Paul Davies: The Mind of God

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## Can the Universe Create Itself?

'Science must provide a mechanism for the universe to come into being.' — John Wheeler

We usually think of causes as preceding their effects. It is therefore natural to try and explain the universe by appealing to the situation at earlier cosmic epochs. But even if we could explain the present state of the universe in terms of its state a billion years ago, would we really have achieved anything, except moving the mystery back a billion years? For we would surely want to explain the state a billion years ago in terms of some still earlier state, and so on. Would this chain of cause and effect ever end? The feeling that 'something must have started it all off' is deeply ingrained in Western culture. And there is a widespread assumption that this 'something' cannot lie within the scope of scientific inquiry; it must be in some sense supernatural. Scientists, so the argument goes, might be very clever at explaining this and that. They might even be able to explain everything within the physical universe. But at some stage in the chain of explanation they will reach an impasse, a point beyond which science cannot penetrate. This point is the creation of the universe as a whole, the ultimate origin of the physical world.

This so-called cosmological argument has in one form or another often been used as evidence for the existence of God. Over the centuries it has been refined and debated by many theologians and philosophers, sometimes with great subtlety. The enigma of the cosmic origin is probably the one area where meaningful historical progression – the Fall, the Covenant, the Incarnation and Resurrection, the Second Coming – pervades these religions, and stands in stark contrast to the Greek notion of the eternal return. In their anxiety to adhere to linear, rather than cyclic, time, the early Church Fathers denounced the cyclic world view of the pagan Greek philosophers, notwithstanding their general admiration for all Greek thinking. Thus we find Thomas Aquinas acknowledging the power of Aristotle's philosophical arguments that the universe must always have existed, but appealing for belief in a cosmic origin on biblical grounds.

A key feature of the Judeo-Christian creation doctrine is that the Creator is entirely separate from and independent of his creation; that is, God's existence does not automatically ensure the existence of the universe, as in some pagan schemes where the physical world emanates from the Creator as an automatic extension of his being. Rather, the universe came into existence at a definite instant in time as an act of deliberate supernatural creation by an already existing being.

Straightforward though this concept of creation may seem, it caused intense doctrinal dispute over the centuries, partly because the old texts are somewhat vague on the matter. The biblical description of Genesis, for example, which drew heavily on earlier creation myths from the Middle East, is long on poetry and short on factual details. No clear indication is given of whether God merely brings order to a primordial chaos, or creates matter and light in a pre-existing void, or does something even more profound. Uncomfortable questions abound. What was God doing before he created the universe? Why did he create it at that moment in time rather than some other? If he had been content to endure for eternity without a universe, what caused him to 'make up his mind' and create one?

The bible leaves plenty of room for debate on these issues. And debate there certainly has been. In fact, much Christian doctrine concerning the creation was developed long after Genesis was written, and was influenced as much by Greek as by



Judaic thought. Two issues in particular are of interest from the scientific point of view. The first is God's relation to time; the second is his relation to matter.

The principal Western religions all proclaim God to be eternal, but the word 'eternal' can have two rather different meanings. On the one hand, it can mean that God has existed for an infinite duration of time in the past and will continue to exist for an infinite duration in the future; or it can mean that God is outside of time altogether. As I mentioned in chapter 1, Saint Augustine opted for the latter when he asserted that God made the world 'with time and not in time.' By regarding time as *part of* the physical universe, rather than something in which the creation of the universe happens, and placing God right outside it altogether, Augustine neatly avoided the problem of what God was doing before the creation.

This advantage is bought at a price, however. Everybody can see the force of the argument that 'something must have started it all off.' In the seventeenth century it was fashionable to regard the universe as a gigantic machine that had been set in motion by God. Even today, many people like to believe in God's role as a Prime Mover or First Cause in a cosmic chain of causation. But what does it mean for a God who is outside of time to cause anything? Because of this difficulty, believers in a timeless God prefer to emphasize his role in upholding and sustaining the creation at every moment of its existence. No distinction is drawn between creation and preservation: both are, to God's timeless eyes, one and the same action.

God's relationship to matter has similarly been the subject of doctrinal difficulties. Some creation myths, such as the Babylonian version, paint a picture of the cosmos created out of primordial chaos. ('Cosmos' literally means 'order' and 'beauty'; the latter aspect survives in the modern word 'cosmetic.') According to this view, matter precedes, and is ordered by, a supernatural creative act. A similar picture was espoused in classical Greece: Plato's Demiurge was restricted by having to work with already existing material. It was also the position taken by the Christian Gnostics, who regarded matter as corrupt, and therefore a product of the devil rather than God.

