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CREATION OF THE COSMOS

PART 2 - CREATING

The World of God; Reason, Design and Form,
Intelligence, Whose workshop spans the stars
Expressed within the Cosmos and alike
In what seems chaos; He Who works as much
In randomness as order, Who to make
Man in His image scorns not to create
By patient evolution on a scale
Of craft divine which dwarfs a million years.

Faith and Thought, 1975, 102, 182

God's Workshop

In Part 1 we grappled briefly with the scale of creation and the relationship of the Creator to it as understood in biblical Theism. We saw time and space as co-related in a way so closely as to make them partially interchangeable aspects of a single entity — space-time — and we saw this as a creature of the Creator upon Whom it is utterly and always contingent and Who as its giver is both beyond and forever the source of this whole.

We spoke of belief in the intelligibility and uniformity of nature, which in any case are but developments of the knowing and trusting without which science is impossible and we recognise that these beliefs were strongly present in the Psalms and Prophets which implicitly record their cultivation in a symbiotic relationship. Modern science is founded on these ideas of intelligibility and uniformity which in a complementary way we can rightly speak of as a divine revelation from God to His human "analogue". The general trustworthiness of these ideas is demonstrated by the success of science in bringing and ordering our understanding and in making possible the outstanding technical achievements which, for good or ill, characterise our time.

We saw that the most successful efforts to piece together our understanding and observations of the Universe lead us to the view that it all started in a "big bang" some fifteen thousand million years ago or that if it had a previous existence that cannot be traced through the confused instant $t = 0$. Granted then that the Christian sees the being of this whole as given then and always by God we must now ask what God would seem to have been up to during the ensuing fifteen thousand million years. What has He been doing in this workshop? Of course the short answer is everything, which would imply a more detailed answer of infinite length. Here, however, we shall limit ourselves to the more manageable task of exploring some of the creative activity of the Creator in the Cosmos. According to the Psalmist "the works of the Lord are great, sought out by all those that take pleasure therein". This pleasing exploration is therefore a truly biblical idea. It is our research into God's creative activity. As we have seen, the strongest word for create at the very beginning of the bible (bara) is used also of God's contemporary activity in animal birth, "Thou sendest forth thy breath they are created and Thou renewest the face of the Earth". (Ps. 104:30)

In seeking to give a good though brief account of this divine creativity in nature we will do so with the quaint words of Cromwell in our minds, "I pray you in the bowels of Christ consider that ye may be mistaken" but at the same time with the confidence that nature reflects the trustworthiness and constancy of its Giver.

Probability and Uncertainty

As scientists we no longer believe as did the cynic Omar Kayaam that "the first morning of creation wrote what the last dawn of reckoning shall read" for the determinism which characterised classical science has given way to the ideas of quantum physics in which the only certainty about physical events is statistical.

In modern physics this probabilistic aspect of nature is found to be very important and is enshrined quantitatively in Heisenberg's well verified "Uncertainty Principle". One form of the Principle says that there is a fundamental uncertainty in the energy of anything related by the very small quantity h known as Planck's Constant, to the time over which we are considering it. Quantitatively if we consider the energy stored, for example, in the spring of a balance over a small time interval Δt then while the instant to which the energy value applies is uncertain to an extent Δt the value of the energy is uncertain to an extent ΔE. Heisenberg's Principle records that the uncertainties Δt and ΔE are very simply related, their product being not less than 10^{-34} joule seconds.

Contemporary Creation and Annihilation

It may seem that the Uncertainty Principle is all about what measurements are in principle possible and to what precision. In a sense that is true. But science is about the observable world. It is without scientific meaning to say that something is quantitatively the case although it cannot ever be determined. To say that the energy of anything in a given microsecond is so much to an accuracy much greater than 10^{-28} joules is to make a metaphysical statement incapable of verification. That is not science.

