COMMITTEE I
The Unity of the Universe

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THE COSMOLOGICAL PROBLEM: THE ORIGIN AND FATE OF THE UNIVERSE

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Introduction

The universe is well and behaving as it should,in accordance with the laws that govern it, but our understanding of it, that is, cosmology, is in a severe crisis, confronting what appear to be insoluble problems, which are all the more perplexing because we seem to to have the basic natural laws and principles to solve these problems, or, at least to obtain a deeper insight into them than we now have. We must take a two-fold approach to the solution of these problems since they are of a two-fold nature, the general characteristics of which we can understand from a consideration of the differences between these two sets of cosmological problems.

We may encompass the first,and more basic set, under the general heading of "origin", which is rather loosely used in cosmology, but must be precisely defined, if possible, if we are to formulate this set of problems meaningfully, let alone solve them. In conjuring up the "origin of the universe" we picture an event at some moment in the distant past, which we now refer to or identify with the "Big Bang", but this identification obscures many important details of the events during the initial stages of the universe and raises many questions. Thus some temporal questions arise such as the moment of the "Big Bang" and its duration, which are not clearly defined, and may, indeed, have no operational meaning. Since time and energy are conjugate quantum mechanical operators, we are confronted with infinite energies if we picture the universe as having originated at some particular moment.

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But the concept of the origin of the universe implies a kind of act of creation during which all the basic elements required for the evolution of the universe from its moment of birth to its present highly organized complex state were created simultaneously. These elements fall into a number of different categories, some of which are of a material nature and some non-material. The non-material elements are the laws and constants of nature, and the initial conditions. Did the laws already exist before the birth of the universe or did they emerge with the universe? Were the values of the natural constants (the gravitational constant, Planck's constant of action, the speed of light, the basic electric charge) pre-ordained or imposed on the universe at its birth by some basic law which inter-relates them; or were these values merely a matter of chance? If the universe evolved from some initial state in accordance with the laws (the differential equations of motion), what were the initial conditions and how did they arise? These, of course, are very difficult questions, which may or may not be answerable, but they should be considered as a basic part of the overall cosmological problem.

The material elements whose origins we must consider together with the origin of the universe are the fields of force and the massive (non-zero rest mass) particles that generate or are coupled to these fields, and here we are confronted with immediate questions that frame the entire cosmological problem. Did the fields or the massive particles come first or were they created together? We distinguish here between massive particles and the massless field quanta, which are, of course, particles in the modern sense of the term, and which originated with the fields. Since no elementary, massive particles without charge and spin are known in nature, (mass, spin, and charge always occur together), these three physical properties must have originated together with the particle. But since the masses and charges of the elementary particles (the quarks) are different, we must seek the reason for these differences, try to understand how charge and mass were conferred upon these particles simultaneously, and why the quark with the smaller mass acquired the larger charge; finally, how did these particles acquire their spins? Clearly, the very nature of the present universe (including the origin and evolution of life) depends on these basic masses, charges and spins. But we have nothing in our theoretical storehouse to call upon to answer these fundamental questions. For the time being, then, we include these parameters, as well as the natural constants in the initial conditions imposed on the universe. A theory that gives us a grand unification of all the forces of nature should, of course, give us all the initial conditions, but we seem to be far from developing such a theory.

Having disposed of the first set of cosmological problems (without solving them) by including them in the initial conditions, we turn to the second set which deal with the evolution of the universe from some amorphous, but well defined state in the distant past, to its present dynamical, chemical, and structural diversity. These problems can be solved, in principle, since the equations of motion of the universe are known and matter and energy (or fields of force) governed by unambiguous laws and principles (or symmetries), as well as the universal constants, are given. The essence of these problems and their solutions is the construction of mathematical models that correctly represent the present universe and that enable us to deduce its past and future states.

On a much reduced scale, the astrophysicist did just this for stellar structure and evolution, with spectacular success, so that very few mysteries, except for higher order details, remain in that area of science; the correlation between the stellar models constructed by astrophysicists and observed stellar properties (the Hertzsprung-Russel diagrams) is one of the most beautiful examples of the interplay, in the history of science, of logic (mathematics), theory, and observation. Pursuing the analogy between the astrophysical and the cosmological problem a bit further, we note that the evolution of a star from an amorphous cloud of dust and gas to its initial stellar state is unique as expressed in the Russell-Vogt theorem which states that this evolution is completely determined by the mass and chemical composition (essentially the hydrogen and helium content) of the cloud. I believe that a similar cosmological theorem applies to the universe except that the atomic composition is replaced by the primordial elementary particle composition, that is, the abundances, initially, of the particles that now constitute protons and neutrons.

