CA

IUCAA - 22/94

July, 94

The Basic Theory Underlying the Quasi-Steady State Cosmology

By

F. Hoyle, G. Burbidge and J.V. narlikar

Inter-University Centre for Astronomy & Astrophysics

An Autonomous Institution of the University Grants Commission

Preprint Request (Please quote the preprint number)
email : preprn@iucaa.ernet.in
Fax : 0212 - 335760
Post : IUCAA, Post Bag 4, Ganeshkhind, Pune 411 007, India.

THE BASIC THEORY UNDERLYING THE QUASI-STEADY STATE COSMOLOGY

F. Hoyle[1], G. Burbidge[2], and J.V. Narlikar[3]

[1]102 Admirals Walk, Bournemouth BH2 5HF Dorset, England

[2]Center for Astrophysics and Space Sciences and Department of Physics, University of California, San Diego, La Jolla, California 92093-0111, U.S.A.

[3]Inter-University Centre for Astronomy and Astrophysics, Post Bag 4, Ganeshkhind, Pune 411 007, India

Abstract

Outside cosmology, the procedure normally followed is science requires the integration of hyperbolic partial differential equations subject to initial data given on a free surface, which is usually taken to be a time section of spacetime. The initial data are determined in experimental science from observation and the results of the integrations are also checked by observations. Friedmann (Big Bang) cosmology suffers, however, from the fact that the observations cannot determine initial conditions. Thus in that theory the initial conditions have only the weak status of guesses.

There is also some question whether the correct equations are being used, since the gravitational equations of that cosmology are not scale invariant, a situation unlike the rest of physics. Since matter exists in what is supposed to be a space of finite temporal duration its origin should be explained, working from a suitable lagrangian and action. Otherwise the origin is placed outside science. This is what is done in Big Bang Cosmology.

In this paper we depart from the standard procedure by first deriving gravitational equations that are scale invariant, whence it is shown that in a scale invariant gravitational theory particles have the property that the two lengths associated with them, the Compton wavelength and gravitational radius, must be comparable, i.e. they are Planck particles. It is then shown that the theory has the scope to explain the genesis of the so-called cosmological constant, and the usually required magnitude of the cosmological constant is derived.

When interactions other than gravitation are included, Planck particles are unstable. The effect of instability on newly-created Planck particles is to introduce terms into the gravitational equations additional to those of general relativity. In particular, there are negative pressure terms which act to expand the universe. The energy terms are such as to suggest that particle creation must be of an explosive nature and that it must occur in the neighbourhoods of highly compacted bodies, a property which appears to provide a connection between cosmological theory and high-energy astrophysics.

1. The case for and against Big-Bang Cosmology

The words "cosmology" and "astrophysics" are widely used without any precise determination of a boundary between them being offered. Here we use the tentative definition that cosmology refers to a study of those aspects of the universe for which spatial isotropy and homogeneity can be used, with the spacetime metric taking the form

$$ds^2 = dt^2 - S^2(t)\left[\frac{dr^2}{1-kr^2} + r^2(d\theta^2 + sin^2\theta d\phi^2)\right] \tag{1}$$

in terms of coordinates t, r, θ, ϕ with $r = 0$ at the observer. The topological constant k in this so-called Robertson–Walker form can be shown to be 0 or ± 1. The "particles" to which (1) applies are thought of as galaxies or clusters of galaxies, each "particle" having spatial coordinates r, θ, ϕ independent of the universal time t. They form, what is often referred to as the Hubble flow. But with "particles" considered in more detail, as stars, or as atoms, or as elementary particles, and with fine-scale inhomogeneities and deviations from isotropy permitted we are in the realm of astrophysics.

Big-Bang cosmology in all its forms is obtained from the equations of general relativity,

$$R_{ik} - \frac{1}{2}g_{ik}R + \lambda g_{ik} = -8\pi G T_{ik}, \tag{2}$$

which follow from the variation of an action formula

$$\mathcal{A} = \frac{1}{16\pi G}\int_V (R + 2\lambda)\sqrt{-g}d^4x + \int_V \mathcal{L}_{phys}(X)\sqrt{-g}d^4x \tag{3}$$

with respect to a general Riemannian metric

$$ds^2 = g_{ik} dx^i dx^k \tag{4}$$

within a general spacetime volume V. The physical Lagrangian $\mathcal{L}_{phys}(X)$ generates the energy-momentum tensor T_{ik} in this variation of g_{ik}. In so-called standard Big-Bang cosmology the physical lagrangian includes only particles and the electromagnetic field, whereas in inflationary forms of Big-Bang cosmology a scalar field is also considered to be added to $\mathcal{L}_{phys}$. This is done in various ways, with the various ways referred to as scenarios and with them being severally advocated by different authors (see Narlikar and Padmanabhan 1991 for a review). They have in common that they are fields without sources and are considered to be explained by describing them as false vacuum, although whether a field without physical sources can be conjured by calling it a vacuum is a matter of opinion.

The action $\mathcal{A}$ associated with the spacetime volume V is a dimensionless number, as are the components of the metric tensor g_{ik}. This requires $L_{\rm phys}$ to have dimensionality $(\text{length})^{-4}$, a situation that is achieved by taking the Compton wavelength of some chosen form of particle as the unit of length. The scalar curvature R is of dimensionality $(\text{length})^{-2}$ and so must be the constant λ, as must also be the reciprocal of the constant G. This is already a strange feature of so-called standard theory. It is strange to have constants with physical dimensionalities appearing in what is supposed to be fundamental theory. It is doubly strange to have two of them, and it is triply strange that they are enormously different in magnitudes. In its usual applications λ is less than G^{-1} by a dimensionless number of order 10^{-120}. When at a later stage we come to what we regard as a more basic theory than the above we shall attempt to explain the origin of both G and λ.

The action $\mathcal{A}$ must be dimensionless from the requirements of quantum mechanics, according to which $\exp i\mathcal{A}$ is the probability amplitude for the occurrence of the particular configuration of fields and particles used in the evaluation of $\mathcal{A}$. The total probability amplitude from which average values are to be computed is given by

$$\sum_{\text{configurations}} \exp i\mathcal{A}. \tag{5}$$

However, in an effectively classical situation only those configurations close to that for which the principle of least action, $\delta\mathcal{A} = 0$, is satisfied with respect to all possible variations of the configurations add systematically in the summation. The rest cancel each other. It is this which leads to the equations (2). Applying these equations when the metric has the special form of (1) gives a result of the form

$$\frac{\dot{S}^2 + k}{S^2} = \frac{A}{S^3} + \frac{B}{S^n} + \frac{1}{3}\lambda, \tag{6}$$

in which the A/S^3 term with $A > 0$ arises from particles and B/S^n from fields, with $n = 4$ for the electromagnetic field and $B > 0$ for all positive energy fields. At small S

$$\frac{\dot{S}^2}{S^2} \simeq \frac{A}{S^3} + \frac{B}{S^n} \tag{7}$$

and with $A, B > 0$, $\dot{S}$ evidently $\to 0$ at some finite time, which can be taken as the zero of t, $t = 0$. This is the Big-Bang.

The initial conditions assumed in the standard model are :

(i) The universe was sufficiently homogeneous and isotropic at the outset for the metric (1) to be used immediately over a range of the r-coordinate of relevance to presentday observation,

(ii) $k = 0$,

(iii) $\lambda = 0$,

(iv) The initial balance of radiation and baryonic matter was such that the light elements D, ^{3}He, ^{4}He, ^{7}Li were synthesised in the early universe in the following relative abundances to hydrogen

$$\frac{D}{H} \simeq \frac{{}^3He}{H} \simeq 2 \times 10^{-5}, \frac{{}^4He}{H} \simeq 0.235, \frac{{}^7Li}{H} \simeq 10^{-10}.$$

From detailed calculations these abundances can be shown to require

$$\rho_{\mathrm{baryon}} \simeq 10^{-32} T^3 \ \mathrm{gcm}^{-3}, \tag{8}$$

the radiation temperature being in degrees kelvin. (Gamow 1946, Alpher, et al 1950, 1953, Hoyle and Tayler 1964).