A great deal of progress has been made in understanding nature at its most microscopic level by interpreting Heisenberg's Principle in a very positive way so that we do not merely say we cannot, in principle, measure certain pairs of quantities more accurately than so much but rather that the quantities must be considered as actually having a range of values within the potential uncertainty of their determination. A very dramatic example of the positive application of the Principle is that interactions between the elementary particles, from which we picture all matter as constructed, are modelled by supposing that certain other particles can have a transient existence, coming into being and disappearing again, providing their life is no more than given by the Uncertainty Principle. In the equation

$$\Delta E \times \Delta t = 10^{-34} \text{ joule seconds}$$

we let ΔE be the uncertainty in total mass/energy of the transient particles. Now obviously if ΔE were zero the particle would not exist but if $\Delta E = mc^2$ where m is the mass of a transient particle then it can exist and exhibit the inertial properties of a mass m. Since ΔE can, by Heisenberg's Principle exceed mc^2 for a brief instant a transient particle of mass m may spontaneously come into being for a time not longer than that instant. To be quantitative

$$\frac{10^{-34}}{\Delta E} = \frac{10^{-34}}{mc^2} \text{ seconds}$$

This time is quite long enough for the transient particle to pass from one atomic constituent, say a proton in the nucleus of an atom, to another, and our current understanding of the way nuclear constituents are being held together involves this very real and important behaviour of transient mesons. In special circumstances if energy is supplied adequately the transience of the particle is no longer set by Heisenberg's Principle and the particle can pass out into its surroundings with a life of its own. Energy has been converted into matter. A new particle has been created.

A very important facet of this for our topic is that the idea of matter as inviolate, uncreatable and indestructible, is no longer valid. Even if we broaden the concept of the conservation of matter into a conservation of total energy, in which any matter is represented by its energy equivalent according to $E = mc^2$, we still have to permit an overdraft of energy on the bank of Heisenberg's Principle sufficient to account in the way I have just described, for such real phenomena as the stability of atomic nuclei.

So we find that in the world we know today particles can be created from energy and even occur briefly "virtually" without an expenditure of energy. The reverse is also true. Particles can be annihilated leaving only their energy behind.

General Relativity

The beginning of the Universe open to our investigation, some fifteen billion years ago has a great deal to do with creation, but not necessarily in any special theological sense because, as we have seen, on the one hand there may have been an "earlier contraction" when *ex nihilo* would not apply in any material way and, on the other, creating as a divine activity cannot properly be limited to *ex nihilo*. The creating that started t = 0 was of the kind I have been describing in the last section and was accompanied by annihilation, also in the sense the physicist uses the word, on a grand scale.

We have three rather good reasons for accepting a hot big bang as the best interpretation available to us at present of what nature is saying about the start of it all. Perhaps I should rather say of the Word of God in nature. The first reason we have already mentioned. It is the existence of a faint flux of microwave (very short wavelength radio waves, almost infra-red) radiation coming to us continually from every direction in space. The second reason is the apparent ages of the galaxies and the third is the observed ratio of atoms of helium to those of hydrogen in space. These three observational facts find a more satisfactory explanation in the big bang than in any other cosmology and at the same time point to the cosmic validity of General Relativity, or something very like it, and the general correctness of our thinking as physicists. Einstein's inspired thinking that led to his formulation first of Special (1905) and then of General (1916) Relativity depended substantially on arguments involving ideas of self consistency and symmetry and very little on already known physical data. The Special Theory sought a formulation of physical laws which would be consistent for all observers irrespective of their uniform motion through space (a concept that was thereby stripped of much of its meaning). Michelson and Morley had done a famous experiment which pointed strongly to the idea that the laws of physics are the same for observers moving uniformly relative to one another although Einstein claimed to have been little influenced by it. The General Theory sought a formulation of physical laws which did justice to the idea that since there seems to be no way of distinguishing between inertial mass (i.e. resistance to acceleration, e.g. the tension in a string swinging a brick in a circle) and gravitational mass (i.e. response to the attractive force of another mass, e.g. tension in a string from which a brick is hanging above the Earth), inertial and gravitational mass should be regarded as one and the same property. This implies that acceleration and gravity are the same and, startling as that may seem, Einstein succeeded in representing them as a unity by choosing a new geometry for space. Not only was the Euclidean geometry, in which for example Pythagoras' Theorem held, abandoned but time retained the characteristic fourth dimension aspect it had in the Special Theory and the relevant Space-Time continuum had a geometry whose local properties were determined by the presence of matter and accounted for its gravitating properties. The General Theory predicted three important effects which were, in principle, observable. Firstly light should be subject to deflection by gravity, secondly, and in view of the first, light should be reddened on climbing its way out of the gravitating field of a star and thirdly the motion of bodies in orbit (specifically the planet Mercury around the Sun) should depart ever so slightly from that described by Kepler and accounted for by Newton's Theory of Gravity.

