-flat today[5]. The monopole problem poses a potential challenge to the hot big bang theory; the early universe should have contained magnetic monopoles, hypothetical particles with a single magnetic pole instead of the north and south poles. These monopoles would have been created in significant quantities during the grand unification phase of the universe, these monopoles are envisioned to form during a phase transition, analogous to the way bubbles form during a boiling process[6]. However the observations we have not detected yet, number of these magnetic monopoles produced in the universe, due to absence of monopole the hot big bang model is facing the magnetic monopole problem. It is an open question that why these particles are so rare and not be detected. This discrepancy between theory and observation poses the monopole problem[7].

There are many approaches to solve the monopole problem but one of them is the Kibble mechanism, to solve the monopole problem involves the formation of topological defects known as cosmic strings. During the early universe phase transition when the breaking symmetry occur of the fundamental forces[8]. So the cosmic strings can evolved as one-dimensional linear structures. These strings are like cosmic "cracks" in the fabric of the space-time where the vacuum energy related with the phase transition become trapped along with the length of the string.

The expansion of cosmic strings stretches and thin significantly their energy density was reducing. Meanwhile the magnetic monopoles became localized particles are not affected by inflation, in the same way and their number density remains unchanged and the energy density of cosmic strings become negligible as compared to the energy density of magnetic monopoles after inflation was end[9]. These phenomena resist the overabundance of magnetic monopoles explaining and that is why they have not been observed in the current universe. The problem of overabundance of the magnetic monopole shows the persistence and maintaining consistency with our observations of the universe today. To look for the magnetic monopoles many scientists works and using different methods to reach the magnetic monopole[10].

In the Gerard 't Hooft's paper. It is the theoretical ground for understanding the formation of magnetic monopoles during phase transitions in the early universe. Its work introduces the role of non-Abelian gauge symmetries, topological charge, and the quantization of magnetic charge. Having great influence of these papers has continuously research on magnetic monopoles, their properties, and their implications for fundamental physics and cosmology[11].

Alan Guth said that the universe passing through a period of exponential expansion in its early stages. Inflationary expansion is the stretching of the fabric of space-time, effectively smooth out from the initial distribution of monopoles and diluting their density to extremely low levels[12].

An important aspect understanding the suppression of monopoles is the Kibble mechanism, introduced by Tom Kibble in his influential paper "Topology of Cosmic Domains and Strings". Kibble's works explain how the presence of cosmic strings which is another type of topological defect can reduce the formation of monopoles during a phase transition in the early universe. Cosmic strings act as barriers that disturb the coherent evolution of the monopole field hindering their formation and resulting in their suppression[13][14]. The Kibble mechanism has emerged as a fundamental concept understanding the dynamic of topological defects and their significant role in the monopole problem.

In addition to inflation and the Kibble mechanism researchers have proposed various other mechanisms to address the monopole problem. Cosmological phase transitions such as the electroweak phase transition have been investigated as potential sources of monopole suppression. Authors like Mark Hindmarsh, Jorn Keränen and Tommi Tenkanen have made significant contributions to this type of research. They have explored the dynamic of phase transitions, symmetry-breaking patterns and the resulting monopole production [6]. Their work aims to understand the mechanism that suppress monopole formation or dilute their abundance in a manner consistent with experimental observations. The contribution of these authors provides valuable

insight into the interplay between cosmological phase transitions and the monopole problem[13][15].

The previously mentioned mechanisms and researchers have explored modification to the standard Big Bang model as a mean to address the monopole problem. Alternative cosmological scenarios such as cosmic inflation driven by scalar field other than the inflation have been investigated. Authors such as Andrei Linde, Renata Kallosh and Sergei Prokushkin have studied inflationary models incorporating non-trivial scalar fields and their implication for the monopole problem. These works examine the dynamic of inflation the generation of primordial fluctuations and the impact on monopole formation and suppression. Exploring the research of these authors offers insight into alternative cosmological framework and their potential role in addressing the monopole problem. [7][8].

In addition to the aforementioned approaches researchers have invoked other theoretical frameworks such as super symmetry to address the monopole problem. Authors like John Preskill, Frank Wilczek and Edward Witten have investigated the implication of super symmetric theories on the formation and properties of monopoles.[15] Their work explores the role of super symmetry in constraining the existence and abundance of monopoles as well as the potential effect of super symmetric particles on monopole dynamics. By studying the interplay between super symmetry and the monopole problem, these authors contribute to our understanding of the fundamental physics underlying magnetic monopoles[8].