Another interesting similarity between the astrophysical and the cosmological problems is contained in the roles that particle physics played and plays in each of them. In astrophysics the early stages of star formation are governed by gravity, which controls the evolution until thermonuclear forces are triggered when the central temperature of the configuration reaches 10 million degrees. Nuclear reactions then dominate the star's evolution during most of its normal normal life. Gravity again takes over in the star's declining years, after its nuclear fuel has been exhausted, and, depending on the star's mass, compresses the star to its final state as a white dwarf, a neutron star, or, ultimately, a black hole. This interplay of gravity and the strong non-gravitational forces among the elementary particles also occurs in cosmology but on an entirely different level and in a different sequence.

Although the similarities between the astrophysical and cosmological problems are striking, their differences preclude the possibility of solving the cosmological problem as easily as the astrophysical problem. The most important difference, which makes the cosmological problem insoluble at present, is in the the initial conditions of the two problems; they are well defined in astrophysics

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but not so in cosmology. Indeed, from Einstein's equations of motion of the universe (the basic cosmological differential equations) it appears that an initial singularity in the history of the universe is inevitable, with infinite temperature and density, so that these equations cannot be applied to the initial state, which therefore has no physical meaning as things now stand. But I believe that this difficulty is more apparent than real and is eliminated if Einstein's equations are properly interpreted, as I shall show. The initial conditions are then contained in the solutions of these equations. In this paper I show that this is, indeed, so if the quarks that constitute baryons are not infinitely confined but bound by a very large potential energy of the order of 10^{19}GeV (10^{19} times the proton mass) which is so if quarks are the unitons (mass $\approx(\hbar c/G)^{1/2}$) that I have proposed as the elementary particles in nature in various papers previously published.

Not only does this model of baryons eliminate the initial singularity in the history of the universe but it also leads to two simple simultaneous algebraic equations whose solutions are the number of baryons now in the universe (of the order of 10^{80}) and the initial radius of the universe (of the order of 10^{12}cm), that is, the radius just before the "big bang". But this uniton model of the universe gives us some cosmological dividends and answers some important questions which no other model does. Thus the hidden or "missing" mass is a direct consequence of the model which leads to an initial state in which only unitons (free quarks) are present, as explained further on. When these unitons combined in triplets to form the present baryons, some were, inevitably, left over to give the hidden mass. Since the mass of a free uniton is of the order of 10^{19} times the mass of a proton, only one such uniton per 10^{17} protons accounts for the hidden mass. The general objection raised against baryons as the "missing" mass does not apply to unitons since their properties are quite different from those of baryons.

If the big bang stemmed from the gravitational collapse of the initial uniton phase, the very energetic photons produced, would have been amplified enormously in number via the shower production of copious quantities of positron-electron pairs, which,by recombination could easily have produced the presently observed photon vs proton excess (10^{10} photons per proton). Moreover the present triplet coalescence of the residual stray unitons can account for most of the presently observed energetic phenomena in the universe.

The standard model and its flaws

The standard cosmological model of the expanding universe is faulty or, at best, incomplete because of the intractable problems associated with its initial stages; since its temperature $T \to \infty$ as the time $t \to 0$, this model (an adiabatically expanding, radiation-dominated hypersphere, governed by the Robertson-Walker metric) becomes singular so that no initial conditions can be defined for it. Moreover, during this model's very early expansion, when its $kT \geq 10^{19}$GeV, the quantum gravitational effects compound the theoretical difficulties to such an extent that cosmologists shun this epoch in their application of the model. Thus Guth[1] in his paper on the inflationary universe states that "...when T is of the order of the Planck mass (...10^{19}GeV) or greater, the equations of the standard model are undoubtedly meaningless since quantum effects are expected to be essential."