Each of these predictions has been amply verified. A star observed as its light grazed the Sun, during a total solar eclipse which made the observation possible, was seen to suffer an apparent displacement from its normal position quantitatively in accord with prediction. Very recently a distant quasar has been seen as a pair (in radio "light") as the radio waves have reached the telescope apparently around opposite sides of an unseen massive galaxy. There have also been reports of another case in which a trio of mirages caused by gravitational deflection have been found.

The most dramatic demonstration of the gravitational redshift was made in 1960 when the change in frequency of gamma rays (very short wavelength "light") on travelling 22.6 metres from the bottom to the top of a laboratory was shown to be within 10% of prediction. The very small changes in the orbits of Mercury, Venus and the Earth due to General Relativity were verified in 1956.

I have spent some time stressing the observational status of General Relativity because of the remarkable cosmological corollaries.

An Expanding Universe

When Einstein contemplated his rather complex equations which expressed the basic relationship which holds between time, space and matter, if the known gravitational and inertial properties of the latter are to be adequately formulated, he found an astonishing thing. He considered for the sake of simplicity a somewhat idealised Universe in which the effect of matter is averaged by thinking of it as spread out uniformly instead of clumped in galaxies, stars and planets and he found that his equations in their simplest form had no stationary solution. Put starkly that implies that the Universe has to be either expanding or contracting. Then Einstein made what he later called the biggest blunder of his life; not that it violated any rules of mathematics or principles of good science, rather the reverse. He realised that his equations might still be an accurate description of local space-time and gravity, that is of the cosmos as he knew it, if they were slightly modified by adding an additional term, a constant of integration, the so-called cosmological constant. This constant represented an unknown but entirely plausible force significant only over huge distances far greater than the average distance between galaxies. It is given to few great scientists to make their biggest scientific mistake simply as a result of "sitting down before fact" in a thoroughly open minded way. After all, who, before Hubble's observations would have dreamt that the Universe was expanding and have chosen to take that as the solution implied by Einstein's equations rather than the equally valid idea of a new, as yet unobserved, force acting on a cosmic scale. In a sense Einstein was very proper. Mathematically the term should be there in his equations. Only now in the light of the evidence for the expansion of the Universe and the absence of any direct evidence for such a force we set it to zero. If Einstein had been a little less honest with himself he might have made literally the greatest scientific prediction of all time — that the Universe is expanding. No doubt he would soon have been pounced upon by theorists who would correctly have pointed out that that conclusion is not inevitable. Only sitting before the facts, so soon to be observed by Hubble, would have resolved the matter. In any case, it turns out that the value of the cosmological constant is irrelevant to the picture General Relativity gives of the big bang once the expansion of the universe has been recognised. At that epoch the Universe was too small and the gravitational forces too large for an unknown but finite cosmological force to affect the picture.

What sort of picture then does General Relativity suggest for those early moments?

It will be a blurred picture in which the detail of any broad structure in the distribution of matter is smeared out. That, after all was how Einstein first evaluated the cosmic implications of his theory. Later we must think about detail on the scale of individual particles.

The equations portray a Universe that is expanding; we cannot quite say from a time $t = 0$ at which, extrapolating its present motion backwards, its volume would have been zero, because ideas associated with Heisenberg's Uncertainty Principle and Quantum physics generally imply that times shorter than a certain amount (10^{-43} seconds) are meaningless. In practice the limitation to our backward vision is much more severe because of inadequacies in our present knowledge of the basic physics, even assuming the laws have not changed with time. The picture presented by extrapolating from what we know today back to within a millisecond (10^{-3} second) of t = 0 is plausible and some inkling of events back to within about a microsecond (10^{-6} second) seems possible.