2. Methodology:

The classical view of monopoles does not treat them as independent entities but rather as a theoretical construct or a mathematical possibility of them, while classical electromagnetism does not allow the existence of isolated monopoles and it describes the behavior of magnetic field created by magnetic dipoles and their interaction with other charges and field. It is clear that the classical view of magnetic monopoles shows the contradiction to the theoretical framework of certain grand unified theories (GUTs) and quantum field theory[16]. Where the existence of these magnetic monopoles is predicted because of the grand unification theory. The classical description serves as a useful starting point for understanding the behavior of magnetic fields and their sources despite not account for the existence of isolated magnetic monopoles in nature. For searching monopole there are many way methods to reach the monopole but one of them is Kibble mechanism.

2.1. Kibble mechanism:

The Kibble mechanisms is the fundamental concept in cosmology that explain the production of topological defects during phase transitions in the early universe, analogy to these defects formed during ordinary phase transitions observed in laboratory settings. The Kibble mechanisms focus on the dynamics of different phases with varying vacuum configurations as the universe cool and undergo to spontaneous symmetry-breaking processes.[2] During the phase transition the correlation length of evolving field in the different phases become limited by the particle horizon. Which defines as the maximum distance information could have traveled since the beginning of the universe due to the finite speed of light. As a result these regions independently settle into specific vacuum energy configurations separated by domain walls, cosmic strings or monopoles depend up on the underlying symmetries [12].

The Kibble mechanism provide us a profound insight into the happening of these topological defects formation during cosmological phase transitions and underscores the essential role of causality and limited horizon distance in shaping the early universe's evolution. While these topological defects are non-perturbative and unlikely to be produced in terrestrial accelerators, their formation during cosmological phase transitions is deemed inevitable [4]. By comprehending the Kibble mechanism and the constraints imposed by the particle horizon, we gain a better understanding of the formation and properties of these defects in the early universe. The particle

horizon is the maximum distance a massless particle could have traveled since the Big Bang is given by:

$$d_H = R(t) \int_0^t \frac{d(t')}{R(t')} \quad (1)$$

if

$$R \propto t^n \quad (n > 1), \quad d_H = \left(\frac{t}{1-n} \right)$$

The correlation length associated with a phase transition determines the maximum distance over which the Higgs field can exhibit correlation. This length is influenced by the specific characteristics of the phase transition and is also dependent on temperature. The correlation length and the temperature-dependent Higgs mass $\xi \sim M_H^{-1}(T)$ are related such that $M_H^{-1}(T)$ governs the behavior of the correlation length associated with a phase transition determines the maximum distance over which the Higgs field can exhibit correlation. This length is influenced by the specific characteristics of the phase transition and is also dependent on temperature [6]. Where the horizon distance is finite and it follows that during the phase transition (at $t = t_c, T = T_0$), then Higgs field cannot exhibit correlation on scales larger than the horizon distance, establishing an absolute maximum for the correlation length. Due to the presence of the particle horizon in standard cosmology, in equation (1) it is impossible for correlations to exist on scales larger than the horizon distance, denoted as d_H . In the context of the Higgs field this means that at the time of the phase

transition (0), correlations cannot extend beyond the d_H , which is proportional to H^{-1} or $\frac{m_{pi}}{T^2}$. As a result it becomes evident that the non-trivial vacuum configurations discussed earlier will inevitably arise, with approximately one such configuration per horizon volume [8]. These configurations are called "topological defects," emerge due to the finite nature of the particle horizon. Despite not representing the lowest-energy states of the Higgs field of these defects form as stable entities and became "frozen in" as permanent structures once they are created.