Actually, the blanket use of the word 'God' in these discussions can be rather confusing, given the wide variety of theological schemes that have been proposed throughout history. Belief in a divine being who starts the universe off and then 'sits back' to watch events unfold, taking no direct part in subsequent affairs, is known as 'deism.' Here God's nature is captured by the image of the perfect watchmaker, a sort of cosmic engineer, who designs and constructs a vast and elaborate mechanism and then sets it going. In contrast to deism is 'theism,' belief in a God who is creator of the universe, but who also remains directly involved in the day-to-day running of the world, especially the affairs of human beings, with whom God maintains a continuing personal relationship and guiding role. In both deism and theism a sharp distinction is made between God and the world, between creator and creature. God is regarded as wholly other than, and beyond, the physical universe, although he is still responsible for that universe. In the system known as 'pantheism,' no such separation is made between God and the physical universe. Thus God is identified with nature itself: everything is part of God, and God is in everything. There is also 'panentheism,' which resembles pantheism in that the universe is part of God, but in which it is not all of God. One metaphor is that of the universe as God's body.

Finally, a number of scientists have proposed a type of God who evolves within the universe, eventually becoming so powerful he resembles Plato's Demiurge. One can envisage, for example, intelligent life or even machine intelligence gradually becoming more advanced and spreading throughout the cosmos, gaining control over larger and larger portions until its manipulation of matter and energy is so refined that this intelligence would be indistinguishable from nature itself. Such a God-like intelligence could develop from our own descendants, or even have developed already from some extraterrestrial community or communities. Fusion of two or more different intelligences during this evolutionary process is conceivable. Systems of this sort have been proposed by the astronomer Fred Hoyle, the physicist Frank Tipler, and the writer Isaac Asimov. The 'God' in these schemes is clearly less than the universe and, though immensely powerful, is not omnipotent, and cannot be regarded as the creator of the universe as a whole, only of part of its organized content. (Unless, that is, some peculiar arrangement of backward causation is introduced, whereby the superintelligence at the end of the universe acts backward in time to create that universe, as part of a self-consistent causal loop. There are hints of this in the ideas of physicist John Wheeler. Fred Hoyle has also discussed such a scheme, but not in the context of an all-embracing creation event.)



## *Creation from Nothing*

The pagan creation myths assume the existence of both material stuff and a divine being, and so are fundamentally dualistic. By contrast, the early Christian Church settled on the doctrine of 'creation *ex nihilo*,' in which God alone is necessary. He is taken to have created the entire universe from nothing. The origin of all things visible and invisible, including matter, is thus attributed to a free creative act by God. An important component in this doctrine is God's omnipotence: there is no limitation to his creative power, as was the case with the Greek Demiurge. Indeed, not only is God not limited to work with pre-existing matter, he is not limited by pre-existing physical laws either, for part of his creative act was to bring those laws into being and thereby establish the order and harmony of the cosmos. The Gnostic belief that matter is corrupt is rejected as being incompatible with the Incarnation of Christ. On the other hand, neither is matter divine, as in pantheistic schemes, where all nature is

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infused with God's presence. The physical universe – God's creature – is regarded as distinct and separate from its creator.

The importance of the distinction between creator and creature in this system is that the created world depends absolutely for its existence on the creator. If the physical world itself were divine, or somehow emanated directly from the creator, then it would share the creator's necessary existence. But because it was created from nothing, and because the creative act was a free choice of the creator, the universe does not have to exist. Thus Augustine writes: 'You created something, and that something out of nothing. You made heaven and earth, not out of yourself, for then they would have been equal to your Only-begotten, and through this equal also to you.'[22] The most obvious distinction between creator and creature is that the creator is eternal whereas the created world has a beginning. Thus the early Christian theologian Iranaeus wrote: 'But the things established are distinct from Him who has established them, and what have been made from Him who has made them. For He is Himself uncreated, both without beginning and end, and lacking nothing. He is Himself sufficient for this very thing, existence; but the things which have been made by Him have received a beginning.'[23]

Even today there remain doctrinal differences within the main branches of the Church, and still greater differences among the various world religions, concerning the meaning of creation. These range from the ideas of Christian and Islamic fundamentalists, based on a literal interpretation of the traditional texts, to those of radical Christian thinkers who prefer a totally abstract view of creation. But all agree that in one sense or another the physical universe on its own is incomplete. It cannot explain itself. Its existence ultimately demands something outside of itself, and can be understood only from its dependence on some form of divine influence.