This picture is of space with a temperature approaching 10^{14} K having already expanded to a volume three hundred metres in diameter but containing all the mass/energy the Universe contains now. In order to get an idea of what we mean by a temperature of 10^{14} K we need to recognise that temperature is a measure of the average energy of motion per particle of an assembly of particles. Although the temperature of radiation can be thought of analogously it is perhaps better to think of it as related to its wavelength or colour. Thus the microwave radiation which pervades space has predominant wavelengths of a millimeter or so and corresponds to the radiation from a body at a very low temperature only about 3 degrees above absolute zero or -270°C. As the wavelength gets shorter and shorter, corresponding to higher and higher energies or temperatures, the particle-like behaviour becomes more and more pronounced. Thus the wavelength of a gamma-ray is comparable to the size of an atomic nucleus so quite an extensive train or packet of such waves could still be of only atomic dimensions. We call a well defined packet of light a photon and a continuous beam of such packets can be thought of as a succession of photons. It is an intriguing and highly unclassical aspect of quantum physics that energy carried by an individual photon is accurately proportional to its frequency (that is inversely proportional to its wavelength). Gamma-ray photons are very energetic (corresponding to a temperature of billions of degrees), X-rays correspond to a somewhat lower energy (millions of degrees), visible light still less energy (thousands of degrees) and the individual photons of microwaves are very unenergetic (just a few degrees). In thus firmly associating temperature with particle (photon) energy we must remind ourselves that temperature is a description of an average energy of a statistical assembly of particles and cannot properly be applied to individuals.

Having considered the meaning of temperature as applied to both particles of matter and photons of light we are now in a position to consider the implications of a big bang fireball at a temperature approaching 10^{14} K. The average kinetic energy of a particle at this temperature is greatly in excess of the energy associated with its rest mass.

To be able to grasp the implications of the huge amount of energy associated with individual particles and photons we need to introduce a suitable 'yardstick'. Such a unit of energy is that necessary to create an electron and its associated antiparticle, a positron. This process, having been predicted by Dirac, was first discovered when the energy of cosmic rays entering the laboratory was found to give rise spontaneously to an electron-positron pair. The photon energy required, although large for those days (1932), is small compared to that given to individual particles and photons in modern high energy accelerators. We must emphasise that although this unit of energy is enough to make two particles we cannot create an electron by itself. It always comes with its antiparticle which has the same mass but opposite electrical charge so that no net charge has been created. This unit of energy is approximately 1 MeV on the electron-volt scale. The mean particle kinetic energy at 10^{14} K is sufficient to create about ten thousand electron-positron pairs. It corresponds to 10^4 MeV.

Because the fireball initially occupied a very small volume the density was huge, particles and photons were continually colliding so their temperature was the same. A typical photon would therefore be a gamma-ray with sufficient energy to create 10^4 electron-positron pairs. Now the mass of protons or neutrons (from which the nuclei of the chemical elements are built up) is less than 2000 times that of the electron so these particles also would be created in abundance from the kinetic energy of the particles and the photon energy of the gamma-rays.

If this was all that was going on we would simply have a Universe in which a great deal of primordial energy gave rise to equal quantities of matter and antimatter. (Every particle kind has its antiparticle). But two other important things were happening. The whole system was expanding, of which more later, and particle annihilation — the reverse of creation of particle pairs was taking place. This too is a familiar process in the laboratory and it explains on the one hand why we do not find antimatter lying around today and on the other, sets us one of the biggest puzzles about the big bang scenario.