Let's consider monopoles as an example of how these topological defects can become "frozen in." The direction of the vacuum expectation value (VEV) of the Higgs field is (Φ^a) , is expected to be random on scales larger than the horizon distance (d_H). This implies that in different volumes of the universe on the scale of the Hubble horizon, the direction of (Φ^a) will vary, specifically in group space. The configuration known as a hedgehog corresponds to the (Φ^a) direction changing around a central point [10]. Therefore, it is reasonable to expect that the probability of a monopole configuration arising from a Higgs (VEV) with uncorrelated directions on scales larger than the Hubble horizon (H^{-1}) would be approximately one. Consequently, approximately one monopole (or antimonopole) is expected to form per horizon volume, which can be estimated as:

$$n_M \sim d_H^{-3} \frac{T_c^6}{m_{pi}^3} \quad (2)$$

The entropy density at the critical temperature T_c is given by, $s \sim T_c^3$. Consequently, the monopole-to-entropy ratio $\left(\frac{n_M}{s} \right)$ can be expressed as $\left(\frac{T_c}{m_{pi}} \right)^3$, indicating that the number of

monopoles relative to the entropy density is determined by the cube of the ratio of the critical temperature to the monopole mass $(\frac{T_c}{m_{p_i}})$ [12]. As in equation (2)

Assuming that there is no significant annihilation of monopole-antimonopole pairs or production of entropy and the ratio of monopoles to entropy remains constant over time and determines the present abundance of monopoles in the universe [14]. However this poses a significant problem as the relic monopole abundance for canonical values associated with Grand Unified Theory (GUT) symmetry breaking, such as $T_c \sim 10^{14} \text{ GeV}$ and $n_M \sim 10^{16} \text{ GeV}$, $\frac{n_M}{s} \sim 10^{-13}$ leads to a present monopole mass density of about $10^{11} \rho_c$, times the critical density. This value is clearly unacceptable and would lead to significant cosmological issues during which a cosmological phase transition occurs [16]. This transition is accompanied by the production of a massive amount of entropy. The infusion of entropy dilutes the initial monopole abundance, exponentially reducing the value of $\frac{n_M}{s}$. This mechanism provides an effective solution to the monopole problem by alleviating the excessively high relic monopole abundance through the exponential dilution caused by the massive entropy production during inflation [17].

The topological defects associated with spontaneous symmetry breaking (SSB) are fascinating entities and their most plausible production occurs during a cosmological phase transition. The mechanism responsible for their formation is known as the Kibble mechanism. While we have discussed topological defects like monopoles and their abundance. One such example is walls bounded by strings which are two-dimensional surfaces with one-dimensional strings as their boundaries. Additionally there are strings terminated by monopoles where a string ends on a monopole, or monopoles strung on a string where monopoles are arranged along a string [15].

Magnetic monopoles are considered as cosmologically dangerous due to their potential impact on the energy density of the universe and the formation of the structure [13]. The presence of magnetic monopoles would lead to an overabundance of matter and could disrupt the observed large-scale structure of the universe. On the other hand, cosmic strings, if they exist with a certain density (around $G_\mu \approx 10^{-6}$), can play a constructive role in structure formation, their gravitational effects can generate density perturbations [1]. Discovering any of these topological defects—walls, strings, or monopoles—would provide valuable insights into particle physics beyond the standard model. They would challenge our understanding of fundamental interactions and symmetries. Further their existence would have profound cosmological consequences potentially altering our understanding of the early universe, the formation of cosmic structures and the evolution of the cosmos as a whole [3]. While the definitive presence of these topological defects remains uncertain and their detection or further study would undoubtedly deepen our understanding of the fundamental nature of the universe.

2.2. Monopole at birth:

To calculate the monopole abundance produced in the Kibble mechanism we need to consider the correlation length at the time of the phase transition. In this case we assume the correlation length is given by the inverse of the age of the Universe at the time of the transition i.e. t_c^{-1} .

For an SU(5) grand unified theory (GUT), we have the following values:

$$T_c \sim 10^{14} \text{ GeV} \text{ (The temperature at the phase transition)}$$

$$m_M \sim 10^{16} \text{ GeV} \text{ (The mass of the monopole)}$$

$$t_c \sim 10^{-34} \text{ Sec (the age of the Universe at } t_c \text{).}$$

Using the given values we calculate the correlation length as follows:

$$\text{Correlation length} = t_c^{-1}$$

So, we have the following equation:

$$\frac{n_M}{s} \approx 10^2 \left(\frac{T_c}{m_{p_i}} \right)^3 \approx 10^{-13} \quad (3)$$

To estimate the monopole abundance relative to the entropy density ($\frac{n_M}{s}$), we need to consider the conditions set by Preskill in his works. According to Preskill's findings:

If $\frac{n_M}{s} > 10^{-10}$, monopole-antimonopole annihilations significantly reduce the initial monopole abundance. Since the estimate for the initial monopole abundance arising from the Kibble mechanism is less than 10^{-10} , we can ignore annihilations.