In burdening cosmology with an insoluble problem by imposing a singularity on the universe at $t = 0$ Guth and most other cosmologists have overlooked or forgotten Einstein's precept: eliminate insoluble (that is, unphysical) problems. The most famous example, among others, of the application of this principle is Einstein's treatment of the ether, which he discarded precisely because it presented insurmountable difficulties and contradictions. Accepting the universe as rational (but not necessarily completely fathomable) we should reject such irrational concepts as singularities with infinite temperatures and densities in discussing it. If we can avoid such unphysical concepts rationally, without violating any physical law or principle, we should do so even if we must depart from current dogma and

and the presently accepted models of baryons and leptons.

Since the singularity at $t = 0$, with its unacceptable infinities, is a necessary consequence of the standard cosmological model, which is radiation-dominated during its initial stages, so that $T \to \infty$ as t and $R(t) \to 0$ (R the radius of the universe) it is clear that we eliminate the undesirable singularity by starting with a finite ($R(0) > 0$), cold, matter-dominated universe at $t = 0$. In their review article on cosmology and elementary particles Dolgov and Zeldovich[2] do consider an initial "cold universe with subsequent generation of energy" but from a point of view quite different from mine; their initial cosmological state is that of a cold baryon fluid which could not, at any later stage, have produced the vast amount of entropy we now observe. Moreover, such a cold state could not have been stable against total gravitational collapse as demanded by the Hawking-Penrose theorem.

To eliminate the pernicious singularity at $t = 0$ we must start from an initial cold state, governed by Einstein's two cosmological equations, but still protected against total collapse by a real physical process (that is, consistent with basic laws) which requires that $\dot{R}(0) = 0$ (the dot means time derivative) and $R(0) > 0$; at the same time this must be a very short-lived transient state which decays, with a rapid, non-adiabatic change of phase (increase of entropy by a factor of the order of 10^{86}), to a hot, radiation-dominated, rapidly expanding state. I show below that the uniton (unit gravitational charge $(\hbar c/4)^{1/2}$) model of the expanding universe, which I described in a previous paper[3] has just those properties which lead to a non-singular, well-behaved initial state. Since certain features of my uniton model are similar to those of Guth's inflationary model, I discuss the latter briefly before describing the former.

Guth's Inflationary Universe

To avoid the problem of the initial singularity in the standard model and the troublesome quantum gravitational effects when $kT \sim$ the Planck mass, Guth simply neglects all cosmological events in the epoch $0 < t < 10^{-38}$ sec and begins his analysis of the standard model and the construction of his inflationary model at $t = 10^{-38}$ sec, with $kT \sim 10^{17}$GeV (the GUTs energy). He then shows 1) that the "two puzzles" (the flatness problem and the horizon problem) inherent in the standard model of the universe stem from the assumption that its expansion has always been adiabatic, and 2) "that both problems would disappear if this assumption were grossly incorrect". Rejecting adiabaticity Guth introduces the non-adiabatic condition

$$S_p = Z^3 S_0, \tag{1}$$

where Z is some large factor ($>3 \times 10^{27}$) and S_0 (of the order of unity) and S_p are the universe's initial (GUTs) and present values, respectively, of the total entropy. The inflationary universe was designed to give precisely this condition; the non-adiabatic expansion of the model was achieved by programming into it an equation of state such that the matter would undergo a first-order phase transition at some critical temperature $T_c \approx 10^{14}$GeV/k. But an additional condition had to be imposed on the model for the whole thing to work; the phase transition was not to occur at the temperature T_c. Instead, the universe (according to the model) was to supercool some 28 orders of magnitude below T_c before the phase transition, with a vast release of energy, was to occur.

Though the temperature $T \to 0$ during the supercooling the Guth universe was designed not to approach the true vacuum state but, rather, a false metastable state of the vacuum with an energy density ρ_0, the density of the latent heat released during the phase transition. If the universe suffered this transition at the temperature $T_s \ll T_c$, the latent heat released reheated the universe to a temperature $T_r \sim T_c$ and equation (1) was satisfied since then Z was $\approx T_r/T_s \approx 10^{28}$.

