

UNIFIED FIELD—THE UNIVERSAL BLUEPRINT?

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ABSTRACT. The current status of the studies of the origin of the fundamental particles and the universe is presented. These studies indicate the unified field to be the source of both the fundamental particles and the universe itself. Furthermore, as a consequence of the unique properties of the quantum vacuum, the unified field is presumed to exist, in a quantum physical sense, everywhere in the very fabric of spacetime. In an analogy to the characteristics of the human genome, unified field appears to have the basic blueprint of at least everything physical in this universe.

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1. Introduction. As the twentieth century comes to a close and a new millennium begins, human beings can be truly proud of having achieved some extraordinary scientific breakthroughs in this century. The early twentieth century started with two revolutionary theories, relativity and quantum mechanics, which dramatically changed our view of the world. Applying special theory of relativity to quantum mechanics gave rise to the quantum field theories that eventually led to the development of the unified field theories.

Among the numerous, exciting scientific achievements of our century, perhaps the most outstanding is the advent of the *unified field*. Both the search for the origin of the fundamental particles and that of our universe point to the unified field as the ultimate source. Thus, for the first time, we are given an objective glimpse of how our universe, and we, came to exist. This profound knowledge at its present state of development is more like an impressionistic painting where the scenery is discernible while all the details are not. But enough elements of the detail have emerged to give us some confidence in the validity of the scenario. However, either the superstring theory or a successful theory of quantum gravity promises to reveal further details some time early next century.

According to the modern cosmology, the distinguishable part of this picture appears to be that the spontaneous symmetry breaking of the unified field started our universe from the incredibly small, Planck's dimension of 10^{-33} cm. The unified field, containing the blueprint of the entire universe, has sequentially unfolded to create everything physical in our universe. After having created the universe, the unified field is also present now in a quantum physical way, everywhere, in the very fabric of spacetime, thereby upholding and administering our universe and, at least, everything physical it contains.

This is quite similar to a reality with which we are more familiar: our genome (DNA), consisting of 23 pairs of chromosomes, which is present in the very first cell, possesses the blueprint of an entire human body. After creating the body, it is also present in each cell of the body, controlling different aspects of our bodily functions. Only a small percentage of the DNA is active in an adult cell, and this percentage of expression allows the proper functioning of that particular cell. Nevertheless, the DNA of *each cell* possesses the *entire blueprint* of the whole body. This was vividly demonstrated by Ian Wilmut and his colleagues when they created the famous ewe, Dolly, using the DNA from an udder cell of an adult ewe.

2. Field as a part of reality. Through scientific investigations, we have discovered that fields are as real as the material world. In fact, fields represent more of a fundamental reality, because the material world is nothing but a manifestation of the underlying fields (through energy). The fields cannot be seen or touched although they are unquestionably present. Their presence is revealed only when they act on material objects (or energy) with which they couple. For example, we cannot see or touch the field of gravity, yet we know it is substantially real; to prove its existence, all we have to do is jump!

People in general, still appear to ignore this seminal realization, perhaps because the esoteric mathematical language, in which fields are usually described, is unfamiliar to most. The ultimate reality is often so abstract for our visualization that an accurate description is possible only through mathematical equations. Although an equation is an elegant and quantitative representation of reality, behind every equation there is a practicable, conceptual reality, the gist of which may be appropriately conveyed sometimes by metaphors. But even for physicists, the development of the concept of a field being a part of reality took almost the entire period covering the development of modern physics itself from Newton to Einstein. Unfolding the ultimate nature of the fields in terms of quantum field theories occurred only recently.

Newton could have been the first to glimpse the concept of a field. But he missed it, because of the prevailing notion at the time that everything was mechanistic and material in nature. Newton realized that the earth is held in orbit around the sun by the force of gravity acting over an enormous distance without any material connection between them. He proposed a vague concept of “instantaneous action at a distance”—presumably through some material medium—to explain the gravitational attraction, although it was puzzling to him as well as to other scientists of the time.

The notion of a field was first introduced by Faraday, who was unencumbered by contemporary thinking. Einstein mused whether Faraday would have come up with the idea of a field if he had not been a high school drop-out. Faraday saw that when a magnet was moved around inside a coil, an electric current was induced in the coil, even though there was no material connection between the magnet and the coil. He explained that the magnetic field, a nonmaterial entity, was inducing a current in the coil and the concept of the field was underway.

This concept was fully developed as a part of reality by Maxwell and experimentally demonstrated by Hertz. But the idea of a material world alone was still ingrained in people’s minds. Therefore they came up with the proposal of a shadowy, all-pervading,

TABLE 1. Particles of force fields (bosons).

Force field	Strength in natural units	Particle	Symbol
Gravity	6×10^{-39}	Graviton	G
Electromagnetism	1/137	Photon	γ
Weak nuclear	10^{-5}	Weak bosons	W^{\pm}, Z^0
Strong nuclear	1	8 gluons	g

TABLE 2. Particles of matter fields (fermions).