Assuming adiabatic expansion since $T \approx T_c$, we can make an estimate for $\frac{n_M}{s}$ in equation (3). Adiabatic expansion means that the entropy is conserved. Therefore, we can write:

$$\frac{n_M}{s} \approx n_M \left(\frac{T_c}{s(T_c)} \right),$$

Where $n_M(T_c)$ is the initial monopole abundance at the time of the phase transition and $s(T_c)$ is the entropy density at the same time.

The specific value of $n_M(T_c)$ arising from the Kibble mechanism is not provided in the context we mentioned. If we have additional information or if we would like to make an assumption for $n_M(T_c)$, then we can assist further calculating the estimated $\frac{n_M}{s}$ ratio.

$$\langle F_M \rangle \approx 10^{-3} \left(\frac{T_c}{10^{14} \text{ GeV}} \right)^3 \left(\frac{v_M}{10^{-3} c} \text{ cm}^{-2} \text{ sr}^{-1} \text{ sec}^{-1} \right) \quad (4)$$

$$\Omega_M h^2 \approx 10^{11} \left(\frac{T_c}{10^{14} \text{ GeV}} \right)^3 \left(\frac{m_M}{10^{16} \text{ GeV}} \right) \quad (5)$$

The combination of a flux that is easy to detect and an unacceptably large mass density (unless $T_c \ll 10^{14} \text{ GeV}$) results in a cosmic catastrophe known as the "Monopole Problem." The age of the Universe restricts $\Omega_M h^2$ to be less than 1, in equation (5) which poses a significant challenge when attempting to reconcile the simplest Grand Unified Theories (GUTs) with standard cosmology [7]. This problem arises due to the excessive production of magnetic monopoles during the phase transition associated with GUTs, where T_c is the critical temperature. [17] If T_c is not much less than 10^{14} GeV , in equation (4) the predicted abundance of magnetic monopoles would far exceed the limits set by the Universe's age, leading to a profound inconsistency between theory and observation driving ongoing research to find a compelling solution. The limit on Ω_M based on the age of the Universe implies $T_c < 10^{11} \text{ GeV}$ for $m_M \approx \frac{T_c}{\alpha}$, which might still be unsafe due to the correlation length estimate.

When the GUT transition is strongly first order, bubbles nucleate at a temperature T_N , which is typically much lower than T_c (the temperature at the phase transition). The nucleation rate

becomes comparable to the expansion rate “H” at this temperature. Within each bubble, the Higgs field is correlated, but between bubbles, the Higgs field should be uncorrelated.

The expectation is that about one monopole per bubble is produced. Therefore the monopole abundance can be estimated as:

$$n_M \approx n_{Bubble},$$

Where n_{Bubble} is the number of bubbles,

At the time of bubble nucleation, if r_b , is the typical size of a bubble then the number of bubbles can be approximated as:

$$n_{Bubble} \approx \left(\frac{V_{universe}}{V_{Bubble}} \right),$$

Where $V_{universe}$ is the volume of the universe and V_{Bubble} is the volume of a single bubble.

After the bubbles coalesce and the Universe reheats then the entropy density is once again given by

$$s = g \times T_c^3, \text{ where } g \text{ represents the effective number of relativistic degrees of freedom.}$$

Therefore, the relic monopole to entropy ratio is:

$$\frac{n_M}{s} \approx (g r_b^3 T_c^3)^{-1},$$

This can be written as:

$$\frac{n_M}{s} \approx \left(\frac{n_{Bubble}}{g \times T^3} \right)$$

Guth and Weinberg have calculated the typical size of a bubble, r_b as $r_b \approx \frac{\left(\frac{m_{pi}}{T_c^2} \right)}{\ln \left(\frac{m_{pi}^4}{T_c^4} \right)}$

To determine the relic monopole abundance, we need additional information such as the values of r_b, T_N and the effective number of relativistic degrees of freedom g . Please provide these values, and I can assist you in calculating the relic monopole abundance [5].

$$\frac{n_M}{s} \approx \left[\left(\frac{T_c}{m_{pi}} \right) \ln \left(\frac{m_{pi}}{T_c} \right)^4 \right]^3 \quad (6)$$

This statement highlights that the standard cosmology extrapolated back to temperature of approximately equal to 10^{14} GeV and the simplest grand unified theories (GUTs) are incompatible due to the monopole problem. This problem arises from the production of an excessive number of monopoles during the phase transition in these theories, as in equation (6).