The Presuppositions of Cosmology

The justification for the scientific process is the ability it gives to interpret an indefinitely large number of highly complex phenomena in terms of relatively few, possibly unfamiliar and startling, ideas. The early history of the Universe is no exception, but how far back can we hope to probe? In suggesting earlier that there is a limit, perhaps 10^{-43} seconds after time zero beyond which the Uncertainty Principle makes the situation undefinable in principle, and in further suggesting that before an age of a millisecond the model becomes increasingly obscure, we have introduced two limitations. The first is concerned with the basic meaninglessness of statements about existence over almost infinitesimal periods. The second arises from inadequacy in knowledge that we can at least hope and work to remedy. But even extrapolating back to a millisecond is a good deal further than we can see, remembering that seeing to great distances is seeing to earlier epochs because of the travel time of the light. The earliest phenomenon we can see is the (nearly) isotropic (i.e. uniform in all directions) microwave radiation flowing in a Universe already ten thousand years old. It must therefore be re-iterated that extrapolation depends on certain assumptions, but that is not just science, it is life. My trust that tomorrow will be another day, whether I am here to see it or not, is no less an aspect of my belief in the Principle of Uniformity than is my belief that I can extrapolate into the past. Only, the longer the extrapolation the greater degree of uncertainty I must be prepared to entertain while recognising that a blurred and distant view is far better than no view at all. To the basic science postulate of the Uniformity of Nature we add two other beliefs of a more specifically astronomical kind. They are the belief in the homogeneity of the Cosmos and belief in its isotropy. These beliefs do justice to the situation as we see it now and they mediate understanding, enabling us to make sense of what seems to have been in the past. Belief in the homogeneity of the Universe is sometimes called the Copernican Principle as it amounts simply to applying to any other hypothetical observer the insight of Copernicus, that we do not occupy any specially significant place in the physical Universe. To put it another way the Universe has the same gross appearance from every point in it. The Isotropy Principle extends this to the view that not only does the Universe look broadly the same in every direction from here and now but that it would do so from everywhere else in time and space. Taken together these two Principles constitute what is known as the narrow Cosmological Principle. A wide Cosmological Principle took it that the gross features of the Universe were not only the same as seen from every point in space but also as seen from every point in time. It has been rejected by almost everybody because it leads logically to the continuous creation or Steady State Theory. Any principle that leads by logic alone, rather than by sitting before the facts, to meaningful statements about nature has to be treated with great caution. This was the great error of Greek science. It is evidence of the caution with which basic presuppositions are tested that the wide Principle was never generally accepted by cosmologists and has now largely been set aside.

Events in the Fireball

The simplest way to understand what we think went on in the fireball and why we think it is to consider the history the Universe would appear to retrace if time were to reverse now. Many details which can be filled in will be overlooked for the present. We would see the distant galaxies retrace their flight and start to approach one another. Since, according to Hubble's (observational) law their velocities are related to their distances they would head to coalesce at t = 0 in around fifteen billion years. However since galaxies are at present separated on the average by distances about one hundred times their average diameter, it is clear that before the time when the Universe was a hundred times smaller in diameter than it is now, matter was not distributed in galaxies. This corresponds to an age of the Universe of around 10^8 years, and shows that the ages of the galaxies, about which we can learn by direct observation of their contents may be not much less than the age of the Universe. Before that time the blobiness that we associate with galaxies and stars must have been very much less, these having condensed from a relatively much more uniform distribution of matter. We know from spectroscopic studies of very old stars that that matter must have been mostly hydrogen with about 25% by weight of helium.

At this point it will be helpful if we think of an analogy to help us understand the idea of an expanding or contracting Universe. From a purely philological point of view we can note that it is the Universe, the whole, that we are talking about. All the space-time there is is expanding. It is not expanding into more space and taking time about it. It is just growing. From a more scientific point of view we see that if this were not so the cosmological principle would be violated. If it were a case of matter expanding into unoccupied space then there would be a centre and a boundary and the view from them would be quite different. Since the Universe is changing in size it is finite, but homogeneity and isotropy require that it is unbounded. Einstein's curved space-time provides the mathematical key but not a complete mental image, for we can picture a curved line on a plane and we can picture a curved surface in space but we cannot picture a curved space in some hyperspace. Instead we restrict ourselves to representing three dimensional space by a surface; the surface of a sphere — a rubber balloon — for example, although since time and space are so closely related we must recognise a four dimensional continuum, curved in an unimaginable hyperspace. For the moment, however, let us picture the Universe by the surface of a balloon and the galaxies as paper discs randomly distributed on it. The view from any one galaxy is broadly the same as that from any other, but we must not think that we can see right round this closed curved space for it is expanding at a velocity near that of light.