While the need for such far reaching assumptions as (i) to (iv) has always prompted a measure of unease they were widely accepted for a decade and a half, and are indeed still fully accepted by the more orthodox supporters of the standard model. Others, however, welcomed the inflationary idea of including a scalar field in the physical lagrangian that initially dominated both matter and other fields and which varied adiabatically in such a way as to give

$$\frac{\dot{S}^2}{S^2} = C, \quad S(t) = S(0) \exp \sqrt{C} t, \tag{9}$$

with C a constant. The solution (9) is considered to apply from $t = 0$ to a value of t large compared to $1/\sqrt{C}$. It greatly reduces the range of the r-coordinate over which (i) is needed and it effectively removes the k-term from (6). It also removes any initial contributions to (6) from matter and radiation, but these are considered to be reasserted through a physical transition of the scalar field, which jumps the equation for $\dot{S}^2/S^2$ from (9) to

$$\frac{\dot{S}^2}{S^2} = \frac{A}{S^3} + \frac{B}{S^4}, \tag{10}$$

the A term being due to matter and the B term due to radiation. The magnitude of terms on the right-hand side of (10) is taken to correspond to the requirement (iv), so that only (iii) remains to be assumed. Then as S continues to increase, the radiation term in (10) eventually becomes unimportant and

$$\dot{S}^2 = \frac{A}{S}, S \simeq \left(\frac{9}{4}A\right)^{\frac{1}{3}} t^{\frac{2}{3}}, \tag{11}$$

which is the so-called closure model with matter just having sufficient expansion to reach a state of infinite dispersal, a condition that is considered most favourable for the eventual formation of stars and galaxies.

At this stage the standard inflationary scenario begins with primordial density fluctuations which are supposed to grow with time. The observational constraints to be satisfied are (i) the observed fluctuations of temperature in the microwave background and (ii) the observed large scale motions of galaxies in our neighborhood. Despite several epicyclic efforts invoking cold dark matter, hot dark matter, a mixture of the two, biasing, etc. as yet no working scenario for structure formation has emerged (for a review see: Padmanabhan 1993). Nor has any experimental verification been available for the super-symmetric particles that are believed to make up the CDM or HDM.

It is worth pausing briefly to consider the basic methodology of classical physics. It consists largely in the solution of hyperbolic partial differential equations subject to stated boundary conditions on some spacelike free surface, which is almost always taken to be a time section of spacetime. Unlike cosmology, where initial conditions are needed over an entire time section, with laboratory investigations the relevant initial conditions extend only over small elements of free surfaces, permitting them to be determined directly by observation. The differential equations are then integrated to future time sections and the calculated results are again compared with observation. This procedure is used in research as a means of verifying the accuracy of the physical laws. In applied science, where the laws are assumed to be correct, it is used to produce wanted practical results. But in Big-Bang cosmology it cannot be used at all, because initial conditions over an entire time section, following closely after the Big-Bang itself, are not susceptible to observational determination.

This inability of observations to extend back in time to the early universe is not just a matter of instrumental limitations, it is inherent. Because the present day observer is necessarily limited to what in cosmological terms are data acquired along a single light cone, which is to say a single characteristic surface, and data acquired down a characteristic surface do not provide suitable initial conditions for the solution of hyperbolic partial differential equations.

Big-Bang cosmology is therefore obliged to proceed from initial conditions that are guesses, as for instance the relation (8) is a guess. Nevertheless, it may happen that a guess made on a time-section shortly after the Big-Bang has multiple, apparently distinct, consequences in the present day world, as (8) does. Putting $T = 2.73$ K for the present day radiation temperature, (8) gives $\rho_{\mathbf{baryon}} \simeq 2.10^{-31}$g cm^{-3} for the average present day baryonic density in the universe, a requirement where Big-Bang cosmology couples to the observed relative abundances of D, ^{3}He, ^{4}He and ^{7}Li. In the standard model, the closure condition demands a present day total universal density of $\sim 10^{-29}h^2$g cm^{-3}, the Hubble constant defined by the present day value of $\dot{S}/S$ being written as $100h$ km s^{-1}mpc^{-1}. Although h remains moderately uncertain – it is considered to lie in the range $0.5 \leq h \leq\sim 1$ – the uncertainty is not sufficient to lower $\sim 10^{-29}h^3$ g cm^{-3} to the value $\rho_{\mathbf{baryon}} \sim 3.10^{-31}$ g cm^{-3} required by (8). This has led to the prediction that 90% or more of the material in the universe is not of baryonic form, thereby generating a problem of identification of interest to particle physicists.

It has for long been known that the visible stellar material in galaxies contributes $\sim 3.10^{-31}h^2$ g cm^{-3} to the mean density of the universe (van den Bergh, 1961). This stellar material lying within distances ~ 15 kpc of the centres of galaxies, gave a value so close to the baryonic value of 2.10^{-31}g cm^{-3} as to apparently give strong support to the standard model, despite the basis of the agreement being the assumption rather than the proof of (8). The view gained ground that the baryonic component was stellar and visible, while the much larger non-baryonic component was non-luminous and so "dark", a view that acquired further credibility when astrophysical evidence showed that the halos of galaxies, extending to distances ~ 50 kpc from galactic centres, contained two to three times more material than the inner luminous stellar regions, so that halo material was also considered to be "dark". Since our own galaxy possesses such a dark halo, and since halo material would be expected to penetrate also into the inner stellar distribution, including the solar system, it was felt that the particles comprising the unknown dark material were immediately on hand to a terrestrial observer, and so potentially detectable.

One could argue that *assuming* the cosmological principle, our observations along the past light cone tell us what the universe was like along any past

t = constant hypersurface, and one can establish consistency of those "initial conditions" with the present state of the universe, using physical laws. This procedure does not, however, work for the big bang cosmology for $t <$ the recombination epoch. No direct observation of the universe prior to this epoch is possible. One therefore is forced to extrapolate the model as well as physical laws to epochs approaching the GUT and Planck epochs. In this process neither the initial conditions are well defined and observable nor is the set of physical laws testable in the laboratory. The best one can hope for is a self consistent scanario that combines the extrapolations in cosmology and particle physics with the observed features of the present state of the universe. The nature of dark matter is one example.

This argument is about two decades old and it has not so far yielded positive results. While particle physicists have been particularly enthusiastic about the possibility of detecting non-baryonic matter, most astrophysicists have speculated that the dark halo material was simply stars or large planets with masses too small to be perceptible as luminous objects, either individually or as a diffuse background. The development in recent years of the concept of microlensing of distant luminous starlike sources by intervening small bodies led to the suggestion (Paczynski, 1986) that, if such baryonic bodies account for the mass of the galactic halo their effect might be observed against the dense starfield of the Large Magellanic Cloud. Two reports on possible detection of dark stars using this technique have appeared recently (Alcock et al 1993, Aubourg et al 1993). Although as yet there appear to be only three microlensing cases there would need to be a very large number of small bodies involved as foreground objects for even three cases to have occurred in the limited time frame of these observations. As is unfortunately the situation in much of astrophysics the position is ambiguous. From the several weeks duration of the microlensing events it can be deduced that the lensing objects could either be small stellar masses, $\sim 0.1 M_{\odot}$ in the galactic halo, or still smaller planetary masses in the galactic disk. The observations do not decide which. Nevertheless, it is impressive that a relatively simple observation should quickly lead to a positive result, whereas the attempts over almost 20 years to identify a mysterious non-baryonic form of particle have as yet led nowhere. Nor have other assumptions besides (S) for the initial conditions been shown to lead to multiple detectable consequences. Hence (S) remains the main support of the theory.

Supporters of the Big-Bang (see, for example, Peebles et al 1991) have sought to advance their position by arguing that no viable cosmological alternative exists, as if to say : "We know that our theory may have weaknesses but since nothing else exists what we say must be correct by default." The existence of the microwave background is the example usually offered of a phenomenon without alternative explanation. Yet even from the late 1960's this was not true. With $\sim 3.10^{-31}$g cm^{-3}

as the average density of stellar material, the corresponding average universal density of ^{4}He, $\sim 3.10^{-31} Y$g cm^{-3} is $\sim 7.5 \times 10^{-32}$g cm^{-3}, with $Y \simeq 0.25$ the mass fraction of helium in stellar material. The energy obtained at $\sim 6.10^{18}$erg g^{-1} would therefore be 4.5×10^{-13} erg cm^{-3} in deriving this helium from hydrogen, which would yield a radiation field of temperature ~ 2.78 K, if thermalised. Unlike (8), which is written down as an assumption, this derivation, although highly abbreviated here, can be seen to offer the possibility of a logical scientific explanation for the background.