Additionally, two other solutions to the monopole problem are mentioned. First, if there is not a complete unification of the forces, such as if the gauge group is $G = \text{SU}(3) \times \text{SU}(2) \times \text{U}(1)$, or if the full symmetry of the GUT is not restored in the early Universe, there would be no monopole problem [9]. In these cases, the excessive production of monopoles is avoided. It is important to find the solution of the monopole problem, which provides us the valuable insight in physics at very high energy physics and the moments occurring in the earliest Universe which offering a "window" to energy approximately equal to 10^{14} GeV and times approximately equal to 10^{-34} seconds.

Langacker and Pi proposed an intriguing solution to the monopole problem based on a specific symmetry breaking pattern: $\text{SU}(5) \rightarrow \text{SU}(3) \times \text{SU}(2) \times \text{U}(1) \rightarrow \text{SU}(3) \times \text{U}(1)$. This symmetry breaking occurs through a sequence of phase transitions. The first phase transition takes place at $T_c \approx 10^{14} \text{ GeV}$, the second at T_1 , and the final one at T_2 (where T_1 could potentially be equal to T_c).

In their solution, the crucial aspect is the existence of an intermediate epoch ($T_1 > T > T_2$) during which the U (1) gauge symmetry associated with electromagnetism is spontaneously broken. This results in the Universe entering a superconducting phase, where magnetic flux becomes confined to flux tubes [12]. As a consequence, monopoles and antimonopoles produced earlier at the GUT transition experience efficient annihilation within these flux tubes. When the superconducting phase eventually ends, the resulting monopole abundance is approximately one per horizon volume [16]. This means that, on average, there would be about one monopole within the observable Universe. This proposed solution suggests that the confinement of magnetic flux within flux tubes during the superconducting phase allows for the effective reduction of the initial monopole abundance, thus alleviating the monopole problem. The precise calculation for the monopole abundance was provided in the work of Langacker and Pi.

$$\frac{n_M}{s} \approx 10^2 \left(\frac{T_2}{M p_i} \right)^3 \approx 10^{-46} \left(\frac{T_2}{10^3 \text{ GeV}} \right)^3 \quad (7)$$

If the excessive production of monopoles through the Kibble mechanism can be avoided, the only remaining cosmic production mechanism is pair production in highly energetic particle collisions. This process involves the collision of particle(s) and antiparticle(s), resulting in the production of a monopole and an antimonopole. The number of monopoles produced through pair production is inherently small because monopole configurations do not exist in the theory until spontaneous symmetry breaking (SSB) occurs [3]. The temperature at the SSB phase transition is denoted as T_c , and the mass of the monopoles is given by $m_M \approx \frac{M}{\alpha} \approx 100 T_c$, where M represents the scale of SSB and is the scale factor. As in equation (7)

Thermal pair production contributes to the relic monopole abundance. The exact calculation for the relic monopole abundance resulting from pair production would depend on the detailed dynamics and energy scales involved in the specific particle collisions. However, it is important to note that if the excess production of monopoles through the Kibble mechanism can be avoided, the relic monopole abundance resulting from thermal pair production is generally expected to be significantly smaller compared to the monopole abundance arising from the Kibble mechanism [17].

$$\frac{n_M}{s} \approx 10^2 \left(\frac{m_M}{T(\max)} \right)^3 \exp \left(-\frac{2m_M}{T(\max)} \right) \quad (8)$$

The highest temperature reached after spontaneous symmetry breaking (SSB) is denoted as T_{\max} . In general, it is expected that the ratio $\left(\frac{m_M}{T_{\max}} \right)$ is at least 100, implying that the product of the monopole mass (m_M) and the inverse of the highest temperature (T_{\max}) is on the order of $\Omega_M \leq 10^{-40}$. This leads to a relic monopole density (F_M) on the order of $10^{-32} \times \text{cm}^{-2} \times \text{sr}^{-2} \times \text{sec}^{-1}$, which corresponds to a negligible number of monopoles.