Family	Leptons	Symbol	Quarks	Symbol
I	Electron neutrino	ν_e	up	u
	Electron	e	down	d
II	Muon neutrino	ν_{μ}	charm	c
	Muon	μ	strange	s
III	Tau neutrino	ν_{τ}	top	t
	Tauon	τ	bottom	b

material medium called *ether*, through which the field is supposed to be transmitted. Einstein finally freed our thinking from the encumbrances of *ether*, when he came up with the idea that a field is a physical state of empty space itself. According to Einstein, a field is a “final irreducible constituent of physical reality,” and, therefore, should be considered a “fundamental constituent of the physical cosmos.” Thus the concept of a field as an essential part of reality came about.

Although natural phenomena appear to be very complex, the underlying force fields controlling their interactions are rather simple. In nature, we come across only four such fields, which we designate as gravity, electromagnetism, and weak and strong nuclear fields. In addition, there are several varieties of matter fields. The fundamental particles are excitations of the different underlying fields and are described in the standard model of particle physics. Along with the particles of the four force fields, it consists of three families of quarks and leptons as well as their antiparticles. These particles are listed in Tables 1 and 2. Also each quark comes in three colors. The standard model further anticipates a class of as yet unobserved particles, the Higg’s particles which are associated with symmetry breaking and generation of particle masses.

These fields organize and control every aspect of the material world. But these diverse fields are now being proven to be just different aspects of only one field, the unified field.

3. Discovery of the unified field. It was the genius of Einstein again that gave seriousness to the idea of a unified field. Einstein strongly believed that the known force fields, which control natural phenomena, have a simple unified foundation. Indeed, his belief was so strong that he spent the last 30 years of his life trying to prove

this concept. Unfortunately, his dream remained unfulfilled. However, his earlier pioneering work led to the development of quantum field theories that would eventually transform his vision into a reality.

Unification of two very diverse forces of nature, namely, the electromagnetic and weak nuclear, have been demonstrated convincingly enough to be the subject of two Nobel prizes. The electromagnetic force has an infinite range, while the weak nuclear force practically vanishes at a distance as small as the size of even the nucleus itself. Yet, electroweak unification showed that these two diverse forces are actually different facets of the same force. This amazing success has broken the barrier in people's minds against the seeming impossibility of unification of nature.

In electroweak unification, the weak fields W^\pm , Z^0 and the electromagnetic field are members of the same mathematical symmetry group $SU(2) \times U(1)$. Since this symmetry is the product of two separate factors, the unification of the weak and electromagnetic forces are not quite complete. A higher degree of unification of the forces and particles occur in Grand Unified Theories (GUTs). The interactions of the strong force belong to the symmetry group $SU(3)$ describing the dynamics of "color" charges which is known as quantum chromodynamics. This is akin to $U(1)$ which describes the dynamics of electric charges and is known as quantum electrodynamics. GUTs unify the strong, weak and electromagnetic forces as well as the quarks and the leptons.

The simplest model of this class of theories is based on a mathematical symmetry group $SU(5)$. Since the grand unified forces also change quarks into leptons, most GUTs predict the proton to be unstable. The nominal $SU(5)$ theory predict a proton lifetime lower than 10^{31} years, while experimental observation indicate a lifetime larger than 10^{32} years. However, the supersymmetric GUTs predict a proton lifetime consistent with the observational limit. In addition, only the supersymmetric GUTs bring about a convergence of the measured coupling constants of the strong, weak and electromagnetic forces. For these reasons, the nominal $SU(5)$ theory has been abandoned in favor of supersymmetric GUTs.

Although a direct proof of grand unification has not been demonstrated, the observed abundance of matter over antimatter in the universe is believed to require such a unification. Recent observation of neutrino oscillations between its various families is considered to be a very encouraging indication of grand unification. Proton decay experiments with higher sensitivity are also in progress to provide a more direct evidence of GUTs.

A theory of final unification of all the fundamental particles and forces including gravity has been a very daunting task. However, sufficient progress has now been made, especially with the development of superstring theories, so that the concept of a final unification of all the fields of nature is being accepted as a real possibility, although a mathematically consistent formulation of unification is still being worked out.

Figure 1 shows how the strength of the various forces changes with energy (per particle) or temperature. As the energy increases, the strength of the electromagnetic force increases while that of the weak nuclear force decreases moderately. (This is not apparent from the figure, since at ordinary temperatures, the range of the weak force is highly reduced due to the heavy mass of its virtual carrier particles.) From

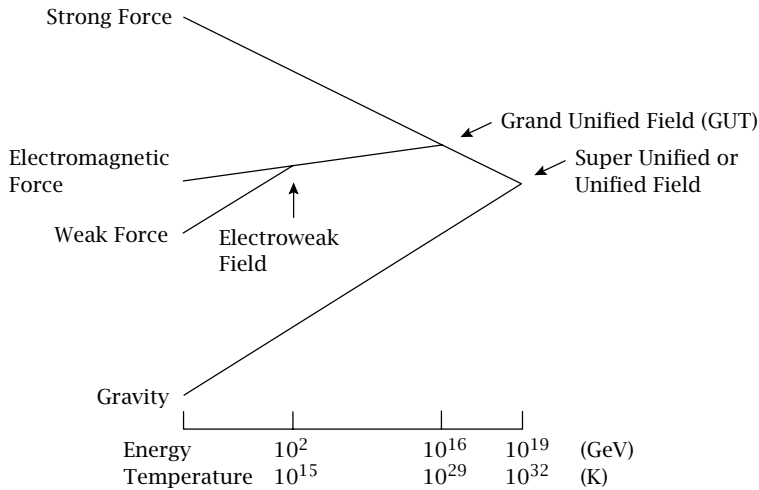


FIGURE 1. Schematic representation of the strength of the force fields as a function of energy (per particle) or temperature.