### *The Beginning of Time*

Turning to the scientific position on the origin of the universe, one can again ask about the evidence that there actually was an origin. It is certainly possible to conceive of a universe of infinite duration, and for much of the modern scientific era, following the work of Copernicus, Galileo, and Newton, scientists did in fact generally believe in an eternal cosmos. There were, however, some paradoxical aspects to this belief. Newton was worried about the consequences of his law of gravity, which holds that all matter in the universe attracts all other matter. He was puzzled about why the whole universe does not simply fall together into one great mass. How can the stars hang out there in space forever, unsupported, without being pulled toward each other by their mutual gravitational forces? Newton proposed an ingenious solution. For the universe to collapse to its center of gravity, there has to *be* a center of gravity. If, however, the universe were infinite in spatial extent, and on average populated uniformly by stars, then there would be no privileged center toward which the stars could fall. Any given star would be tugged similarly in all directions, and there would be no resultant force in any given direction.

This solution is not really satisfactory, because it is mathematically ambiguous: the various competing forces are all infinite in magnitude. So the mystery of how the universe avoids collapse kept recurring, and persisted into the present century. Even Einstein was perplexed. His own theory of gravitation (the general theory of relativity) was formulated in 1915, and almost immediately 'fixed up' in an attempt to explain the stability of the cosmos. The fix consisted of an extra term in his gravitational-field equations corresponding to a force of repulsion – a type of antigravity. If the strength of this repulsive force was tuned to match the gravitational pull of all the cosmic bodies on each other, attraction and repulsion could be balanced to produce a

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static universe. Alas, the balancing act turned out to be unstable, so that the merest disturbance would cause one or the other of the competing forces to win out, either dispersing the cosmos in a runaway outward rush, or sending it crashing inward.

Nor was the collapsing-cosmos mystery the only problem with an eternal universe. There was also something called Olbers' paradox, which concerned the darkness of the night sky. The difficulty here was that, if the universe is infinite in spatial extent as well as in age, then light from an infinity of stars will be pouring down upon the Earth from the heavens. A simple calculation shows that the sky could not be dark under these circumstances. The paradox can be resolved by assuming a finite age for the universe, for in that case we will be able to see only those stars whose light has had time to travel across space to Earth since the beginning.

Today, we recognize that no star could keep burning forever anyway. It would run out of fuel. This serves to illustrate a very general principle: an eternal universe is incompatible with the continuing existence of irreversible physical processes. If physical systems can undergo irreversible change at a finite rate, then they will have completed those changes an infinite time ago. Consequently, we could not be witnessing such changes (such as the production and emission of starlight) now. In fact, the physical universe abounds with irreversible processes. In some respects it is rather like a clock slowly running down. Just as a clock cannot keep running forever, so the universe cannot have been 'running' forever without being 'rewound.'

These problems began to force themselves on scientists during the mid-nineteenth century. Until then physicists had dealt with laws that are symmetric in time, displaying no favoritism between past and future. Then the investigation of thermodynamic processes changed that for good. At the heart of thermodynamics lies the second law, which forbids heat to flow spontaneously from cold to hot bodies, while allowing it to flow from hot to cold. This law is therefore not reversible: it imprints



upon the universe an arrow of time, pointing the way of unidirectional change. Scientists were quick to draw the conclusion that the universe is engaged in a one-way slide toward a state of thermodynamic equilibrium. This tendency toward uniformity, wherein temperatures even out and the universe settles into a stable state, became known as the 'heat death.' It represents a state of maximum molecular disorder, or entropy. The fact that the universe has not yet so died – that is, it is still in a state of less-than-maximum entropy – implies that it cannot have endured for all eternity.

In the 1920s astronomers discovered that the traditional picture of a static universe was in any case wrong. They found that the universe is, in fact, expanding, with the galaxies rushing away from each other. This is the basis of the well-known big-bang theory, according to which the entire universe came into existence abruptly, about fifteen billion years ago, in a gigantic explosion. The expansion seen today can be regarded as a vestige of that primeval outburst. The discovery of the big bang has often been hailed as confirmation of the biblical account of Genesis. Indeed, in 1951 Pope Pius XII alluded to it in an address to the Pontifical Academy of Sciences. Of course, the big-bang scenario bears only the most superficial resemblance to Genesis, so that the latter has to be interpreted in an almost completely symbolic way for any connection to be made. About the best that can be said is that both accounts demand an abrupt rather than a gradual beginning, or no beginning at all.