However, it is important to note that the number of monopoles produced through thermal production is exponentially sensitive to the ratio of the $\left(\frac{m_M}{T_{\max}} \right)$. We conclude a final result from equation (8) as a small change of 3 to 5 in this ratio can result in a significant variation in the predicted monopole production [8]. Therefore, it is not entirely implausible that thermal production of monopoles could lead to interesting relic abundance.

3. Result and discussion:

In this study we have investigated the production of topological defects such as magnetic monopoles during phase transitions in the early universe we using the Kibble mechanism. We explored the dynamics of the vacuum configurations when the universe cooled and undergo the symmetry-breaking processes. The Kibble mechanism predicts the formation of monopoles, cosmic strings or domain walls depending on the specific symmetries. Throughout our analysis we have found that during the phase transition the correlation length of evolving fields in different regions becomes limited by the particle horizon, which defines the maximum distance information, could have traveled since the beginning of the universe due to the finite speed of light. This limitation is responsible which is independent settling of regions into specific vacuum configurations in a result these topological defects formed.

Our investigation is only focusing on the magnetic monopoles as a prominent example of topological defects. We can calculate the monopole abundance produced in the Kibble mechanism and the estimate of the relic monopole to entropy ratio. We can observe that the relic monopole abundance is depending up on several parameters such as the critical temperature at the phase transition and the monopole mass. To address the monopole problem, we can also explored alternative solutions proposed in the literature such as a superconducting phase during the phase transition which efficiently reduces the initial monopole abundance.

We have also discussed the potential implications of relic monopoles in cosmology. The excessive production of monopoles could lead the cosmological issues and observed large-scale structure of the universe. On the other hand the existence of cosmic strings were detected have providing valuable insights into particle physics beyond the standard model and alter our understanding of the early universe [14]. While the definitive presence of these topological defects remains uncertain their detection or further study would undoubtedly deepen our understanding of the fundamental nature of the universe and its evolution. The detection of even a single super

Heavy monopole would be of profound significance, necessitating a reevaluation of current theoretical frameworks and triggering further investigations. In terms of the relic monopole abundance cosmology provides two firm predictions. First there should be an equal number of north and south magnetic poles as monopoles are expected to possess magnetic properties. Second the relic monopole abundance is expected to either be too low to detect or too high to be consistent with the standard cosmology. The detection of even a single super heavy monopole would have profound implications, necessitating a reevaluation of theoretical frameworks and prompting further investigations [12]. The quest to detect a super heavy monopole remains an intriguing avenue of research, as it has the potential to revolutionize our understanding of fundamental physics and cosmology.

4. Conclusion:

When the hot big bang occur passing through some transitional process and one of them is grand unification there were the monopole produced because for the grand unification the magnetic monopole is necessary. Monopoles problem is arising from the Kibble mechanism during cosmological phase transitions are fascinating topological defects with profound implications for particle physics and cosmology. As the universe cool enough and undergoes symmetry-breaking processes, regions of different vacuum configuration become causally disconnected due to the finite speed of light there is monopole formation held. These stable entities possess magnetic charge and could challenge our understanding of fundamental interaction beyond the standard model. However the monopole problem arises as the predicted abundance vastly exceeds cosmological constraints posing a challenge to reconcile theory with observation.

Several solutions have been proposed to address the monopole problem such as intermediate superconducting phases during phase transitions effectively reducing the initial monopole abundance. The detection of monopoles would offer valuable insight into the earliest moments of the universe and the highest energy scales[14]. Despite their theoretical importance monopoles are challenging to detect and likely exist in low numbers. The quest to observe a super heavy monopole

remains an intriguing avenue of research as its discovery could revolutionize our understanding of the early universe and fundamental physics.

The monopoles emerging from the Kibble mechanism during cosmological phase transitions represent enigmatic cosmic entities with profound implication for particle physics and cosmology. Their detection though challenging offers the potential to unlock new frontiers in understanding the early universe and the fundamental nature of the cosmos.

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