experimental data, their underlying identity has been established at an energy of about 200 billion electron volt (GeV) or a temperature of 10^{15} K, where these two force fields behave as just different aspects of a united electroweak field. The strong nuclear force decreases in strength with increasing energies and is predicted to converge with that of the electroweak force at 10^{16} GeV (10^{29} K). The strength of the force of gravity increases continually until it is presumed to become the same with that of all the other forces at or near 10^{19} GeV (10^{32} K), where the final unification of all the fields is thought to occur.

The Nobel Laureate Steven Weinberg, says [16, p. 231] in his book, *Dreams of a Final Theory*, “If history is any guide at all, it seems to me to suggest that there is a final theory.” Stephen Hawking, who is considered by many today to have the stature of Einstein, expresses it even more emphatically in his book, *A Brief History of Time*. He provides some strong arguments to support his view [8, p. 167]: “I think that there is a good chance that the study of the early universe and the requirements of mathematical consistency will lead us to a complete unified theory within the lifetime of some of us who are around today, always presuming we do not blow ourselves up first.” Another Nobel Laureate, Murray Gell-Mann, gives further support to this view in his recent book, *The Quark and the Jaguar*. He states that [3, p. 129] “Superstring theory, in particular the heterotic form, may really be the long-sought unified quantum field theory.” He also suggests that [3, p. 200] “there are many possible ways of confronting the theory with experimental results.”

Partly, what supports such confidence of the physicists about the existence of the unified field, is perhaps the realization that natural forces, which are so immensely diverse in our daily environment, appear to have the same strength at the natural scale of the universe. Our civilization depends on an agreed upon unit of mass, length and time like pound, foot and second. But these units are man-made. Interestingly enough, nature has its own units of mass, length and time. They would be the same

for all possible civilizations anywhere in the universe and are determined by three fundamental, natural constants.

In the very first paper in which Max Planck proposed his quantum theory, he was more elated about finding nature's units of mass, length and time than the radical consequences of quantum theory, which was not quite envisioned at that time. With his discovery of the quantum of action h , which is known as Planck's constant, he was able to determine nature's units of mass, length and time, using two other natural constants, the velocity of light c and Newtonian gravitational constant G . (Instead of the Planck's constant h , a constant $\hbar = h/2\pi$ is generally used today. However, we will use the original constant h .)

The constants of nature h , c and G have the dimensional relationship in terms of mass M , length L and time t as $h = ML^2t^{-1}$, $c = Lt^{-1}$ and $G = M^{-1}L^3t^{-2}$. Nature's units of mass, length and time are, therefore, given by

$$M = \left(\frac{hc}{G}\right)^{1/2}, \quad L = \left(\frac{Gh}{c^3}\right)^{1/2}, \quad t = \left(\frac{Gh}{c^5}\right)^{1/2}. \quad (3.1)$$

The values of the natural constant h , c and G in our units of measurements are 6.63×10^{-27} erg·s, 2.99×10^{10} cm/s and 6.67×10^{-8} cm³gr⁻¹s⁻², respectively. Using these values, we get nature's units of mass, length and time in terms of our units as 5.4×10^{-5} gm (3×10^{19} GeV), 4×10^{-33} cm and 1.3×10^{-43} s. These units of nature, called the Planck's units in honor of its proponent, give a scale for measurements that holds true throughout the universe, and therefore, may be appropriately called the universal scale.

The value of the Planck's units of length and time are unbelievably small compared to those of atomic or even nuclear scale. On the other hand, Planck's mass is 10^{19} times larger than the mass of the proton. Although, the sizes of these nature's units appear to be so diverse, they are believed [5] to be necessary for the desirable features of the universe. The practical consequences of the diverseness of the values of the nature's units make the strength of the various forces at ordinary temperatures very disparate as shown in Table 1.

But when we extrapolate our laboratory measurements, using the quantum dynamics of the highly successful models of particle physics, we find that the strengths of the four forces of nature, indeed, tend to converge at the Planck scale. At the Planck scale, the force fields of nature, all having equal strength of interaction, appear to behave as just different aspects of one field, the unified field, which additionally unites force fields with matter fields. The matter fields package energy into fundamental particles like quarks and electrons, while the force fields utilize them as building blocks to generate everything physical. The unified field is presumed to unify fermions and bosons through nature's supersymmetry. Thus, a unified theory appears plausible to describe the underlying unity of the elementary particles that make up the physical world.

4. The origin of the universe. Since we have good reasons to believe in constructing a credible theory for unifying all the fundamental particles and forces, it would be natural to inquire how the universe itself containing all these particles began. Until the twentieth century, cosmology, dealing with the subject of the creation of the uni-

verse, was mostly a part of metaphysics. Only recently, for the first time in the human history, we are able to get some answers based on scientific evidence about how all this came to be. This has been possible by gathering the evidence left over from the early moments of creation. By running the frames of the cosmic movie backwards, we have been able to recount the drama of creation, with the help of the theories of fundamental particle physics at very high energies. Again, the evidence points to the unified field as the source of the universe.