The big-bang theory automatically evades the paradoxes of an eternal cosmos. Because the universe is finite in age, there are no problems with irreversible processes. The universe evidently began, in some sense, 'wound up,' and is currently still busy unwinding. The night sky is dark because we can see only a finite distance into space (about fifteen billion light-years), this being the maximum distance from which light has been able to travel to Earth since the beginning. Nor is there a difficulty

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about the universe collapsing under its own weight. Because the galaxies are flying apart, they avoid falling together, at least for a while.

Nevertheless, the theory solves one set of problems only to be confronted by another, not least of which is to explain what caused the big bang in the first place. It is here that we encounter an important subtlety about the nature of the big bang. Some popular accounts give the impression that it was the explosion of a concentrated lump of matter located at some particular place in a pre-existing void. This is badly misleading. The big-bang theory is based on Einstein's general theory of relativity. One of the main features of general relativity is that the affairs of matter cannot be separated from the affairs of space and time. It is a linkage that has profound implications for the origin of the universe. If one imagines 'running the cosmic movie backward,' then the galaxies get closer and closer together until they merge. Then the galactic material gets squeezed more and more, until a state of enormous density is reached. One might wonder whether there is any limit to the degree of compression as we pass back to the moment of explosion.

It is easy to see that there can be no simple limit. Suppose that there were a state of maximum compression. This would imply the existence of some sort of outward force to overcome the enormous gravity; otherwise gravity would win, and the material would be still more compressed. Furthermore, this outward force would have to be truly enormous, because the inward force of gravity rises without limit as the compression rises. So what could this stabilizing force be? A type of pressure or material stiffness, perhaps — who knows what forces nature might deploy under such extreme conditions? However, although we do not know the details of the forces, certain general considerations must still apply. For example, as the material gets stiffer and stiffer, so the speed of sound in the cosmic material gets faster. It seems clear that, if the stiffness of the primeval cosmic material were to become large enough, the



speed of sound would exceed the speed of light. But this is strictly contrary to the theory of relativity, which requires that no physical influence should travel faster than light. Therefore, the material cannot ever have been infinitely stiff. Consequently, at some stage during the compression, the force of gravity would have been greater than the stiffness force, which implies that the stiffness would have been unable to contain gravity's compressing tendency.

The conclusion that was drawn concerning this tussle between primeval forces was that, under conditions of extreme compression such as occurred during the big bang, there is no force in the universe capable of beating off the crushing power of gravity. The crushing has no limit. If the matter in the universe were spread uniformly, then it must have been infinitely compressed at the first moment. In other words, the entire cosmos would have been squeezed into a single point. At this point the gravitational force, and the density of material, were infinite. A point of infinite compression is known to mathematical physicists as a 'singularity.'

Although one is led on quite elementary grounds to expect a singularity at the origin of the universe, it required a mathematical investigation of some delicacy to establish the result rigorously. This investigation was mainly the work of British mathematical physicists Roger Penrose and Stephen Hawking. In a series of powerful theorems, they proved that a big-bang singularity is inevitable as long as gravity remains an attractive force under the extreme conditions of the primeval universe. The most significant aspect of their results is that a singularity isn't avoided even if the cosmic material is distributed unevenly. It is a general feature of a universe described by Einstein's theory of gravitation — or, for that matter, any similar theory.

There was a lot of resistance to the idea of a big-bang singularity among physicists and cosmologists when it was first mooted. One reason for this concerns the above-mentioned fact that matter, space, and time are linked in the general theory of relativity. This linkage carries important implications for the nature of the expanding universe. Naïvely, one might suppose that the galaxies are rushing apart through space. A more accurate picture, however, is to envisage space itself as swelling or stretching. That is, the galaxies move apart because the space between them expands. (Readers who are unhappy about the idea that space can stretch are referred to my book *The Edge of Infinity* for further discussion.) Conversely, in the past, space was shrunken. If we consider the moment of infinite compression, space was infinitely shrunk. But if space is infinitely shrunk, it must literally disappear, like a balloon that shrivels to nothing. And the all-important linkage of space, time, and matter further implies that time must disappear too. There can be no time without space. Thus the material singularity is also a space-time singularity. Because all our laws of physics are formulated in terms of space and time, these laws cannot apply beyond the point at which space and time cease to exist. Hence the laws of physics must break down at the singularity.