Returning now to our time reversed history of the Universe we have seen that the reversed evolution of the galactic paper discs would have shown them dissolving as their matter became smeared over a sphere now only one hundredth of its size today. As we watch the contraction further the density continues to rise and with it the temperature. This is no more mysterious than the rise in temperature of the gas in a diesel engine cylinder as it is compressed and its reverse, in the actually expanding Universe, is a cooling like that produced in certain refrigeration cycles. There is, however, a subtle difference. The Universe is full of microwave radiation and as we compress this in our time reversed model its wavelength gets shorter. This, as we have seen is equivalent to increasing its energy. Its temperature rises. If we change the radius of our model Universe by a factor of a thousand we change the wavelength of the photons by the same factor and their energy in inverse proportion. Because of the change in volume the energy density (if we neglect particles) changes by 10^{12}. So when the Universe was only one thousandth of its present day radius the microwave radiation was no longer microwave but red or even yellow hot, corresponding to a temperature of 3000K. Now the matter in a Universe full of light, like that in an oven whose walls are incandescent tungsten, cannot be unaffected by the situation. At this temperature hydrogen atoms — the most abundant stuff of the cosmos — are torn apart into protons and electrons. Such a gas is called a plasma and because electrons, being charged particles, interact very strongly with electromagnetic radiation (c.f. the electrons in a radio aerial) no photon can travel far without being scattered. The sun like other stars, although gaseous, is opaque in this way and in just this way at that epoch the whole Universe too will have looked like a fireball. But the only viewpoints are in space-time, that is to say inside the ball. It is, to reverse the argument and restore time's arrow, just this fireball which we see everywhere with the radiation Doppler shifted by the expansion of the Universe to the microwave region of the spectrum. The reality of the fireball can hardly be in doubt; we can see it with our microwave telescopes. But just because we can see it we cannot see beyond it. For earlier epochs we must rest more heavily on the Cosmological Principle, Uniformity and well tried theory.

We have now seen that the microwave radiation points to, we can even say is, the fireball, and that the ages of the galaxies fit the big bang picture. The remaining main piece of evidence is the 25% helium to hydrogen ratio in the Cosmos and this takes us back to events in the first minute or so of the life of the Universe.

Helium

If we continue the technique of watching the action replay of the Universe in reverse we shall realise that the ever decreasing volume of "india rubber" space will see an ever increasing temperature due both to doppler shift in the radiation and to compression of the gas. The process of nuclear fusion to make heavier elements from hydrogen is humanity's hope as an energy source for the 21st Century. It is also well understood as the process by which normal stars stoke their fires and so shine almost unchanged for millions of years. One might expect that conditions in the first second of life of the primordial fireball were not dissimilar to those in the deep interior of a star. Computations based on the time reversed compression idea show, however, that the temperature was higher and the density lower at t = 1 second than is typical of stellar interiors. This has a profound consequence. At the huge temperatures of the first second, after which the fireball has cooled to 10^{10} K no chemical elements other than hydrogen could exist undisrupted by the turmoil. Not only would they have been stripped of their electrons, even at much lower temperatures, but the atomic nuclei themselves, built up of their basic components, protons and neutrons, could not endure. Indeed even protons themselves, the elementary nuclei of hydrogen could not retain their identity during the first few seconds, but would dissolve to a sea of quarks. During that period, therefore, no enduring nuclear synthesis of elements could occur. But as the seconds ticked by towards the first minute neutrons and protons would stabilise and colliding would give rise to the heavy isotope of hydrogen, deuterium. Deuterium nuclei colliding produce a rare variety of helium the light isotope which soon absorbs a neutron to become normal helium — an element so stable that it is shot intact out of a radio-actively decaying heavy element and so earned the name α-particle as if it were an elementary nuclear constituent like the proton and neutron. We shall see later that even these are not unstructured. It is because of its great stability that the helium concentration could build up to quite high levels. Once formed it is not easily destroyed. Later as the density and temperature fell little more would be produced until once again high temperatures and densities were available in the deep interiors of stars. It turns out that calculations of the relative amount of helium formed in a cooling fireball of hydrogen, at the temperatures and densities backward extrapolation points to are not very sensitive to the accuracy of the extrapolation. The figure of 25% by mass is in astonishingly good agreement with what we find today for the Universe as a whole.

We have now traced the history of the Universe back to the point at which the third pillar of evidence on which the contemporary evolutionary picture of the Universe primarily rests is seen to be well founded. The time is not long after t = 1 second. At this point as we peer back further it is, perhaps, worth digressing briefly to relate the exercise to an important and unfortunately sometimes heated discussion that took place in the latter years of the last century.