Edwin Hubble gathered the first evidence of this story in the early 1920s at the Mt. Wilson Observatory. By accurately measuring the distances of the nebulae, he showed that they were not only separate galaxies, but also that they all had a redshift, implying that they were all moving away from us. Hubble also observed that the further away the galaxy was, the larger was its redshift. In fact, the speed of the recession of the galaxies, derived from the redshift, was proportional to their distance. It was soon realized that such an expanding universe was predicted by mathematical models of the universe based on Einstein's general theory of relativity.

To construct a model universe, using his newly developed general theory of relativity, one essential feature used by Einstein was the cosmological principle, which states that the universe is homogeneous and isotropic. If the universe is isotropic, it can be shown to be also homogeneous. Homogeneity means that the density is distributed uniformly throughout the universe. Although it was a bold and unsubstantiated assumption at the time, since one could then locally see the dense milky way, it turns out to be an accurate one. Because on a larger scale, universe is now found to be indeed homogeneous.

The generalized solution for Einstein field equations for a homogeneous universe was first presented by Alexander Friedmann and therefore bears his name. The Friedmann equation for the evolution of the cosmic scale factor $R(t)$, which represents the size of the universe, is

$$\left[\frac{\dot{R}(t)}{R(t)} \right]^2 = \frac{8\pi G}{3} \rho(t) - \frac{kc^2}{R^2(t)}, \quad (4.1)$$

where $\rho(t)$ is the uniform density of the universe and k is a time-independent constant. The expansion rate of the universe is determined by $\dot{R}(t)/R(t) = H(t)$, the Hubble parameter. At time t , it is a constant known as the Hubble constant H . Equation (4.1) shows that the speed of recession is proportional to distance, as observed at a particular time.

Using $H(t) = \dot{R}(t)/R(t)$ and defining $\Omega(t)$ as the ratio of the density $\rho(t)$ to the critical density $\rho_c(t) = 3H^2(t)/8\pi G$, equation (4.1) can be expressed as

$$\frac{kc^2}{H^2(t)R^2(t)} = \Omega(t) - 1. \quad (4.2)$$

It is evident from equation (4.2) that for $k = +1$, $\Omega > 1$, when the universe is called closed; for $k = 0$, $\Omega = 1$, the universe is flat and for $k = -1$, $\Omega < 1$, the universe is open. A closed universe will eventually collapse on itself while an open universe will expand forever.

Equation (4.1) can be recast as

$$\dot{R}^2(t) = \frac{8\pi G}{3} \left[\rho(t)R^3(t) \right] \frac{1}{R(t)} - kc^2. \quad (4.3)$$

Differentiating equation (4.3) with respect to time, and since the total matter in a given expanding volume is unchanged, $\rho(t)R^3(t)$ is constant,

$$2\dot{R}(t)\ddot{R}(t) = -\frac{8\pi G}{3} \left[\rho(t)R^3(t) \right] \frac{\dot{R}(t)}{R^2(t)}, \quad (4.4)$$

$$\frac{\ddot{R}(t)}{R(t)} = -\frac{4\pi G}{3} \rho(t). \quad (4.5)$$

Since $\ddot{R}(t)$ is always negative, at a finite time in the past, R must have been equal to zero. Then, according to these models, the contents of all the galaxies must have once been squeezed together in a small volume where the temperature would have been immensely high. The radiation left over from this fireball must still be around today, although cooled to a much lower temperature due to expansion of the universe. Precisely such a relic radiation was observed in 1965, which provided compelling evidence for the “big bang” model of the universe. This radiation is known as the cosmic microwave background radiation, at a temperature of 2.73 K.

The observed radiation decoupled from the ionized soup of matter and radiation of the cooling fireball, when electrons combined with the nuclei. The equilibrium between ionization and recombination is given by the Saha equation

$$\frac{x^2}{1-x} = \frac{(2\pi m_e kT)^{3/2}}{\eta h^3} \exp\left(-\frac{I}{kT}\right), \quad (4.6)$$

where x is the ionized fraction, I , the ionization potential, m_e , the mass of electron and η , the ratio of number densities of photons to baryons. Since about 90% of the nuclei are hydrogen, we can take the ionization potential to be that of hydrogen which is 13.6 eV. Since $\eta \sim 10^{10}$, the fractional ionization drops sharply at a temperature of about 4000 K or at 3000 K if ionization from the first excited level is included. This temperature of radiation decoupling occurred at about 300,000 years after the big bang. Matter was then free to form galaxies and stars under gravitational clumping.

The primordial fireball was a giant thermonuclear reactor. Therefore, our knowledge of nuclear reactions allows us to calculate the abundance of light elements, like hydrogen, helium, deuterium and lithium, produced in the cooling fireball. The observed relative abundances agree very well with theoretical predictions, which gives added support to the hot, early universe. The pioneering book by Steven Weinberg entitled, *The First Three Minutes*, gives [15] a comprehensive account of this model. Further support came from the observation of the minute fluctuations in the cosmic microwave background radiation, as well as from the observed evolution of galaxies with time.