The picture that we then obtain for the origin of the universe is a remarkable one. At some finite instant in the past the universe of space, time, and matter is bounded by a space-time singularity. The coming-into-being of the universe is therefore represented not only by the abrupt appearance of matter, but of space and time as well.

The significance of this result cannot be overstressed. People often ask: Where did the big bang occur? The bang did not occur at a point in space at all. Space itself came into existence with the big bang. There is similar difficulty over the question: What happened before the big bang? The answer is, there was no 'before.' Time itself began at the big bang. As we have seen, Saint Augustine long ago proclaimed that the world was made with time and not in time, and that is precisely the modern scientific position.

Not all scientists were prepared to go along with this, however. While accepting the expansion of the universe, some cosmologists attempted to construct theories that nevertheless avoided a singular origin to space and time.



### *Cyclic World Revisited*

In spite of the strong Western tradition for a created universe and a linear time, the lure of the eternal return always lies just beneath the surface. Even during the modern big-bang era there have been attempts to reinstate a cyclic cosmology. As we have seen, when Einstein formulated his general theory of relativity, scientists still believed in a static cosmos, and this prompted Einstein to 'fix up' his equations to create a gravitational–levitational equilibrium. Meanwhile, however, an obscure Russian meteorologist by the name of Alexander Friedmann began studying Einstein's equations and their implications for cosmology. He discovered several interesting solutions, all of which describe a universe that either expands or contracts. One set of solutions corresponds to a universe that starts out at a big bang, expands at an ever-diminishing rate, and then starts to contract again. The contracting phase mirrors the expanding phase, so that the contraction gets faster and faster until the universe disappears at a 'big crunch' – a catastrophic implosion like the big bang in reverse. This cycle of expansion and contraction can then be continued into another cycle, then another, and so on *ad infinitum* (see figure 1). In 1922 Friedmann sent the details of his periodic-universe model to Einstein, who wasn't impressed. It was only some years later, with the discovery by Edwin Hubble and other astronomers that the universe is indeed expanding, that Friedmann's work came to be properly recognized.

Friedmann's solutions do not compel the universe to oscillate with phases of expansion and contraction. They also provide for a universe which starts out at a big bang and goes on expanding forever. Which of these alternatives prevails turns

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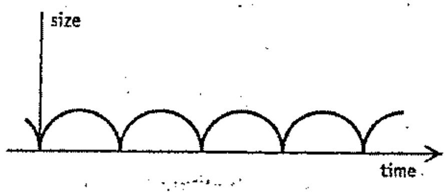


**Figure 1.** Oscillating universe. The graph shows how the size of the universe varies with time as it expands and contracts in a cyclic manner.

out to depend on the amount of matter that exists in the universe. Basically, if there is enough matter, its gravity will eventually halt the cosmic dispersal, and bring about recollapse. Thus Newton's fear of cosmic collapse would actually be realized, albeit only after billions of years had elapsed. Measurements reveal that the stars constitute only about 1 percent of the density needed to collapse the universe. However, there is strong evidence for a large amount of dark or invisible matter, possibly enough to make up the deficit. Nobody is sure what this 'missing matter' is.

If there is sufficient matter to cause recontraction, we have to consider the possibility that the universe might be pulsating, as indicated in figure 1. Many popular books on cosmology feature the pulsating model, and point out its consistency with Hindu and other Eastern cosmologies of a cyclic nature. Could it be that Friedmann's oscillating solution is the scientific counterpart of the ancient idea of the eternal return, and that the multibillion-year duration from big bang to big crunch represents the Great Year of the Life Cycle of Brahma?

Appealing though these analogies may seem, they fail to hold up to scrutiny. First of all, the model isn't strictly periodic in the mathematical sense. The points of turnaround from big crunch to big bang are actually singularities, which means that the equations concerned break down there. In order for the



universe to bounce from a contraction to an expansion without encountering singularities, it is necessary for something to reverse the pull of gravity and propel the material outward again. In essence, a bounce is possible only if the motion of the universe is overwhelmed by a huge repulsive (i.e., levitational) force, such as the 'fix-up' force Einstein suggested, but bigger in magnitude by an enormous factor.

Even if a mechanism to do this could be contrived, the cyclicity of the model concerns only the gross motion of the cosmos, and ignores the physical processes within it. The second law of thermodynamics still demands that these processes generate entropy, and that the total entropy of the universe goes on rising from one cycle to the next. The result is a rather curious effect, discovered by Richard Tolman in the 1930s. Tolman found that, as the entropy of the universe rises, so the cycles grow bigger and bigger, and last longer and longer (figure 2). The upshot is that the universe isn't strictly cyclic at all. Strangely, in spite of the continued rise in entropy, the universe never reaches thermodynamic equilibrium – there is no maximum-entropy state. It just goes on pulsating forever, generating more and more entropy along the way.