The inflationary character of this highly contrived model of the universe is at once evident from the solution of the first of Einstein's two cosmological differential equations (5) below. Expressed in terms of the temperature T, this equation has the form

$$(\dot{T}/T)^2 = f(T) + 8\pi G\rho_0/3 \,, \tag{2}$$

where G is the gravitational constant and f(T) is a complicated function of T which $\to \infty$ rapidly as $R \to 0$. Since $\rho_0 >> f(T)$ for temperatures close to T_s (near the zero point, owing to the supercooling), Guth neglected f(T) at the phase change and, taking the negative square root of (2), obtained

$$T(t) = \text{const} \times e^{-(8\pi G\rho_0/3)^{1/2}t} \,, \tag{3}$$

and, since RT = const,

$$R = \text{const} \times e^{(8\pi G\rho_0/3)^{1/2}t} \,, \tag{4}$$

so that the Guth model expands exponentially after the phase change. The conservation of energy is insured by placing the pressure p that appears in the second order Einstein equation (5) below equal to $-\rho_0$; the negative pressure is thus "the driving force behind the exponential expansion."[1]

I have presented this brief description of the inflationary universe to show (below) that its essential features: a cold state in its very early history (produced by supercooling); a sudden change of phase with a rapid, exponential nonadiabatic expansion and a vast increase in entropy; and a negative pressure are similar to those of the uniton-based universe I described in reference 3. However, the latter, as I show in the next section, requires no special effects such as supercooling by 28 orders of magnitude (no less an example of precise tuning than those pointed out by Guth in the standard model) and the requirement that "the universe be essentially devoid of any strictly conserved quantities."[1]

The Uniton Model of the Universe with Varying Rest Mass

In reference 3, assuming that the initial (t = 0)state of the universe consisted of a cold degenerate Fermi gas of unitons, I showed that the present expansion of the universe and its hidden mass can be explained as the result of the vast release of gravitational potential energy when 3N of the initial $N(3+10^{-17})$ free unitons combined into N baryons, leaving a residue of $N\times10^{-17}$ unitons as the hidden mass. This explosive change of phase from a degenerate Fermi gas of unitons (mass = $(\hbar c/4G)^{1/2}$) to a degenerate Fermi gas of baryons (mass = m = proton mass) leads to two simple algebraic equations for N and R_0, the radius of the universe in its initial degenerate baryon phase. The solution of these simultaneous equations, which, in addition to N and R_0 contain only the universal constants $\hbar$,c,G, and m, gives $N = 2.26\times10^{80}$.

One immediately notes that the Pauli exclusion principle requires that, long before the baryon phase was thermalized by the gravitational radiation released in this phase change, an inflationary phase occurred during which the radius of the universe expanded by a factor of the order of $(\hbar/mc)/[\hbar/(\hbar c/4G)^{1/2}c] \approx 10^{19}$, that is, by 19 orders of magnitude

To justify replacing the singularity of the standard model at t = 0 by a cold degenerate Fermi gas (a matter-dominated rather than a radiation-dominated state) I present a solution of Einstein's two cosmological equations which has been overlooked until now, but which is all important if the rest mass of the universe was drastically altered at some early stage in its history. In their simplest form Einstein's equations are

$$\begin{aligned} \dot{R}^2 + kc^2 &= (8\pi G R^2/3)[\rho + (u/c^2)] \\ \ddot{R} &= -(4\pi G/3)[\rho + 3(p/c^2 + u/3c^2)], \end{aligned} \qquad (5)$$

where the curvature parameter k = ±1 or zero, ρ is the rest-mass density of the universe, and u is its energy density, to which all forms of energy (electromagnetic, gravitational, kinetic, and neutrino) other than rest mass contribute. [See Robertson's and Noonan's discussion of this point in their RELATIVITY AND COSMOLOGY, chap. 17, pg 373 (1968) Saunders].

The second of these equations seems to indicate that an initial singularity in the standard model is unavoidable since $\ddot{R} < 0$ as long as $[\rho + 3(p/c^2 + u/3c^2)]$

is positive, a condition that is absolutely required if $p > 0$. Canuto[4] has investigated the various suggestions (other than inflation) that have been made to obtain a negative p and has rejected them as untenable. This is as it should be if our cosmological model is to remain simple, and so it would be if the rest mass of the universe were substantially constant.