All of this evidence has established cosmology as a branch of science and the existence of the primordial fireball appears in physics text books as part of the standard big bang model. However, there are some glaring shortcomings of the model, known as the horizon problem, the flatness problem, etc. The proposed, inflationary paradigm, rooted in plausible theories of particle physics, offers a unique solution to these prob-

lems. It also identifies the source of the enormous amount of mass and energy of the big bang fireball.

To go beyond the standard big bang model, we depend primarily upon the results of investigation of particle physics; because, towards its origin, the universe would have been smaller and the temperature increasingly higher. Such temperatures are available only in the laboratories of particle physicists today. In turn, the particle physicists look to the relics of the events of the early universe to provide support for their theories. At temperatures higher than what is attainable by machines, the only resource available for particle physicists is the study of the early universe itself. This symbiotic relationship of particle physics, which deals with the smallest, and cosmology, which is the study of the largest, has provided an essential link in our pursuit of an understanding of the origin of the universe.

As we proceed beyond the standard model of big bang to higher temperatures, the various stages of unification of the fields contemplated by the particle physicists provide a basis for recounting the early universe. Since the early universe was radiation dominated, the temperature and size is related [15] to time t by $1/T \propto R \propto t^{1/2}$ except when there is a phase change. The well-established electroweak unification must have been present when the temperature of the fireball was about 10^{15} K at about 10^{-12} s after the origin. Discovery of the asymptotic freedom of quarks at higher energies allows us to treat the fireball as a super dense, weakly interacting gas containing quarks, electrons and other particles of the standard model of particle physics. At still higher temperatures, the phenomenon of inflation is presumed to have come into the picture.

Alan Guth, who conceived the idea of the inflationary theory of cosmology, gives [6] a detailed account of it in his book, *The Inflationary Universe*. A main feature of the unified field theories of particle physics is that a class of scalar fields, called Higgs fields, are thought to be responsible for spontaneous symmetry breaking of the various stages of unification of the fields.

During symmetry breaking, which separates the strong nuclear field, the potential energy of the scalar field is given [7] by

$$\rho \simeq \frac{E_{\text{GUT}}^4}{(hc)^3} \simeq 10^{100} \text{ erg/cm}^3, \quad (4.7)$$

where E_{GUT} is 10^{16} GeV, the energy scale for GUT symmetry breaking. This enormous potential energy density of the scalar field can lead to an exponential expansion of the universe for a fleeting moment (during 10^{-37} to $\sim 10^{-35}$ seconds after the origin), allowing the universe to expand by at least a factor of 10^{30} , *while maintaining a constant energy density*. Consequently, a prodigious amount of positive energy can be created, balanced by an equal amount of negative gravitational potential energy, the total energy of the universe still being zero. Therefore, the big bang fireball can essentially grow out of an embryonic universe as a result of a momentary instability of a scalar field, and the basic features of the baby universe become established. Guth amusingly describes this by his famous phrase, "In the context of inflationary cosmology, it is fair to say that the universe is the ultimate free lunch."

Even though cosmologists generally agree on the necessity of an inflationary

paradigm, no such agreement exists on its details or exactly when it occurred. Some superstring cosmology model suggests its occurrence to be even much closer to the Planck's dimensions. At its present stage of development, the inflationary universe is more of a model whose actual details still need to be finalized, based on some observations, such as the characteristics of fluctuations of the cosmic microwave background radiation. Especially, the study of the pattern of polarization of these radiations caused by the primordial gravitational waves could distinguish between the different scenarios of inflation. Some inflationary model even envisions multiple universes or a multiverse arising out of continuing inflation. In such a model, the beginning of the universe is pushed back to an indeterminate past.

In our universe today, the cosmic microwave background radiation essentially looks the same in all directions, coming from regions, which cannot be connected even with the speed of light. This is known as the horizon problem. But if the universe initially started with a small enough size before inflation, there would have been time for communication between the various regions. This would explain why the universe, as represented by the microwave background radiation, is so isotropic and homogeneous, on a large scale. The observed smoothness of the microwave background radiation also provides a graphic validation of the cosmological principle.

Equation (4.2) shows that the value of the critical density $\Omega(t)$ determines whether the Universe is open, closed or flat. Any deviation in the value of Ω from 1 in the early universe would rapidly grow with time. If Ω was slightly less than 1 in the early universe, it would have rapidly fallen to zero resulting in a universe with no structures such as galaxies and stars. Instead, if Ω was slightly greater than 1, it would have rapidly increased and the universe would have already collapsed.

The age of the universe has been determined to be 10–20 billion years by a variety of *independent* methods such as expansion rate of the universe, radioactive dating, oldest stars in globular clusters, Sunyaev-Zeldovich effect, gravitational lensing, cooling of white dwarf star, etc. For the universe to be this old with the observed structures, it had to start out with $\Omega = 1$, with an accuracy of about 1 part in 10^{60} which is rather unnatural. This is referred to as the flatness or the age problem.