The Omphalos Question

Omphalos is the Greek word for navel though it is derivatively used for central point, hub or perhaps even the crux of an argument. The question debated, sometimes in its exact form, but more often in terms of its more general philosophical implications was "Did Adam have a navel?". An analogous question is "Did the trees in the Garden of Eden have rings?". The philosophical meaning of the argument is quite unrelated to one's view on biblical interpretations and the early chapters of Genesis. Put baldly the crux is, if Adam had no navel then he was (at least in that respect) not a real man — the argument can, of course, be extended to every other property which in a real man relates him to his mother (and father), his heredity written in his genes, his memory, his psychology and so on. Similar questions were posed about Eden's trees, and a parallel debate went on in geology. This is, probably, the central (*omphalos*) problem for a narrow unbiblical creationism. I say unbiblical because the Genesis record does not suggest creation from nothing but says rather "let the seas bring forth", "let the earth bring forth" and Adam is singled out as formed from the dust of the ground like the creatures of Psalm 104. The whole issue can be sharpened by bringing it up to the present and asking myself how I know that I and all my surroundings have not just been created complete with my memories of a never experienced past and the remains in my digestive system of a never eaten meal? It cannot be denied that God could create a being or a whole Universe with an apparent past and it may be thought impious to ask if He would. But even to assume that He did is not to bring science to a halt, for providing the apparent past He creates shows all the fundamental characteristics of the world I take to be real today I can continue to study it as if real. At any point in the past, therefore an *ex nihilo* creationist can suppose the past I am describing is only apparent and not real and I cannot refute him. Equally he cannot call a halt to my exploration. That halt, as we have pointed out, may well be called by the nature of science soon after $t = 0$. At $t = 0$ itself all pattern and structure is gone and all trace of any former history would seem to be lost in the mathematical singularity. Any effort to look beyond, at the most, mirrors what I see on this side of the beginning and who shall say that mirror is not real?

Encouraged therefore to assume that neither God nor the Devil puts fossils in the rocks to test or tempt Christians let us look back beyond $t = 1$ second and see what we can descry.

The First Moments

Looking back towards the earliest moments of the Universe is closely related to researching deeper and deeper into the nature of matter. Modern elementary particle physics started with the search for the basic building blocks of the Universe. As everyone knows the Greeks had a word for such blocks, *atomos*, and in the last century it was realised that there were several score different elemental atoms. Even then it had been suggested that these atoms were really made up of hydrogen — a hypothesis which is correct in essence since although the hydrogen nucleus contains only a proton, carrying one atomic unit of positive charge, and other elements contain also neutrons having about the same mass but no charge, we now know how protons and neutrons transmute into one another with the aid of electrons (or their antiparticles) and some further mysterious and elusive particles known as neutrinos. The structure of atomic nuclei is studied by examing the effects of an impact from a high energy subatomic projectile such as an electron or a gamma-ray photon. The main function of the projectile is to supply energy to the system under study so as to break it down into its constituents, but here we encounter a problem. Energy can create new particles and as higher and higher energy projectiles become available from huge particle accelerators so a bewildering spectrum of known and unknown particles materialised at the points of impact. Increasingly over the last two decades order has been introduced into this chaos by the demonstration that even the neutron and proton, and indeed the transient pion (π-meson) which binds them together, have a structure. The components that constitute them are called quarks and these are helpfully conceived as bound together by transient gluons.

This is not the place to dwell at length on the beauty and symmetry of modern elementary particle physics but firstly to draw the parallel that as we approach either $t = 0$ or sub-protonic space we find a world in which Heisenberg's Uncertainty reigns in its most creative and positive role and in which particles come and go in a way that must shatter any simplistic or grossly materialistic ideas and secondly to note that whatever particles may exist at the heart of such basic atomic constituents as neutrons and protons or may materialise when electromagnetic radiation interacts with matter, we can expect to find also in the early moments of existence in what was formerly called the primordial atom. Thirdly and more mysteriously and uncertainly we can note that while twenty years ago or less it would have been claimed that there are four fundamental forces of nature — electromagnetic, the weak nuclear force of radioactivity, the strong nuclear force which binds the nucleus of atoms and gravity which rules the Cosmos — today the first two of these are seen as aspects of a single type of process unified by a single theory. Symmetry ideas suggest that the six basic elementary particles with their six antiparticles (they are called leptons) which interact, as described by this unified theory, have counterparts in six types of quark (with their antiquarks) which account for the strong nuclear force. These quarks, only five of them have been discovered, at the time of writing seem to come in three different kinds called colours for want of a better name; hence the name of the theory Quantum Chromo-dynamics. The symmetry between the leptons and quarks points strongly to a basic, as yet undiscovered unity, and already there are hints that gravity, the fourth fundamental force may be brought into the fold.