Consider now the application of equations (5) to the uniton-based cold universe when it is changing from its uniton to its baryon phase, or vice versa. Differentiating the first of these equations with respect to time, with $\rho=3M/4\pi R^3$, and $u = 3U/4\pi R^3$, where M is the rapidly changing rest mass of the universe and U is its changing energy, I obtain

$$\dot{R}\ddot{R} = \frac{G}{R}\{[\dot{M} - (M/R)\dot{R}] + (1/c^2)(\dot{U} - \frac{U}{R}\dot{R})\} \quad (6)$$

so that

$$\ddot{R} = \frac{G}{R}[(dM/dR - M/R) + (1/c^2)(dU/dR - U/R)]. \quad (6a)$$

Here I divide U into two parts, U_1 and U_2, which, though little more than an energy book-keeping operation under normal conditions, as in the present epoch, is very important when the universe is undergoing a first order phase change. In such a situation, which would prevail if the universe were collapsing, with baryons being dissociated rapidly into unitons, the distinction between these two parts of U, as I define them below, is very important. I define U_1 as the amount of energy which is absorbed in the dissociation of the baryons and is just enough to create the total rest mass of the free unitons; thus U_1 does not reappear as free energy but is represented as rest mass after the phase transition. U_2, on the other hand, reappears as gravitational potential energy after it has been absorbed during the baryonic dissociation. Of course the division of U into U_1 and U_2 is not unique in any sense, for there is no way of determining (nor is it meaningful to do so) which parts of U reappear as rest mass and which as potential energy. But now the bookkeeping is important for $dU_1/dt = -dM/dt$ (M increases as U_1 decreases) whereas $dU_2/dt < 0$ as the absorption of U begins and baryonic dissociation proceeds; but then, after the baryonic dissociation has been completed,

$dU_2/dt > 0$, with U_2 reappearing first as the kinetic energy of the emerging unitons and then changing into gravitational potential energy as expansion occurs.

To simplify the physical description we may picture the entire process as occurring in two steps: 1) an amount U_1 of the total energy U is first absorbed to dissociate all the baryons into unitons at rest (no expansion); 2) the balance U_2 of U is then absorbed to produce an expansion until the total gravitational energy equals U_2 and the phase change from baryons to a uniton gas is complete (the vapor phase). During these two processes U_1 is transformed entirely into rest mass and U_2 into potential energy, that is, into available free energy. Note that U_2 first decreases and then increases.

Substituting the expression for $\ddot{R}$ from the second equation (5) into (6), I obtain

$$-\dot{R}(4\pi G/3)[\rho + (3p + u)/c^2]R = G\dot{M}/R - 4\pi G\rho R\dot{R}/3 + (\dot{U} - \frac{U}{R}\dot{R})/c^2 . \qquad (7)$$

Hence, since $dU_1/dt = -dM/c^2dt$

$$p = -dU_2/4\pi R^2 dR = -dU_2/dV, \qquad (8)$$
$$(V = \text{volume of universe}).$$

This is a remarkably simple (essentially the Helmholtz-Gibbs free energy thermodynamic equation[5] for an isothermal, reversible change of phase with change of volume dV from a liquid to a vapor) and yet profound result, for, as I show below, it gives us a singularity-free universe.

Under ordinary circumstances, such as prevail now in the universe, $dM/dR < 0$ since the rest mass (owing to stellar radiation) is slowly decreasing as the universe expands. But reversing the expansion and time, we arrive at a moment in the past when, still going back in time, a change of phase from baryons to unitons with expansion is occurring, as described above. This reverse transition is accompanied by a rapid increase in rest mass, a rapid cooling and decrease in entropy, and an expansion since the unitons, bound in the baryons are released to form a uniton vapor. Thus, if the universe were to contract at some future time to this point, its dM/dR and dU_2/dR would be positive and its p, according to (8) would be negative. We would thus obtain a negative pressure which would save the universe from the horrible fate of a singularity at $t = 0$. This natural way of introducing a negative pressure is far simpler and far more satisfying intellectual than introducing unobservable Higgs fields and a mysterious false vacuum with all their undesirable side effects.