During the process of inflation, the term kc^2/H^2R^2 in equation (4.2) is suppressed enormously [7], so that the universe starts out with $\Omega = 1$. This is also supported by recent observations [13] showing that the universe today is actually flat. However, the observed [9] mass density of the present universe appear to give Ω_m of only 0.3–0.6. To reconcile the value of $\Omega = 1$ with the observed low mass density, the existence of a vacuum energy density, consistent with a cosmological constant Λ , has been proposed. Recent measurements [1] of H at high redshifts, using type I_a supernovae, indicate that the value of H in the present epoch is actually increasing, rather than decreasing, as has been assumed before. The observation has prompted the existence of a small value of Λ to be taken seriously.

While constructing a model universe, Einstein originally introduced Λ to find a static solution of his field equations. He abandoned it as his “biggest blunder” when the static solutions turned out to be unstable and the universe was actually found to be expanding. A nonzero value of Λ is being introduced now to explain the observed flatness of a low density universe. Accordingly, equation (4.1) is modified as

$$\left[\frac{\dot{R}(t)}{R(t)} \right]^2 = \frac{8\pi G}{3} \rho(t) + \frac{1}{3} \Lambda c^2 - \frac{kc^2}{R^2(t)}. \quad (4.8)$$

By defining $\rho_\Lambda = \Lambda c^2/8\pi G$ and an effective $\rho_e(t) = \rho(t) + \rho_\Lambda$, equation (4.8) can be written in the identical form as equation (4.1),

$$\left[\frac{\dot{R}(t)}{R(t)} \right]^2 = \frac{8\pi G}{3} \rho_e(t) - \frac{kc^2}{R^2(t)}. \quad (4.9)$$

Thus the existence of Λ can be represented as a fixed mass density of the vacuum. Since the value of Λ is small ($\sim 10^{-56} \text{ cm}^{-2}$), its effect is significant only at large values of R , and therefore its exclusion is justified for the early and adolescent universe, except for the extraordinary circumstances during the fleeting inflationary period.

When the cosmological constant is included, equation (4.2) becomes

$$\frac{kc^2}{H^2(t)R^2(t)} + 1 = \Omega(t) + \frac{\Lambda c^2}{3H^2(t)}. \quad (4.10)$$

Again, during inflation $kc^2/H^2(t)R^2(t)$ is suppressed enormously [7], so that the relation

$$\Omega(t) + \frac{\Lambda c^2}{3H^2(t)} = 1, \quad (4.11)$$

holds to a high degree of accuracy.

We can then consider $\Omega = \Omega_m + \Omega_\Lambda = 1$, where $\Omega_m = \rho_m/\rho_c$ and $\Omega_\Lambda = \rho_\Lambda/\rho_c = \Lambda c^2/3H^2$. By integrating equation (4.8) using Ω_Λ , the present age t_0 of the universe is given by

$$t_0 = \frac{2}{3} H_0^{-1} \Omega_\Lambda^{-1/2} \ln \left[\frac{1 + \Omega_\Lambda^{1/2}}{(1 - \Omega_\Lambda)^{1/2}} \right]. \quad (4.12)$$

Taking the recent accurate value of $H_0 = 65 \pm 10 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and $\Omega_\Lambda = 0.6$, the value of t_0 is about 13.4 billion years. This age is consistent with the recent determination [12] of the age of the oldest stars in the globular clusters to be 12–14 billion years. If the critical density of the universe today consisted only of matter, the age of the universe would be $t_0 = 2/3H_0^{-1} \approx 10$ billion years, which is lower than the age of the oldest stars. This provides a compelling reason for resurrecting Λ . Furthermore, the observed flatness of the universe and estimates of Ω_m and H_0 , combined with the preliminary value of Λ obtained from the high redshift supernovae studies, satisfies equation (4.11) to a large extent, which gives significant support to the inflationary paradigm.

The quantum fluctuations of the scalar field also become enlarged by the process of inflation, which provides the seed for subsequent galaxy formation. These minute density fluctuations imprint tiny temperature variations (about six parts per million) over the smooth, microwave background radiation, recently discovered [14] by the COBE satellite. The pattern of fluctuations observed by COBE as well as by some recent experiments is consistent with those predicted by the inflationary model and

inconsistent with other postulates like topological defects. Further studies are planned with more sensitive MAP and PLANCK satellites which are expected to provide some indication of the type of inflation, in addition to furnishing accurate values of cosmological parameters such as H , Ω_m , and Ω_Λ .

According to the prevailing notions, what preceded the inflationary universe is known as the GUT epoch. Our knowledge at the beginning of the GUT epoch is quite murky, primarily due to our inability to correlate it to any observable data. Still, some attempts have been made to clarify the picture as we finally approach the origin. Before inflation increased it, the size of the universe would have been about 10^{-30} cm. At earlier times, the universe must have been constrained to even smaller, gradually diminishing sizes. According to general theory of relativity, as we approach the origin, spacetime end up at a point known as singularity, where all the classical laws of physics will break down. But before reaching the conjectured singularity, quantum effects should come to the rescue at Planck's length of 10^{-33} cm. The subject of quantum cosmology has been developed to deal with this problem. The quantum cosmological aspects of the superstring theory makes a prediction [4, pp. 357-358] that space cannot contract beyond its minimum at the Planck length.