In a situation where even the most elementary particles can change into others (quarks can decay radioactively for example; indeed this is the basic event of beta radioactivity), where they can annihilate or materialise with their antiparticles and where the intense gravity (space curvature) of the early Universe may itself create particle pairs as the intense electromagnetic fields of gamma-rays do it is important to enquire what, if anything, is conserved. Conservation laws in fact are amongst the most important in physics.

Our understanding of the Universe so far, which is the eating which proves the pudding, suggests that total energy is conserved (remembering $E = mc^2$) in elementary particle interactions, in the Universe as a whole and in everything in between. Electric charge is similarly conserved and so, it would appear is the mysterious colour of quarks. A charged particle is never found to come or go without its antiparticle keeping the net change in charge zero. Momentum and angular momentum are also conserved.

As we address the earliest moments we will abandon the reversed action replay approach and simply suppose that all the energy of the Universe at a time very close to $t = 0$ was an enormously rapidly varying, unimaginably intense electromagnetic field. That is a description of light of all wavelengths, far beyond the visible spectrum. Whatever the writer of Genesis 1.2 understood by his words and whatever God meant him to teach no big bang cosmologist could quarrel on cosmological grounds with an exegisis that applied "And God said let there be light" to a time close to $t = 10^{-43}$ second Before that perhaps we should invoke the wholly unclassical quantum gravitational soup described by Hawking as a "foam of constantly exploding and reforming mini black holes". Now, as we have seen, Quantum Physics recognises electromagnetic radiation not only as varying electric and magnetic fields but complementarily as individual photons (quanta) each with an energy defined by the frequency of the variations in the field. These photons when sufficiency energetic, and as we have seen at 10^{14} K most of them are, can create pairs of particles.

During the brief millisecond while the expanding Universe cooled from 10^{14} to 10^{12} K we can imagine literally all kinds of elementary particles being created and, colliding again because of the great density with its twin or another antiparticle, annihilating in a fresh burst of gamma-radiation. At this time those mysterious leptons, the neutrinos, would leave the game but not the field. Neutrinos are mysterious because they hardly react with matter at all. Those generated (and there are many) deep in the Sun have little difficulty in passing out and on reaching the Earth, for example, for the most to part pass right through totally unaffected. It is just because a neutrino can go so far in dense matter without any interaction that I say that at about $t = 10^{-3}$ seconds they leave the game. They just do not play any more part in the mêlée of interactions which is going on. But I mention them because they may still be important for at least two reasons. First since they are so unreactive they are still in the field, still around in huge quantities and may contribute to the unobservable (at present) mass of the Universe. Secondly because few of them have interacted with anything since $t = 10^{-3}$ seconds. If we ever find a way of observing them we will be directly observing right back to the end of the first millisecond of the Universe.

At the moment the important question of whether they have a rest mass is being vigorously pursued, firstly because it bears on the whole question of our understanding of the relationships between fundamental particles. It is an intriguing point that the properties of these mysterious barely observable particles may hold the clue to such questions as to why the Universe is not all radiation or at any rate not matter and antimatter in equal quantities, whether the Universe is closed, that it will eventually contract to a Big Crunch. They relate also to the question of the finite life of all gross matter — the half life of a proton may be (only!) 10^{30} years. Neutrinos, like photons outnumber other particles by 10^{8} to 10^{9}. Even a rest mass of 10 eV would point to a final event. But that is another story.

Reason, Design and Form

Such then is God's workshop, an expanding space in whose initial chaos randomness and order are indistinguishable, where in a "light that no man can approach unto" He set out His bench, assembled His tools, collected His materials and prepared as He evolved the Universe to pursue His creative craft. And "those whom He foreknew He also predestined to be conformed to the image of His Son."