Against this possibility it was claimed that the projected thermalisation was not possible, because no form of thermalising particle could have the high opacity needed at wavelengths ~ 1 mm, without intergalactic radiation at other wavelengths being blocked and so failing to reach the observer in an observable way. This claim was surely advanced without much of an effort being made to discover whether it was true or not, since there was already laboratory evidence of such a particle in the metallurgical literature, in the form of metallic whiskers (for example Nabarro and Jackson, 1958). Table 1 gives mass absorption values at cryogenic temperatures at various wavelengths at various lengths and for iron whiskers standardised to a diameter of $0.02 \mu m$. Opacity curves for mixtures of iron whiskers can be constructed from this table, when it is readily seen that mixtures possessing very high microwave opacity and yet with low optical and long-wave radio opacities are easily obtainable.

Table 1

DC–CONDUCTIVITY = 6.90E18

WL (MU)	Mass Absorption Coefficient (cm^2 g^{-1}) LENGTH = 1000	500	300	200	100	$50\mu m$
1.00E0	1.86E3	1.86E3	1.86E3	1.86E3	1.86E3	1.86E3
2.00E0	5.00E3	5.00E3	5.00E3	5.00E3	5.00E3	5.00E3
3.00E0	9.24E3	9.24E3	9.24E3	9.24E3	9.24E3	9.24E3
5.00E0	2.04E4	2.04E4	2.04E4	2.04E4	2.04E4	2.04E4
1.00E1	6.00E4	6.00E4	6.00E4	6.00E4	6.00E4	6.00E4
2.00E1	1.72E5	1.72E5	1.72E5	1.72E5	1.72E5	1.72E5
3.00E1	3.19E5	3.19E5	3.19E5	3.19E5	3.19E5	3.19E5
5.00E1	7.12E5	7.12E5	7.12E5	7.12E5	7.12E5	7.12E5
1.00E2	2.21E6	2.21E6	2.21E6	2.21E6	2.21E6	2.21E6
2.00E2	6.89E6	6.89E6	6.89E6	6.89E6	6.89E6	1.01E6
3.00E2	1.30E7	1.30E7	1.30E7	1.30E7	5.81E6	4.49E5
5.00E2	2.68E7	2.68E7	2.68E7	2.42E7	2.14E6	1.62E5
1.00E3	5.73E7	5.73E7	2.73E7	6.99E6	5.39E5	4.04E4
2.00E3	8.88E7	3.96E7	8.11E6	1.82E6	1.35E5	1.01E4
3.00E3	8.54E7	2.13E7	3.73E6	8.14E5	6.00E4	4.49E3
5.00E3	5.50E7	8.63E6	1.37E6	2.94E5	2.16E4	1.62E3
1.00E4	2.06E7	2.27E6	3.45E5	7.37E4	5.40E3	4.04E2
2.00E4	5.89E6	5.76E5	3.65E4	1.84E4	1.35E3	1.91E2
3.00E4	2.69E6	2.57E5	3.84E4	8.19E3	6.00E2	4.49E1
5.00E4	5.81E5	9.28E4	1.38E4	2.05E3	3.16E3	1.62E1
1.00E5	3.47E5	2.32E4	3.46E3	7.37E2	5.40E1	4.04E0

It can be shown that thermalisation is complete at all wavelengths except at the long wavelength end ($\lambda \gtrsim 20$ cm) where the galactic contribution also becomes significant (Hoyle et al 1994a). The observed spectrum of the microwave background is claimed to be Planckian, although the error bars on the effective temperature become large at long wavelengths. Thus the present observations and the above theory are mutually consistent.

2. Scale invariant gravitational equations

General relativity is known to give an accurate description of gravitational phenomena in the limit of weak gravitational fields. However, there is no evidence, either experimental or observational, to show the precise quantitative correctness of general relativity for strong gravitational fields. Thus Big-Bang cosmology is engaged in working from assumed initial conditions according to a law for which there is no clear evidence. It is hardly necessary, therefore, to make a case for attempting to do something better. We start from what we consider to be a major defect of general relativity, that it is not scale invariant, unlike the rest of physics.

We are well-used to physical results being independent of the units in which quantities are expressed. This is because results are always dimensionless numbers. This usual situation is for units that stay the same at every spacetime point X. But should anything in physics be altered if units were changed differently at different spacetime points? Using the Compton wavelength of some specified particle as the length unit, and noting that $c = 1$ requires the time and space units to be the same, this question can be discussed by a general change of the length scale achieved by transforming from $ds^2 = g_{ik}dx^i dx^k$ to

$$ds^{*2} = \Omega^2(x) g_{ik} dx^i dx^k. \tag{12}$$

In such a transformation the spacetime coordinates of points on the path of a particle stay fixed. It is the proper distance between adjacent points that changes according to the choice of the twice differentiable scalar function $\Omega(X)$. Experiments confined to a locality over which Ω does not change appreciably will evidently be unaffected. It is possible, however, for events in one locality to be related to distant localities through the propagation of some field, for example the electromagnetic field. The possibility that physics will be unaffected by $\Omega(X)$ even for observations related to widely-separated localities is suggested by the circumstance that light-cones are not affected by the transformation (12), provided Ω is restricted to the so-called conformal condition $\Omega \neq 0$. And indeed Maxwell's equations are invariant with respect to (12), with the electromagnetic field tensor unchanged,

$$F^*_{ik} = F_{ik}, \tag{13}$$

and with $A^*_i = A_i$ followed by a suitable gauge transformation leaving the wave-equation for the 4-potential also invariant.

Since the coordinate positions of particles remain unchanged, the number of particles counted in a specified 3-dimensional coordinate volume must be unaltered, despite the proper 3-dimensional volume being changed by Ω^3. Because $|\psi|^2$ measures particle probabilities per unit proper 3-volume, the wave function ψ in quantum mechanics is therefore required to transform from ψ to ψ^* according to

$$\psi^* = \Omega^{-3/2}\psi. \tag{14}$$

Moreover, the spatial coordinate distance between two particles remains unchanged whereas the proper distance is altered by Ω. Since the Compton wavelength m^{-1} of some standard particle measures the latter, it is necessary for m to transform to m^* according to

$$m^* = \Omega^{-1}m. \tag{15}$$

The number of Compton wavelengths separating two particles then remains the same. This inference can be tested strictly by considering the behaviour of the Dirac equation

$$i\gamma^k \frac{\partial \psi}{\partial x^k} + m\psi = 0. \tag{16}$$

under the transformations (12), (14) and (15). To this end it is necessary firstly to generalise (16) to Riemannian space, writing

$$i\gamma^k \psi_{;k} + m\psi = 0 \tag{17}$$

in place of (16), with non-Euclidean terms entering into the covariant derivative of ψ (see, for example, Hoyle and Narlikar, 1974, p. 149). A demonstration of the invariance of the Dirac equation, i.e., the transformation to

$$i\gamma^{*k}\psi^*_{;k} + m^*\psi^* = 0 \tag{18}$$

can then be given (Hoyle and Narlikar, 1974, p. 254).

With quantum mechanics invariant to (12), subject to (14) and (15), and with the electromagnetic field also invariant, quantum electrodynamics is invariant. More recent developments in physics concerned with abstract particle spaces are also considered to be scale invariant. So why should gravitation be the only aspect of physics that is not? We think the first step towards a better understanding of cosmology is to remedy this deficiency, which we shall now proceed to do.