Hartle and Hawking have developed [8, pp. 134-137] a unique version of quantum cosmology using sum over histories and imaginary time. According to their solution, a singularity is avoided by describing the initial conditions of the universe with quantum effects, whereby space and time together form a surface that is finite in size but does not have a boundary. This is how the surface of the earth would appear to a hypothetical, two dimensional flatlander living on the surface of a sphere. The earth would be finite in size, but there would be no boundary, or edge to fall off. Hawking calls this proposal a "no boundary" boundary condition.

Murray Gell-Mann lends some support [3, p. 131] to this effort in his book, *The Quark and the Jaguar*: "If the elementary particles are indeed described by a unified theory (which Hartle and Hawking did not explicitly assume), then the appropriately modified version of their initial condition can be calculated in principle from that unified theory, and the two fundamental laws of physics, for the elementary particles and the universe, become a single law." Thus the unified field and the initial condition of the universe are assumed to be mutually consistent.

Although there is no general consensus on how the universe initially came to be, the most plausible explanation yet is that an energetic fluctuation caused the universe to begin from the Planck's dimensions. The spontaneous symmetry breaking of the unified field occurred, thereby separating gravity, matter fields and GUT force field, as well as initiating the expansion of the universe. The universe cooled by expansion to cause another symmetry breaking, when the strong field separated along with the creation of the primordial fireball by inflation. As the temperature cooled by further expansion, the weak and electromagnetic fields separated; all the force fields and the matter particles assumed their separate identities. Thus, the unified field sequentially unfolded to create this universe and everything physical in it.

5. The ever-present unified field. The quantum physical presence of the unified field everywhere in the fabric of spacetime today can be understood in terms of the

inescapable consequences of the quantum field theory and Heisenberg's uncertainty principle, which represent the essence of the quantum nature of the ultimate reality. According to the quantum field theories, the fundamental elements of reality are the underlying quantum fields. Every elementary particle is an excitation of its respective underlying field. Furthermore, all fields are present in all space throughout the universe at all times. However, to be consistent with the uncertainty principle, no quantum field can be at rest. All the fields that are manifest since the early moments of the universe should be present as vacuum fluctuations even when they are not coupled or localized. The ubiquitous existence of vacuum fluctuations of the electromagnetic quantum field is readily observed in the Casimir effect, the Lamb shift and a variety of other phenomena.

The Casimir effect predicts that vacuum fluctuation of the electromagnetic field will induce a force between two uncharged conductors, separated by a small distance in vacuum. Such a force has been measured [11] recently by Lamoreaux. The Lamb shift was observed [10] by Willis Lamb, for which he was awarded the Nobel prize. Lamb observed an unexpected spectral line splitting in hydrogen, which stimulated the development of quantum electrodynamics and established the effect of vacuum fluctuation. The tiny magnetic moment of the electron is also affected by vacuum fluctuations; the measured value agrees with prediction, deduced from vacuum fluctuations, to better than eight decimal places.

Thus, empty space is not empty at all. On the contrary, the quantum vacuum is the "home" of nature's infinite dynamism. It is the substrate in which all of high energy physics takes place. But this frenzied activities of the empty space must be subject to some systematic order. The vacuum state of a quantum field should correspond to a superposition of the fluctuation of all possible field shapes. Since the vacuum state represents the absence of all real physical particle and forces, it should possess spatial symmetry in conformity with *Poincaré invariance*, which would preclude arbitrary superposition of fields.

Our knowledge of the unification of the fields can guide us to determine how the fields in the vacuum state may be further organized. The electroweak unification happens when the symmetry represented by $SU(2) \times U(1)$ is restored. This has been demonstrated experimentally, using particle accelerators, where the energy E per particle was about 200 GeV, corresponding to an equivalent temperature of 10^{15} K. The wavelength λ of a particle of 200 GeV is given by $\lambda = hc/E \sim 10^{-16}$ cm. Thus, when we probe the spatial distance at about 10^{-16} cm, the presence of the symmetry required for the electroweak unification becomes evident.

To probe what happens at shorter and shorter distances, we need higher and higher energy per particle, since the distance probed depend upon the wavelength of the particle which inversely depends upon its energy. With the present or anticipated experimental capabilities, we cannot probe distances much shorter than 10^{-16} cm. Fortunately, however, calculations using supersymmetry, show that if the forces are examined as they act on distances of about 10^{-30} cm the strength of the electromagnetic, weak and the strong nuclear forces appear to become equal. This would indicate that the GUT symmetry is restored at about 10^{-30} cm.

Detail quantum field theoretic analysis on a tiny time slice indeed show that, with

the exception of any phase transition characteristic of a cooling, high temperature ensemble, physics at fundamentally small dimensions is equivalent to physics at high temperatures. Therefore, restoration of the GUT symmetry at about 10^{-30} cm at ordinary temperatures is based on some solid theoretical foundation.

Finally at the Planck's dimension, the calculations show that the strength of the gravitational force become equal to that of the three gauge forces. Thus, as we proceed towards Planck's length anywhere in the universe, all the symmetries of nature are restored gradually, thereby creating the conditions for the various stages of unification of all the forces possible in sequence. Furthermore, supersymmetry is surmised to unify the bosons and the fermions. Thus, at the Planck scale, all the underlying quantum fields are presumed to behave as just different aspects of a single unified field. Even though, the high temperatures necessary for unification are physically absent today in the Planck's dimension of the vacuum, presence of unification is indicated quantum physically.