We see, then, that although $p = 0$ and its influence on the evolution of the universe is negligible at the present time, it played a very important role in the early cosmic expansion stages, as it will in the late stages of collapse if, as I assume, $k = 1$ so that the universe is closed. Returning to equation (7) I now obtain the following important solution of Einstein's equations for $\dot{M} = 0$ (when a phase change has been completed):

$$\dot{R} = 0, \; R \neq 0. \qquad (9)$$

Since k does not appear in (7), this solution holds regardless of whether the universe is open, euclidean, or closed. Hence it can apply to the universe only when it was very young ($t = 0$). But a necessary condition for $\dot{R} = 0$ is that $\ddot{R} > 0$ at some time in the universe's early history, and (6a) tells us that this condition is met if

$$d(Mc^2 + U)/dR = f(Mc^2 + U), \quad f > 1. \qquad (10)$$

This eliminates the singularity at $t = 0$.

Another conclusion can be drawn from (6) if we go back in time to the epoch when a reverse change of phase is occurring from a baryon, radiation-dominated state of the universe to a uniton, matter-dominated state so that $\dot{M}$ and $\dot{R}$ are both negative (an expansion, with absorption of radiation) and $dM/dR > 0$. This reverse change of phase will continue until $\dot{M} = 0$, and then (6) tells us that $\ddot{R} < 0$ so that R is a maximum. We may define this as the initial state of the universe at $t = 0$, since it is the state of minimum entropy.

Since we have no general relativistic quantum equation of state for an ensemble of "free" unitons in a strong gravitational field, we can only speculate as to the order of events that led from this initial state to the "big bang". I can beg the question by stating, in a very general way, that the reverse of what I described above occurred: a first order change of phase from unitons to baryons (an implosion) with the release of a vast amount of latent heat (the big bang) followed by an expansion. But such a broad statement covers a number of subtle points that should be elucidated. Thus it is not immediately clear how the collapse that led to the uniton → baryon phase change was halted; only if $\ddot{R}$ became positive at some stage during the collapse could $\dot{R}$ have become positive.

Suppose, now, that this initial uniton phase had first contracted to a more compact cold state with a very small rate of change of its rest mass ($dM/dR \ll M/R$); a critical phase change rather than a first order one so that $\ddot{R}$ was negative even though the pressure was negative. We may picture this collapse as having proceeded until the unitons began to coalesce into baryons so rapidly that dM/dR exceeded M/R and $\ddot{R}$ became positive. We may picture dM/dR as having reached its maximum value when the uniton phase had collapsed down to a cosmic nucleus with $R = (3N)^{1/3}\hbar/m_u c$ (m_u = uniton mass) and with $\ddot{R} \gg 0$. With this accelerated phase transition to baryons the collapse was halted and $\dot{R}$ became positive; at that point the Pauli exclusion principle played its inflationary role and R expanded to the value $N^{1/3}\hbar/mc$. From then on the universe expanded normally (that is with $\dot{M} = 0$) to its present state.

Returning now to equation (10) we see that if f had been constant during the phase-changing collapse M and R would have been related by the equation

$$(Mc^2 + U) = (M_o c^2 + U_o)(R/R_o)^f \,, \tag{11}$$

where M_0 and R_0 were the initial rest mass and radius, respectively. But f is certainly a complicated function of M and R during a first-order phase change such as described above, so that (11) holds only in a short interval for a given f. Nevertheless (11) is important because it shows us the direction of of the phase change: an expansion gives an increase in M and a collapse (a condensation) results in a decrease.

Since MR^{-f} is constant if f is constant, one can rewrite (11) as an exponential equation for R as a function of t by introducing the mean life τ of a uniton triplet against decay into a baryon:

$$R = R_0 e^{-t/f\tau} . \quad (12)$$

For t positive, this represents a collapse and for t negative (regressing in time) an expansion. In connection with this it is interesting to note that if the decay of uniton triplets into baryons involves the emission of quadrupole gravitational radiation, as it must according to my point of view, then $1/\tau f$ can be expressed in terms of universal constants and the density ρ_0 of the gravitational quadrupole as it is radiating, and we have

$$R = \text{const} \times e^{-(8\pi G\rho_o/3)^{1/2}t} . \quad (13)$$

This is to be compared with Guth's equation (4).