It is necessary to begin by finding an action $\mathcal{A}$ that is unaffected in its value by a scale transformation. The second term on the right-hand side of (3) satisfies this requirement. For a set of particles $a, b, \ldots$ of masses $m_a, m_b, \ldots$ the form of $\mathcal{L}_{\text{phys}}$ usually considered in gravitational theory is

$$\sum_{a,b,\ldots} \int \frac{\delta_4(X, A)}{\sqrt{-g(A)}} m_a(A)da, \tag{19}$$

where the possibility of the particle masses varying with the spacetime position requires the mass $m_a(A)$ of particle a to vary with the point A on its path, and similarly for the other particles. Hence the second term on the right-hand side of (3) is

$$-\sum_a \int m_a(A)da. \tag{20}$$

With $da^* = \Omega da$ and $m_a^* = \Omega^{-1} m_a$ it is clear that (20) is invariant with respect to a conformal (scale) transformation. On the other hand it can be shown that (Hoyle and Narlikar, 1974, p. 28)

$$R^* = \Omega^{-2}(R + 6\Omega^{-1}\Box\Omega) \tag{21}$$

and it is equally clear that the first term on the right-hand side of (3) is not invariant, the trouble evidently coming from this first term. Since one can already remark on the artificial appearance of (3), in its strange combination of physical and geometrical quantities, it is surely here that a change must be made. Investigation shows that an attempt to replace the geometrical integral in (3) by some other geometrical quantity does not succeed, leaving

$$\mathcal{A} = -\sum_a \int m_a(A)da \tag{22}$$

as seemingly the only possibility, a possibility that is startling in its simplicity. The gravitational equations are to be obtained in the usual way, by making a slight change of the metric tensor, $g_{ik} \to g_{ik} + \delta g_{ik}$, in a general 4-dimensional volume with $\delta g_{ik} = 0$ on the boundary of the volume. The outcome can be written in the form

$$\delta\mathcal{A} = -\frac{1}{2}\int [T^{ik} + (?)]\delta g_{ik}\sqrt{-g}d^4x, \tag{23}$$

where the energy-momentum tensor T^{ik} has its usual form,

$$T^{ik}(X) = \sum_a \int m_a(A)\frac{\delta_4(X, A)}{\sqrt{-g(A)}}\frac{da^i}{da}\frac{da^k}{da}da, \tag{24}$$

and (?) is a tensor whose form is determined by the properties of the masses of the particles, by the variations of $m_a(X), m_b(X), \ldots$ with respect to spacetime position. The gravitational equations following from the principle of stationary action, $\delta\mathcal{A} = 0$ for all δg_{ik}, are simply

$$T^{ik} + (?) = 0. \tag{25}$$

Now choose a "mass field" $M(X)$ to satisfy

$$\Box_X M(X) + \frac{1}{6} R M(X) = \sum_a \int \frac{\delta_4(X, A)}{\sqrt{-g(A)}} da. \tag{26}$$

Equation (26) has both advanced and retarded solutions. We particularize an advanced solution $M^{\text{adv}}(X)$ and a retarded solution $M^{\text{ret}}(X)$ in the following way. $M^{\text{ret}}(X)$ is to be the so-called fundamental solution in the flat spacetime limit (Courant and Hilbert, 1962). This removes for $M^{\text{ret}}(X)$ the ambiguity that would obviously arise from the homogeneous wave equation. The corresponding ambiguity for $M^{\text{adv}}(X)$ is removed by the physical requirement that fields without sources are to be zero. Since

$$\Box[M^{\text{adv}} - M^{\text{ret}}] + \frac{1}{6} R [M^{\text{adv}} - M^{\text{ret}}] = 0, \tag{27}$$

the immediate consequences of this boundary condition is that $M^{\text{adv}} - M^{\text{ret}}$, being without sources, must be zero, so that

$$M^{\text{adv}}(X) = M^{\text{ret}}(X) = M(X) \text{ say}. \tag{28}$$

The gravitational equations are now obtained by putting

$$m_a(A) = M(A), \quad m_b(B) = M(B), \ldots \tag{29}$$

The tensor (?) can then be determined and it can also be shown that in a conformal transformation the mass field $M(X)$ transforms as in (15),

$$M^*(X) = \Omega^{-1}(X) M(X), \tag{30}$$

a result that follows from the form of the wave equation (26) (c.f. Hoyle and Narlikar, 1974, 111). The outcome (*loc. cit.*, 112 *et seq*) is

$$K(R_{ik} - \frac{1}{2} g_{ik} R) = -T_{ik} + M_i M_k - \frac{1}{2} g_{ik} g^{pq} M_p M_q + g_{ik} \Box K - K_{;ik}, \tag{31}$$

where

$$K = \frac{1}{6} M^2. \tag{32}$$

These gravitational equations are scale invariant. It may seem curious that from a similar beginning, (20) for the action rather than (3), the outcome is more complicated, but this seems to be a characteristic of the physical laws. As the laws are improved they become simpler and more elegant in their initial statement but more complicated in their consequences.

Now make the scale change

$$\Omega(X) = M(X)/\tilde{m}_0, \tag{33}$$

where $\tilde{m}_0$ is a constant with the dimensionality of $M(X)$. After the scale change the particle masses simply become $\tilde{m}_0$ everywhere and in terms of transformed masses the derivative terms drop out of the gravitational equations. And defining the gravitational constant G by

$$G = \frac{3}{4\pi\tilde{m}_0^2}, \tag{34}$$

the equations (31) take the form of general relativity

$$R_{ik} - \frac{1}{2}g_{ik}R = -8\pi G T_{ik}. \tag{35}$$

It now becomes clear why the equations of general relativity are not scale invariant. These are the special form to which the scale invariant equations (31) reduce with respect to a particular scale, namely that in which particle masses are everywhere the same.

It is also clear that the transition from (31) to (35) is justified provided $\Omega(X) \neq 0$ or $\Omega(X) \neq \infty$. For example, if $M(X) = 0$ on a spacelike hypersurface the above conformal transformation breaks down. It is because of the existence of such time sections that the use of (35) leads to the (unphysical) conclusion of a spacetime singularity. It has been shown [Hoyle and Narlikar 1974, Kembhavi 1979] that the various spacetime singularities like that in the big bang or in a black hole collapse arise because of the illegitimate use of (35) in place of (31).

3. Planck particles

It is easily seen from the wave equation (26) that $M(X)$ has dimensionality $(\text{length})^{-1}$, and so has $\tilde{m}_0$. Units are frequently used in particle physics for which both the speed of light c and Planck's constant $\hbar$ are unity and in these units mass has dimensionality $(\text{length})^{-1}$. If we suppose these units apply to the above discussion then from (34)

$$\tilde{m}_0 = (3/4\pi G)^{1/2}, \tag{36}$$

which with $c = \hbar = 1$ is the mass of the Planck particle. This suggests that in a gravitational theory without other physical interactions the particles must be of mass (36), which in ordinary practical units is about 10^{-5} gram, the empirically determined value of G being used. This conclusion can be supported at greater length.

The action (20) from which the theory is derived is a dimensionless number obtained by counting the number of units $\tilde{m}_0^{-1}$ there are along portions of the paths of all the particles within some chosen 4-dimensional volume. Since this count is the same in all conformal frames it does not matter that the frame used is the special one defined in (33). For such a count to have the basic significance that the theory requires it to have it is necessary that the length unit $\tilde{m}_0^{-1}$ have basic significance. The significance is required to relate to the nature of the particles and so to quantum mechanics, as it does if we require $\tilde{m}_0^{-1}$ to be the Compton wavelength of the particles. There seems no other plausible way of developing the theory.

Let m_0 be the mass of the particles with respect to some practical unit and consider practical units also for time and length, so that neither c nor $\hbar$ is unity. Then we have

$$\tilde{m}_0 = m_o c/\hbar. \tag{37}$$

The gravitational equations (31) are

$$\frac{1}{6}\tilde{m}_0^2(R^{ik} - \frac{1}{2}g^{ik}R) = -\sum_a \tilde{m}_0 \int \frac{\delta_4(X,A)}{\sqrt{-g(A)}}\frac{da^i}{da}\frac{da^k}{da}da. \tag{38}$$

Using (37) to replace $\tilde{m}_0$ by m_0 we get

$$R^{ik} - \frac{1}{2}g^{ik}R = -\frac{6\hbar}{c^3 m_0^2}\sum_a m_0 c^2 \int \frac{\delta_4(X,A)}{\sqrt{-g(A)}}\frac{da^i}{da}\frac{da^k}{da}da. \tag{39}$$

Identifying $8\pi G/c^4$ with $6\hbar/m_0^2c^3$ these are the equations of general relativity, i.e. for

$$m_0 = \left(\frac{3\hbar c}{4\pi G}\right)^{1/2}. \tag{40}$$

When the empirically determined value of G is used in (40) this is the mass of the Planck particle, the value 1.06×10^{-5} gram quoted above.