A mathematically consistent final theory of the unified field is still being worked out. In the absence of such a theory, the basic principle of the much tested theory of general relativity may be applied to get an over all framework of quantum gravity and super unification which can serve to conceptualize the nature of the ultimate ground state of the vacuum, although its mathematical formulation in terms of a smooth spacetime continuum is inadequate for a quantum description of nature. The fundamental tenet of Einstein's general theory of relativity is that space, time and field cannot exist separately. As an outcome of the special theory of relativity, space and time are inseparable. According to the general theory of relativity, spacetime is not just a passive background in which events take place, but rather they are active participants in the dynamics of the universe. In Einstein's words [2, p. 348], "the physical reality of space is represented by a field whose components are functions of spacetime." Therefore, a field is not only an irreducible physical state of space itself, spacetime and fields must also exist simultaneously.

In addition, we know that in the quantum domain, systems can possess a minimum quantum energy without having to dissipate it. The ground state energy of an atom and zero point energy of vibration of a molecule are typical examples. In the superstring formulation, the unified field can vibrate forever without losing its energy, while the coordinates of spacetime are not ordinary numbers but possess quantum mechanical characteristics. As Steven Weinberg says [16, p. 214] in his book, *Dreams of a Final Theory*, "In contrast, the strings that concern us here are truly fundamental and keep vibrating forever; they are not composed of atom or anything else, and there is no place for their energy of vibration to go." Therefore at Planck scale, the fluctuating spacetime geometry, and the "zero point" fluctuation of the unified field can be deemed to constitute the self-interacting dynamics of the vacuum ground state of the universe.

Since spacetime is not expected to contract beyond Planck scale, unified field may be considered to be present in the ultimate fabric of spacetime everywhere in the universe. During the earliest moments of creation of the universe, when the temperature dropped as the universe expanded, the various fields sequentially became manifest. Equivalently, from a quantum physical perspective, this process of sequential differentiation of the unified field into its various components takes place, as the dimension

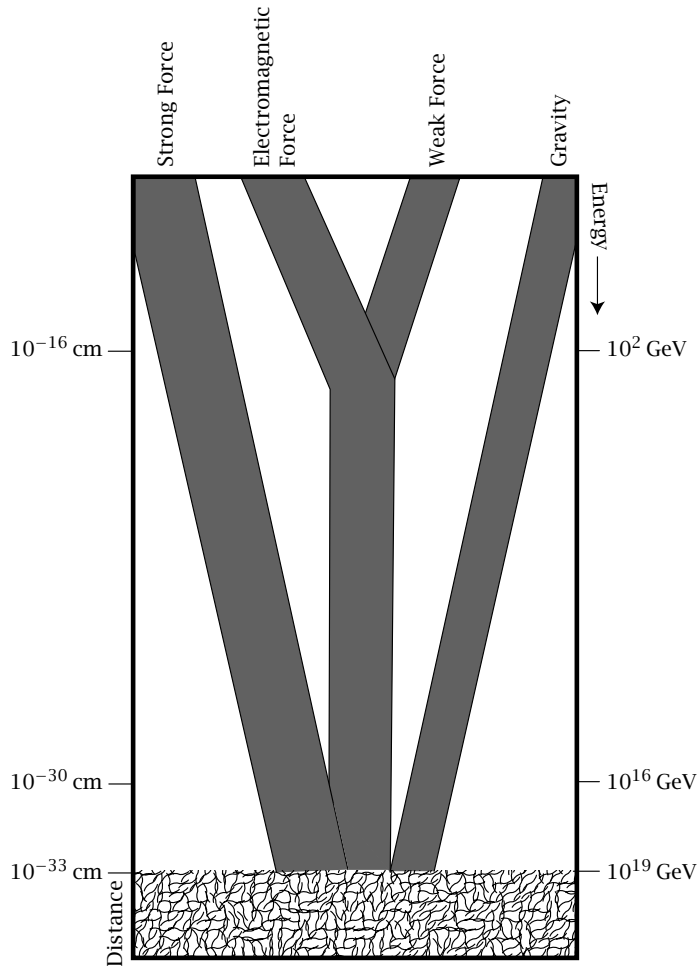


FIGURE 2. In the ultimate fabric of space (the Planck's dimension, 10^{-33} cm), is the unified field, which gradually unfolds resulting in vacuum fluctuations of the various fields as we proceed outward from the fabric of space.

of space encountered becomes larger than the Planck's length today. This is schematically shown in Figure 2. The various fields manifest themselves whenever appropriate energy or matter is available for them to couple. Thus, the structure and dynamics of the vacuum state foreordain all the properties of the fundamental particles that arise out of it. This is why any fundamental particle has its exact same particular properties everywhere in the universe. The properties of the fundamental particles, in turn, govern the characteristics of all physical interactions, which then owe their ultimate origin to the unified field.

In summation, recent scientific discoveries point to the fact that unified field sequentially unfolded to create our universe. The unified field, is still encoded in the

very fabric of spacetime throughout the universe in a quantum physical way, thereby upholding and administering at least everything physical it contains. It seems nature has repeated this pattern in the characteristics of the human genome. Following the analogy of the genome, should we not then call the unified field the universal field, possessing the universal blueprint?

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