The "Flatness" and the "Horizon" Problems

In the standard, hot, big-bang cosmological model the flatness problem arises because at the time $t = 10^{-38}$sec, when the kT of the universe, according to this model was 10^{17}GeV, the density parameter $|\rho - \rho_{cr}|/\rho$ was $< 10^{-55}$, where ρ_{cr} is the critical density. This means that $\Omega \equiv \rho/\rho_{cr} \approx 1$ to within 55 orders of magnitude and remained so over an expansion time of billions of years. Such a close agreement between these two densities required such a concordance of cosmological parameters initially (so-called "fine tuning")as to be unacceptable. Guth shows that his equation (1), with $Z \approx 10^{27}$ rids his inflationary model of the flatness problem because the density parameter defined above contains Z^2 as a factor so that this parameter is increased by 54 orders of magnitude; thus the density parameter is ≈ 1 and $\Omega^{-1} \approx 0$.

This flatness problem or "puzzle" does not arise in the uniton-based model because ρ_{cr}, obtained from the first of Einstein's equations (5), equals $(3R^2\dot{R}/8\pi G)$. Thus it was of the order of 0 initially since $\dot{R}(0) = 0$. But at that moment ρ was >> 1 so that the density parameter defined above was = 1.

The horizon problem falls by the wayside also. The puzzle presented by this problem stems from the ineluctable conclusion drawn from the standard model that the volume of space encompassed by the physical horizon (the distance traveled by a light pulse in the time t) was some 83 orders of magnitude smaller than the volume of space encompassed by the expansion of the universe if t was its age when its $kT = 10^{17}$ GeV. The standard model universe thus consisted of 10^{83} causally disconnected regions, all of which, without in any way being able to confer with each other, evolved into our present homogeneous universe. Equation (1) also rids Guth's infldtionary universe of this problem because the large Z factor it defines reduces the expansion volume below that of the physical horizon volume of the universe.

That the uniton-based model does not suffer from the horizon malady is obvious from its initial conditions. At t = o, when $\dot{M}$ and $\dot{R} = 0$, the universe is a completely homogeneous, cold ensemble of free unitons with all the unitons interrelated gravitationally. With $\dot{M} \neq 0$ and $\dot{R} < 0$, as the uniton phase gives way to the baryon phase, all parts of the collapsing universe certainly remain causally connected via the emitted radiation since the horizon volume is always greater than the collapsing volume. When the first-order phase transition is completed, the radiation is uniformly distributed among all the baryons and there are no causally disconnected regions; the present homogeneity of the universe is thus explained in a simple, direct way.

Summary and Conclusions

I have shown that if unitons (the uniton is the basic gravitational charge $(\hbar c/4)^{1/2}$) exist and are identified with the Gell-Mann quarks, then these particles must have been the primordial constituents of the universe. The big bang can then be identified with the vast release of energy (heat of condensation) that stemmed from the non-adiabatic phase change from a cold Fermi ensemble of unitons to a Fermi ensemble of baryons. Since this entailed a decrease in the rest mass of the universe by 19 orders of magnitude, the integration of Einstein's cosmological equations during this phase change must take into account $\dot{M}$, the rate of change of the rest mass of the universe. This has not been done until now because the standard model (the starting point of all current treatments) assumes an initially radiation-dominated universe, with its permanent matter already in baryon form. With this assumption a singularity at $t = 0$ is inevitable.

If, however, a vast change in the rest mass of the universe occurred at some time in the past, another solution of Einstein's equations exists for which $\dot{R}(0) = 0$ and $R(0) \neq 0$, so that there is no singularity at $t = 0$. According to this solution the pressure p in Einstein's second order differential equation is given by $-(c^2/4\pi R^2)dM/dR$; it is thus negative when $dM/dR > 0$, and this happens during a phase change from baryons to unitons (expansion with an increase of mass) and from unitons to baryons (collapse with a decrease of mass). During these phase changes M and R are related by the equation $MR^{-f} = \text{const.}$, where $f > 1$, and $R(t) = R_0 e^{-t/\tau f}$, where τ is the mean life of a uniton triplet against decay into a baryon.

If we accept the principle that unphysical concepts such as singularities must be eliminated from theoretical models that are designed to describe nature, we must accept concepts that enable us to do so as long as these do not violate any natural law or basic principle. This, then, forces us to accept events during the early history of the universe for which $\dot{M}$ was large. But this means that a change of phase must have occurred from a gas of very massive particles (unitons) to very small mass triplet combinations of such particles, that is, baryons. This in itself gives strong support to my assertion that tho Gell-Mann quarks are unitons.

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