4. A derivation of the cosmological constant

Writing $M^{(a)}(X), M^{(b)}(X), \ldots$ as the mass fields produced by the individual Planck particles $a, b, \ldots$, the total mass field

$$M(X) = \sum_a M^{(a)}(X) \tag{41}$$

satisfies the wave equation (26) when $M^{(a)}, M^{(b)}, \ldots$ satisfy

$$\Box M^{(a)} + \frac{1}{6} R M^{(a)} = \int \frac{\delta_4(X, A)}{\sqrt{-g(A)}} da, \ldots \tag{42}$$

Scale invariance throughout requires all the mass fields to transform as

$$M^{*(a)} = M^{(a)} \Omega^{-1} \tag{43}$$

with respect to the scale change Ω, when both the left and right hand sides of every wave equation transform to its starred form multiplied by Ω^{-3}, i.e. the left hand side of (42) goes to $(\Box M^{*(a)} + \frac{1}{6} R^* M^{*(a)}) \Omega^{-3}$ and the right hand side to

$$\Omega^{-3} \int \frac{\delta_4(X, A)}{\sqrt{-g^*(A)}} da^*. \tag{44}$$

Then the factor Ω^{-3} cancels to give the appropriate invariant equation. This cancellation is evidently unaffected if, instead of (42) for the wave equation satisfied by M^a,

$$\Box M^{(a)} + \frac{1}{6} R M^{(a)} + M^{(a)^3} = \int \frac{\delta_4(X, A)}{\sqrt{-g(A)}} da. \tag{45}$$

Since the cube term transforms to $M^{*(a)^3} \Omega^{-3}$ with respect to Ω changing (42) to (45) preserves scale invariance in what appears to be its widest form. Since in other respects the laws of physics always seem to take on the widest ranging properties that are consistent with the relevant forms of invariance we might think it should also be here, in which case (45) rather than (42) is the correct wave equation for $M^{(a)}$, and similarly for $M^{(b)}, \ldots$, the mass fields of the other Planck particles.

But this departure from linearity in the wave equations for the individual particles prevents a similar equation being obtained for $M = \sum_a M^{(a)}$. Nevertheless, the addition of the individual equations can be considered in a homogeneous universe to lead to an approximate wave equation for M of the form

$$\Box M + \frac{1}{6} R M + \lambda M^3 = \sum_a \int \frac{\delta_4(X, A)}{\sqrt{-g(A)}} da, \tag{46}$$

$$\Lambda = N^{-2}, \tag{47}$$

where N is the effective number of particles contributing to the sum $\sum_a M^{(a)}$. The latter can be considered to be determined by an Olbers-like cut-off, contributed by the portion of the universe surrounding the point X in $M(X)$ to a redshift of order unity. In the observed universe this total mass $\sim 10^{22} M_{\odot}$, sufficient for $\sim 2.10^{60}$ Planck particles. The actual particles are of course nucleons of which there are $\sim 10^{79}$ But if suitably aggregated they would give $\sim 2.10^{60}$ Planck particles and with this value for N

$$\Lambda \simeq 2.5 \times 10^{-121}. \tag{48}$$

The next step is to notice that the wave-equation (46) would be obtained in usual field theory from $\delta \mathcal{A} = 0$ for $M \rightarrow M + \delta M$ applied to

$$\begin{aligned} \mathcal{A} = &-\frac{1}{2}\int (M_i M^i - \frac{1}{6} R M^2)\sqrt{-g}d^4x + \frac{1}{4}\Lambda \int M^4 \sqrt{-g}d^4x \\ &- \sum_a \int \frac{\delta_4(X, A)}{\sqrt{-g(A)}} M(X) da. \end{aligned} \tag{49}$$

In the scale in which M is m_0 everywhere the derivative term in (49) vanishes and since $G = 3/4\pi m_0^2$ the term in R is the same as in (3), as are also the line integrals, requiring the remaining term to be the same gives

$$\lambda = -3\Lambda m_0^2. \tag{50}$$

Thus we have obtained not only a cosmological constant but also its magnitude, something that lies beyond the scope of the usual theory. With 2.5×10^{-121} for Λ as in (48) and with m_0 the inverse of the Compton wavelength of the Planck particle, $\sim 3.10^{32}$ cm^{-1}, (50) gives

$$\lambda \simeq -2.10^{-56} \text{ cm}^{-2}, \tag{51}$$

agreeing closely with the magnitude that has previously been assumed for λ. In the classical big bang cosmology there is no dynamical theory to relate the magnitude of λ to the density or other physical properties of matter. For observational consistency it is assumed that λ is of order (51). A dynamical derivation is possible if one goes into the very early inflationary epochs. However, the values of λ deduced from those calculations are embarrassingly large, being 10^{108} - 10^{120} times the value given by (51). The problem then is, how to reduce λ from such high values to the presently acceptable range (Weinberg 1989). By contrast, the present derivation leads to the acceptable range of values with very few theoretical assumptions.

Planck particles are subject to rapid decay, when their mass couplings are replaced by those of more stable secondaries. Provided the secondaries interact together in the same way in the cube terms as the Planck particles from which they are derived, the result (51) continues to hold.

5. The origin of the light elements

It is not possible for a Planck particle with a Compton wavelength of $\sim 3.10^{-33}$ cm to decay immediately into $\sim 6.10^{18}$ nucleons. Considerations of degeneracy prevent such a dense packing, so that the resulting aggregrate of secondaries is required to spread out initially as bosons. Only when a dimension of $\sim 10^{-7}$ cm has been reached can a swarm of $\sim 2.10^{19}$ quarks appear. The situation in this respect is the same as in the first moments of Big-Bang cosmology.

But whereas in Big-Bang cosmology the early Planck particles are contiguous to each other here they are well separated, each producing its own cluster of expanding secondaries. A further difference is that the Planck particles here consist of matter decaying into matter, so that the overwhelming loss of energy that occurs into radiation in Big-Bang cosmology does not happen here. It happens in Big-Bang cosmology because of an essentially contradictory double assumption. First the decay products of the Planck particles are said to be balanced between matter and antimatter and then the balance is said to be not quite perfect, as if to say -1 does not quite balance $+1$. The surviving remnant of matter embedded in a greatly dominant radiation field produces the low mass density in a high temperature radiation field which is the essential feature of the relation (8), $\rho = 10^{-32}T^3$, that is considered necessary for the synthesis of the light elements in Big-Bang cosmology.

The challenge here is to produce a synthesis of the light elements with a very much larger coefficient than 10^{-32} in such a relationship. Energy lost into radiation early in the expansion of a Planck fireball goes quickly into the dynamical expansion of the secondary particles. Without knowing this loss at all precisely it can be taken simply to produce a speed of expansion of order c. Thus the time scale for the expansion to a dimension of 10^{-7} to 10^{-6} cm is of the order of 10^{-16} seconds and the particle density when large numbers of baryons are at last produced is in the range 10^{36} to 10^{40} cm^{-3}.

The discussion begins, however, at a much higher density than this, at a quark phase with the quark density high enough, above 10^{42} quarks cm^{-3}, for degeneracy to force the six quark flavours to be represented nearly equally. But as expansion continues and degeneracy becomes less relevant, the high masses of the top, bottom and charmed quarks become an increasing energy burden and it is considered that transitions occur within the available time scale to the up, down and strange quarks. Because we are outside known laboratory physics, however, this step is necessarily conjectural, not we think in principle but in the quantitative details of the time scale for the occurrence of the relevant transitions.

The only electrons present are from pair production from γ-rays, and because electrons have negligibly short mean free paths, charge neutrality must be maintained among the quarks themselves. That is to say, a charge excess among the quarks cannot be balanced by electrons and since any such excess must be small, again for energy reasons, the strange quark cannot be dispensed with in the manner of the charmed, top and bottom quarks. To obtain charge neutrality, equal densities of up, down and strange quarks with charges $+\frac{2}{3}, -\frac{1}{3}, -\frac{1}{3}$ respectively are needed. This has the effect, when baryons are eventually formed in their lowest energy state through associations of the quarks, of producing $P, N, \sum^+, \sum^0, \sum^-, \equiv^-$ and $\equiv^+$ almost equally. There is a little Ω^- but this is effectively negligible. Hence with N and P eventually combining into stable nuclei of ^{4}He, and with the other six baryons not forming stable nuclei – with them eventually decaying into protons – the ultimate mass ratio of ^{4}He to H is ~ 0.25.

These later stages in the expansion of Planck fireballs can be calculated quantitatively (Hoyle, 1992 and Hoyle, et al, 1993). A radiation field becomes established through the 75 MeV decay of $\sum^0$ into Λ. Using this radiation field it can be shown from detailed nuclear reaction rates that only a small fraction of N and P remain uncombined into ^{4}He, giving a more precise mass ratio of ^{4}He/H between 0.23 and 0.24. The relative abundances of the other light nuclei agree very well with the solar system meteoritic values, as shown in the following table :

Table 2

LIGHT-ELEMENT ABUNDANCES EMERGING FROM PLANCK FIREBALLS

D/H	2×10^{-5}
^{3}He/H	2×10^{-5}
^{7}Li/H	10^{-9}
^{9}Be/H	3×10^{-11}
^{11}B/H	10^{-10}
^{6}Li/^{7}Li	10^{-1}
^{10}B/^{11}B	10^{-1}

Our purpose here is to raise two points about these results. First, it is remarkable that such results can be obtained under conditions relating density, temperature and time scale greatly different from those in Big-Bang cosmology – if the present discussion were illusory this would hardly be expected. The second is that, with (8) no longer necessary, there is no reason why the presentday cosmological density, $\sim 10^{-29}$ g^{-3}, should not be entirely baryonic. All this follows, it may be noted, from the present consideration that the gravitational equations should be scale invariant, a consideration it seems to us with deeper consequences than the assumptions of Big-Bang cosmology, which like (8) do not come from any need of physical theory but are assumed *ad hoc*, or at any rate have been so over more than a quarter of century – already in 1967 the need for (8) to be understood in basic physical terms was strongly emphasized (Wagoner, et al, 1967) but this understanding has not as yet been forthcoming in that theory.

6. The creation of matter

The observation that ^{4}He/H is indeed about 0.23 by mass, taken with the preceding section, requires the observed matter to have emerged in the present theory from the decays of Planck particles and therefore to have been created at times in the past. Big-Bang cosmology requires the same, with particle creation occurring during the brief moments following the Big-Bang. Here there is no such need for creation to occur at essentially a particular moment, however, creation can be distributed in time, it can be an ongoing process.

Planck particle a exists from A_0 to $A_0 + \delta A_0$, in the neighbourhood of which it decays into n stable secondaries, $n \simeq 6.10^{18}$, denoted by $a_1, a_2, \dots a_n$. Each such secondary contributes a mass field $m^{(a_r)}(X)$, say, which is the fundamental solution of the wave equation

$$\Box m^{(a_r)} + \frac{1}{6} R m^{(a_r)} + n^2 m^{(a_r)^3} = \frac{1}{n} \int_{\sim A_0+\delta A_0} \frac{\delta_4(X, A)}{\sqrt{-g(A)}} da, \qquad (52)$$

while the brief existence of a contributes $c^{(a)}(X)$, say, which satisfies

$$\Box c^{(a)} + \frac{1}{6} R c^{(a)} + c^{(a)^3} = \int_{A_0}^{A_0+\delta A_0} \frac{\delta_4(X, A)}{\sqrt{-g(A)}} da, \qquad (53)$$

Summing $c^{(a)}$ with respect to $a, b, \dots$ gives

$$c(X) = \sum_a c^{(a)}(X). \qquad (54)$$

the contribution to the total mass $M(X)$ from the Planck particles during their brief existence, while

$$\sum_a \sum_{r=1}^{n} m^{(a_r)}(X) = m(X) \tag{55}$$

gives the contribution of the stable particles.

Although $c(X)$ makes a contribution to the total mass function

$$M(X) = c(X) + m(X) \tag{56}$$

that is generally small compared to $M(X)$, there is the difference that, whereas $m(X)$ is an essentially smooth field, $c(X)$ contains small exceedingly rapid fluctuations and so can contribute significantly to the derivatives of $c(X)$. The contribution to $c(X)$ from Planck particles a, for example, is largely contained between two light cones, one from A_0, the other from $A_0 + \delta A_0$. Along a timelike line cutting these two cones the contribution to $c(X)$ rises from zero as the line crosses the light cone from A_0, attains some maximum value and then falls back effectively to zero as the line crosses the second light cone from $A_0 + \delta A_0$. The time derivative of $c^{(a)}(X)$ therefore involves the reciprocal of the time difference between the two light cones. This reciprocal cancels the short duration of the source term on the right-hand side of (53). The factor in question is of the order of the decay time τ of the Planck particles, $\sim 10^{-43}$ seconds. No matter how small τ may be the reduction in the source strength of $c^{(a)}(X)$ is recovered in the derivatives of $c^{(a)}(X)$, which therefore cannot be omitted from the gravitational equations.

The derivatives of $c^{(a)}(X), c^{(b)}(X), \ldots$ can as well be negative as positive, so that in averaging many Planck particles, linear terms in the derivatives do disappear. Omitting for the moment the cosmological constant, it is therefore not hard to show that after such an averaging the gravitational equations become

$$R_{ik} - \frac{1}{2} g_{ik} R = \frac{6}{m^2} \Big[- T_{ik} + \frac{1}{6}(g_{ik} \Box m^2 - m^2_{;ik}) + (m_i m_k - \frac{1}{2} g_{ik} m_l m^l) + \frac{2}{3}(c_i c_k - \frac{1}{4} g_{ik} c_l c^l) \Big]. \tag{57}$$

Since the same wave equation is being used for $c(X)$ as for $m(X)$, the theory remains scale invariant. A scale change can therefore be introduced that reduces $M(X) = m(X) + c(X)$ to a constant, or one that reduces $m(X)$ to a constant. Only that which reduces $m(X)$ to a constant, viz

$$\Omega = \frac{m(X)}{m_0} \tag{58}$$

has the virtue of not introducing small very rapidly varying ripples into the metric tensor. Although small in amplitude such ripples produce non-negligible contributions to the derivatives of the metric tensor, causing difficulties in the evaluation of the Riemann tensor, and so are better avoided. Simplifying with (58) does not bring in this difficulty, which is why separating of the main smooth part of $M(X)$ in (56) now proves an advantage, with the gravitational equations simplifying to

$$8\pi G = \frac{6}{m_0^2}, \quad m_0 \text{ a constant,} \tag{59}$$

$$R_{ik} - \frac{1}{2}g_{ik}R = -8\pi G[T_{ik} - \frac{2}{3}(c_i c_k - \frac{1}{4}g_{ik}c_l c^l)]. \tag{60}$$

Using the metric (1) with $k = 0$ the dynamical equations for the scale factor $S(t)$ are

$$\frac{2\ddot{S}}{S} + \frac{\dot{S}^2}{S^2} = \frac{4\pi}{3}G\bar{\dot{c}^2}, \tag{61}$$

$$\frac{3\dot{S}^2}{S^2} = 8\pi G\left(\bar{\rho} - \frac{1}{2}\bar{\dot{c}^2}\right), \tag{62}$$

with $\bar{\rho}$ the average particle mass density and $\bar{\dot{c}^2}$ being the average value of $\dot{c}^2$, the average value of terms linear in c and of $\ddot{c}$ being zero. It is easily shown from (61) and (62) that

$$\frac{\partial\bar{\rho}}{\partial t} + \frac{3\dot{S}}{S}\bar{\rho} = \frac{1}{2}\left(\frac{\partial\bar{\dot{c}^2}}{\partial t} + \frac{4\dot{S}}{S}\bar{\dot{c}^2}\right). \tag{63}$$

If at a particular time there is no creation of matter then at that time the left-hand side of (63) is zero with $\bar{\rho} \propto S^{-3}$. And with the right-hand side also zero at that time $\bar{\dot{c}^2} \propto S^{-4}$. The sign of the $\bar{\dot{c}^2}$ term in (61) is that of a negative pressure, a characteristic of the fields introduced into inflationary cosmological models. The concept of Planck particles forces the appearance of a negative pressure. In effect the positive energy of created particles is compensated by the sign of the $\bar{\dot{c}^2}$ terms, which in (61) increases $\ddot{S}/S$ and so causes the universe to expand. One can say that the universe expands because of the creation of matter. The two are connected because the divergence of the right-hand side of the gravitational equations (60) is zero.

As would be expected from this conservation property the sign of the $\bar{c}^2$ term in (62) is that of a negative energy field. Such fields have generally been avoided in physics because in flat spacetime they would produce catastrophic instabilities - creation of matter with positive energy producing a negative energy $\bar{c}^2$ term, producing more matter, producing a still larger $\bar{c}^2$ term, and so on. Here the effect is to produce explosive outbursts from regions where any such instability takes hold, through the $\bar{c}^2$ term in (61) generating a sharp increase of $\ddot{S}$. The sites of the creation of matter are thus potentially explosive. The explosive expansion of space serves to control the creation process and avoids the catastrophic cascading down the negative energy levels.

The requirement is in agreement with observational astrophysics which in respect of high energy activity is all of explosive outbursts, without evidence for the ingoing motions required by the popular accretion-disk theory for which there is no direct observational support. The profusion of sites where X-ray and γ-ray activity is occurring are on the present theory sites where the creation of matter is currently taking place.

A similar discussion to that given above leads to the appearance of a cosmological constant in the gravitational equations, viz.

$$R_{ik} - \frac{1}{2}g_{ik}R + \lambda g_{ik} = -8\pi G[T_{ik} - \frac{2}{3}(c_i c_k - \frac{1}{4}g_{ik}c_l c^l)]. \tag{64}$$

It has been on (64) that the discussion of what has been called the quasi-steady state cosmological model (QSSC) has been based as, for example, in Hoyle, et al (1994a,b).

A connection with Hoyle, et al (1993) can also be given. Writing

$$C(X) = \tau c(X), \tag{65}$$

where τ is the decay lifetime of the Planck particle, the action contributed by Planck particles $a, b, \ldots,$

$$-\sum_a \int_{A_0}^{A_0+\delta A_0} c(A)da \tag{66}$$

can be approximated as

$$-C(A_0) - C(B_0) - \ldots, \tag{67}$$

which form was used in Hoyle, et al (1993). And the wave-equation for $C(X)$, using the same approximation, is

$$\Box C + \frac{1}{6} R C = \tau^{-2} \sum_a \frac{\delta_4(X, A_0)}{\sqrt{-g(A_0)}}, \tag{68}$$

which was also used in Hoyle, et al (1993), except that previously an unknown constant f appeared in place of τ^2. When cube terms leading to a cosmological constant are also included, a term ΛC^3 appears on the left-hand side of (68).

The question now arises of why astrophysical observation suggests that the creation of matter occurs in some places but not in others. For creation to occur at the points $A_0, B_0, \ldots$ it is necessary classically that the action should not vary with respect to small changes in the spacetime positions of these points, which was shown in Hoyle, et al (1993) to require

$$C_i(A_0) C^i(A_0) = C_i(B_0) C^i(B_0) = \ldots = m_0^2. \tag{69}$$

More precisely, the field $c(X)$ is required to be equal to m_0 at $A_0, B_0, \ldots,$

$$c(A_0) = c(B_0) = \ldots = m_0. \tag{70}$$

As already remarked above, this is in general not the case, in general the magnitude of $c(X)$ is much less that m_0. However, close to the event horizon of a massive compact body $C_i(A_0)C^i(A_0)$ is increased by a relativistic time dilatation factor, whereas m_0 stays fixed. Hence, near enough to an event horizon the required conservation conditions can be satisfied, which has the consequence that creation events occur only in compact regions, agreeing closely with the condensed regions of high excitation observed so widely in astrophysics.

The theory would profit most from a quantum description of the individual creation process. The difficulty, however, is that Planck particles are defined as those for which the Compton wavelength and the gravitational radius are essentially the same, which means that, unlike other quantum processes, flat spacetime cannot be used in the formulation of the theory. A gravitational disturbance is necessarily involved. Nor is the process simply one of absorption of a boson from the $c(X)$ field. Rather we see it is as anologous to stimulated emission, with such a boson serving to trigger the emission of a similar boson of negative energy, energy and momentum bring conserved through a gravitational reaction. This is simply an outline. We do not yet possess such a theory in quantitative detail. We estimate that of the order of 10^{60} bosons exist in cosmological space, out to distances such that redshifts of order unity are obtained from the most distant visible objects in it. These energies are normally not adequate for them to serve as triggers for the creation process. On falling into the strong gravitational fields of sufficiently compact objects, however, the boson energies are multiplied by a dilatation factor, viz $(1-\mu/r)^{-1/2}$ for a local Schwarzschild metric

$$(1-\mu/r)dt^2 - \frac{dt^2}{1-\mu/r} - r^2(d\theta^2 + sin^2\theta d\phi^2). \tag{71}$$

Bosons then multiply up in a cascade, one makes two, two makes four, ..., as in the discharge of a laser, with particle production multiplying up similarly and with negative pressure effects ultimately blowing the system apart. While still qualitative, this view agrees well with the empirical facts of observational astrophysics.

7. Discussion and Summary

The theory developed in this paper differs from Big-Bang cosmology in what we believe to be an important aspect, that the gravitational equations are scale invariant. The invariance is achieved through a scalar mass field $M(X)$ which was divided into two parts

$$M(X) = c(X) + m(X), \tag{72}$$

where $c(X)$ is in general small compared to $m(X)$ because the primary particles which produce it, Planck particles, exist only for a brief moment $\tau \simeq 10^{-43}$ second. The field $m(X)$ produced by the stable secondaries was set equal to the value of m_0 given by

$$m_0^2 = \frac{3\hbar c}{4\pi G} \tag{73}$$

through the adoption of a suitable scale. The gravitational equations then reduce to

$$R_{ik} - \frac{1}{2}g_{ik}R + \lambda g_{ik} = -8\pi G[T_{ik} - \frac{2}{3}(c_i c_k - g_{ik}\frac{1}{4}c_l c^l)], \tag{74}$$

where

$$T^{ik} = \sum_a \sum_{r=1}^{n} \frac{m_0}{n} \int \frac{\delta_4(X, A_r)}{\sqrt{-g(A_r)}} \frac{da^{i(r)}}{da^{(r)}} \frac{da^{k(r)}}{da^{(r)}} da^{(r)}, \tag{75}$$

the summation being over all stable secondary particles each of mass m_0/n, with n the number of secondaries from each Planck particle $a, b, \ldots$, each of mass m_0. The field

$$c(X) = \sum_a c^{(a)}(X), \tag{76}$$

although in general small, has derivatives that nevertheless make significant contributions in (74). The cosmological constant λ arose from the inclusion of a third order term in the wave-equations for $c^{(a)}(X), c^{(b)}(X), \ldots$

$$\Box c^{(a)} + \frac{1}{6} R c^{(a)} + c^{(a)^3} = \int_{A_0}^{A_0+\delta A_0} \frac{\delta_4(X, A)}{\sqrt{-g(A)}} da, \tag{77}$$

$$\Box c + \frac{1}{6} Rc + \Lambda c^3 = \int_{A_0}^{A_0+\delta A_0} \frac{\delta_4(X, A)}{\sqrt{-g(A)}} da + \ldots \tag{78}$$

approximately, and

$$\lambda = -3 \Lambda m_0^2, \tag{79}$$

Λ being the square of the reciprocal of the number of primary Planck particles from which the secondaries present in the observable universe were derived, and similar third order terms being maintained for the mass field terms generated by the secondaries.

The classical conditions for the creation of primaries are

$$c(A_0) = c(B_0) = \ldots = m_0, \tag{80}$$

conditions that can be satisfied only in the vicinities of highly collapsed objects.

The immediate successes of the theory are :

(i) The circumstance that G determined by (73) is necessarily positive requires gravitation to act as an attractive force. Aggregates of matter must tend to pull together. This is unlike general relativity where gravitation can as well be centrifugal, with aggregates of matter blowing always apart, as follows if G in the action (3) of general relativity is chosen to be negative.

(ii) In the cosmological case with homogeneity and isotropy the pressure contributed by the c-field term in the gravitational equations is negative, explaining the expansion of the universe.

(iii) Also in the cosmological case, the energy contribution of the c-field is negative, which ensures that when the creation conditions (80) are satisfied the creation process tends to cascade with explosive consequences.

(iv) The magnitude of the constant λ is shown to be of the order needed for cosmology. Unlike Big-Bang cosmology this is a deduction not an assumption.

(v) With newly-created particles shown to be Planck particles their decay process provides a means for generating the light elements.

The theory has been applied to a new cosmological model (Hoyle, et al, 1993, 1994a and 1994b) in which the scale factor $S(t)$ in the metric (1) with $k = 0$ has the form shown in Figure 1. We have called this the quasi-steady state cosmology (QSSC). This describes an ongoing universe in which the dissipative effects of permanent expansion by a factor exp t/P are compensated by the effects of creation over some $P/3Q$ oscillatory cycles, the time scales Q, P being $\sim 50 \times 10^{10}$ years and $\sim 10^{12}$ years respectively. Details are given in the papers cited, particularly of the generation of the microwave background from the thermalization of starlight over a number of oscillatory cycles. Other problems discussed in these papers were the counts of radio sources, dark matter, cluster formation, stellar age problems and star formation. The discussion was prompted by the need for the universe to regenerate itself in all its properties, at a rate which on average compensates for the expansion factor exp t/P in $S(t)$. This steady-state concept, used now in a more effective way than in the old classical steady-state theory, shifts the cosmological problem to one in which the parameters on which calculations are made can be determined from astrophysical observatons. They are not guesses as in Big-Bang cosmology. And the aim of the investigations is to test the laws set out above; the form of logical developments that is usual in science.

The outstanding stumbling block to progress lies in the mathematical difficulty of solving partial differential equations explicitly in Riemannian spacetime. While special solutions can sometimes be found, progress towards general solutions is really needed. As an example, the simple solution $\dot{C}$ = constant satisfies the wave-equation (68) in the exterior of the Schwarzschild metric (71), whence for this particular solution $C_i C^i$ behaves as a constant multiplying $(1 - \mu/r)^{-1}$. Thus however small $\dot{C}$ may be, it follows that for r near enough to μ the classical creation condition $C_i C^i = m_0^2$ must become satisfied. It would evidently be desirable to prove this result generally by including the back reaction of the creation process on the metric. The circumstance that the wave-equation for C is the scalar analogue of the equations for the electromagnetic 4-potential might suggest that results for the latter be taken over in a suitably modified form. But the hope is dashed by the extraordinary situation that after almost a century of endeavour in the theory of general relativity, little in the way of solutions for the electromagnetic 4-potential exists, even for the simple Schwarzschild metric. While this lack of progress for the electromagnetic case illustrates the difficulties which still have to be faced in a theory of the creation of matter, we feel that it is in this direction that progress will eventually lie, not in abrogating the need to understand the origin of matter through arbitrary initial assumptions.

References

Alcock, C. et al, 1993, *Nature*, **365**, 769.

Alpher, R.A., Follin, J.W. and Herman, R.C., 1953, *Phys. Rev.*, **92**, 1347.

Alpher, R.A., Follin and Herman, R.C., 1950, *Rev. Mod. Phys.*, **22**, 153.

Aubourg, E. et al, 1993, *Nature*, **365**, 623.

Courant and Hilbert, D., 1962, *Methods of Mathematical Physics, Vol. II* (Interscience, New York), p. 727-744.

Gamow, G., 1946, *Phys. Rev.*, **70**, 572.

Hoyle, F., 1992, *Ap. Sp. Sci.*, **198**, 177.

Hoyle, F., Burbidge, G.R. and Narlikar, J.V., 1993 *Ap. J.*, **410**, 437.

, 1994a, *M.N.R.A.S.*, **267**, 1007.

, 1994b, *A & A*, to be published.

Hoyle, F. and Narlikar J.V., 1974, *Action at a Distance in Physics and Cosmology* (W.H. Freeman, New York).

Hoyle, F. and Taylor, R.J., 1964, *Nature*, **203**, 1108.

Kembhavi, A.K., 1979, *M.N.R.A.S.*, **185**, 807.

Nabarro, F.R.N. and Jackson, P.J., 1958, in R.H. Doremus, B.W. Roberts, D. Turnbull (eds.) *Growth and Perfection in Crystals* (J. Wiley, New York).

Narlikar, J.V. and Padmanabhan, T., 1991, *Ann. Rev. A & A*, **29**, 325.

Paczynski, B., 1986, *Ap. J.*, **304**, 1.

Padmanabhan, T., 1993, *Structure Formation in the Universe* (Cambridge University Press, Cambridge).

Peebles, P.J.E., Schramm, D.N., Turner, E.L. and Kron, R.G., 1991, *Nature*, **352**, 769.

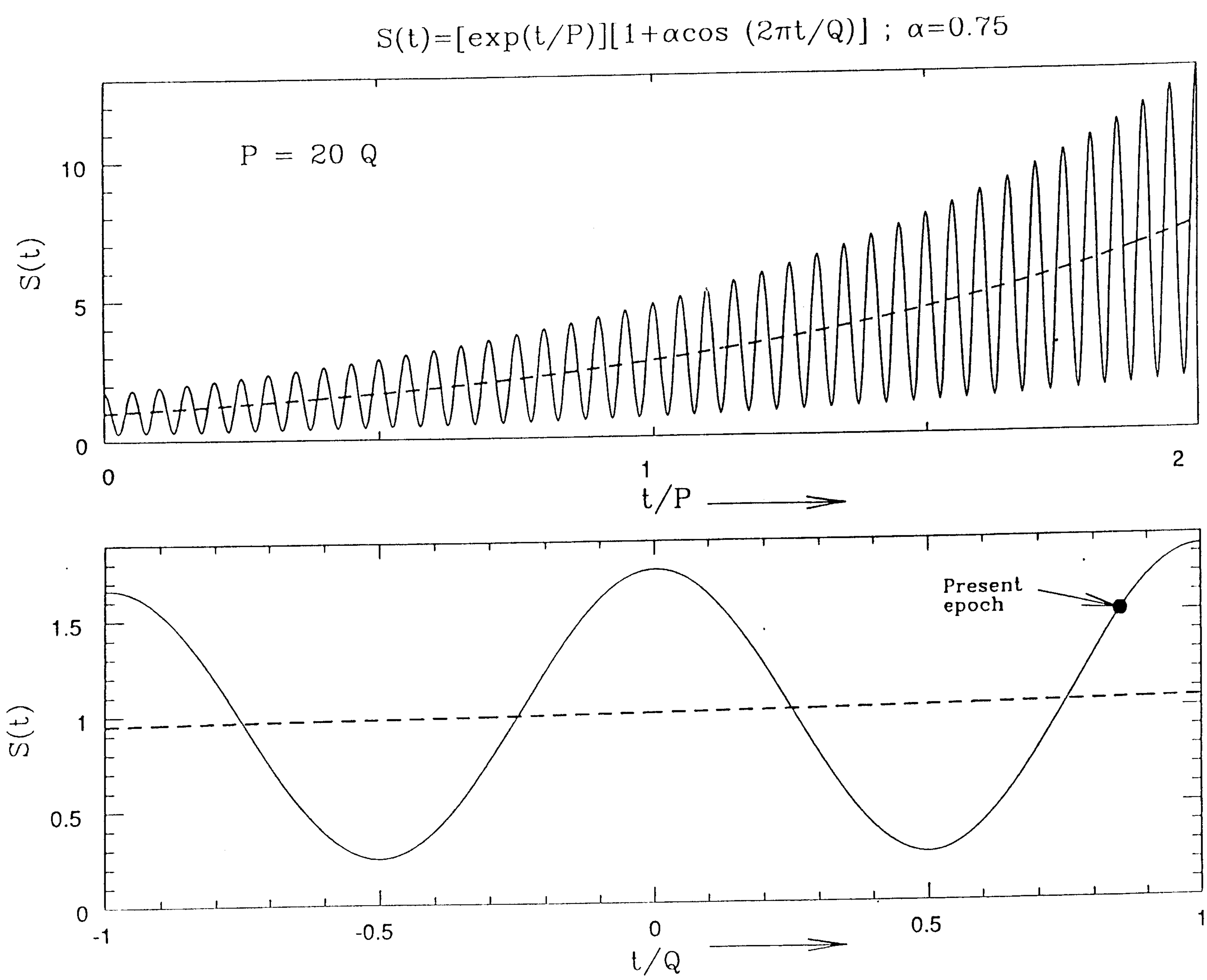
van den Berg, 1961, *Z. Ap.*, **53**, 219.

Wagoner, R.V., Fowler, W.A. and Hoyle, F., 1967, *Ap. J.*, **148**, 3.

Weinberg, S., 1989, *Rev. Mod. Phys.*, **61**, 1.

Figure Caption

Figure 1 : The scale factor $S(t)$ of the QSSC plotted (in the upper half of the figure) against t to show how several oscillatory cycles of short period Q are accommodated in the longer e-folding time P of the exponential expansion. Here $P = 20Q$ and (in the lower half of the figure) we see a few oscillations on an expanded time scale with our present epoch marked.



S(t)=[exp(t/P)][1+αcos (2πt/Q)] ; α=0.75
P = 20 Q
S(t)
10
5
0
0
1
2
t/P
S(t)
1.5
1
0.5
0
-1
-0.5
0
0.5
1
t/Q
Present epoch