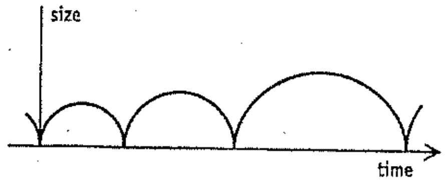


**Figure 2.** In a more realistic model of an oscillating universe, the cycles grow larger with time.

In the 1960s the astronomer Thomas Gold believed he had found a truly cyclic model of the universe. Gold knew that an eternally static universe is untenable because it would reach thermodynamic equilibrium in a finite time. He was struck by

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the fact that the expansion of the universe worked against thermodynamic equilibrium by continuously cooling the cosmic material (this is the familiar principle that matter cools when expanded). It seemed to Gold that the rise in cosmic entropy could be attributed to the fact that the universe is expanding. But this conclusion carried with it the hint of a remarkable prediction: if the universe were to contract, everything would run backward – entropy would fall again, and the second law of thermodynamics would be reversed. In a sense, time would flow backward. Gold pointed out that this reversal would apply to all systems, including the human brain and memory, so that the psychological arrow of time would also be reversed: we would 'remember the future' instead of the past. Any conscious beings living in what we would regard as the contracting phase would reverse our definitions of past and future, and also consider themselves as living during the expanding phase of the universe (figure 3). By their definition, ours would be the contracting phase. If, as a result of the reversal, the universe were truly symmetric in time, then the final state of the universe at the big crunch would be identical to its state

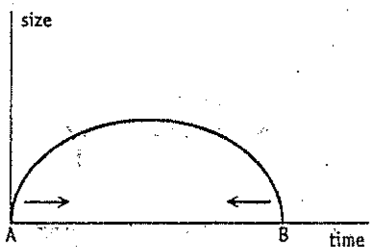


**Figure 3.** Time-reversing universe. During the expanding phase time runs forward, and during the contracting phase it runs backward. As a result, it is possible to identify the first and last moments A and B, thus closing time into a loop.



at the big bang. These two events could therefore be identified, and time closed into a loop. In that case the universe would indeed be cyclic.

The time-symmetric universe was also investigated by John Wheeler, who conjectured that the turnaround might not occur abruptly, but gradually, like the turning of the tide. Instead of the arrow of time suddenly reversing at the epoch of maximum expansion, perhaps it might slowly falter and then fade away altogether before swinging round to point the other way. Wheeler speculated that as a result some apparently irreversible processes, such as the decay of radioactive nuclei, might show signs of slowing down ahead of the reversal. He suggested that a comparison of the rates of radioactive decay now with their values in the remote past might indicate such a slowing down.

Another phenomenon that displays a distinct arrow of time is the emission of electromagnetic radiation. A radio signal, for example, is always received after it is sent, never before. This is because, when radio transmitters generate radio waves, the waves flow outward from the antenna into the depths of the universe. We never observe organized patterns of radio waves coming from the edges of the universe and converging onto radio antennae. (The technical term for outflowing waves is 'retarded,' whereas inflowing waves are 'advanced.') If, however, the arrow of time were to reverse in the contracting phase of the universe, then the direction of radio-wave motion would also have to reverse – retarded waves would be replaced by advanced waves. In the context of Wheeler's 'turning of the tide,' this would suggest that close to the big bang all radio waves would be retarded; then, as the epoch of maximum expansion was approached, so increasing amounts of advanced waves would occur. At maximum, there would be equal advanced and retarded waves, whereas during the contracting phase advanced waves would dominate. If this idea is correct, it would imply that there is a very slight admixture of advanced radio waves at our present cosmic epoch. In effect, these would be radio waves 'from the future.'

Fanciful though the idea may seem, it was put to the test in an experiment performed by the astronomer Bruce Partridge in the 1970s. The principle of the experiment is that, if radio waves emitted by an antenna are directed toward a screen where they are absorbed, the waves will be 100 percent retarded; if they are allowed to flow away into space, part of them will continue unaffected until the 'tide has turned.' The latter, but not the former, set of waves might then possess a tiny advanced component. If that is the case, the advanced waves will put back into the antenna a small fraction of the energy that the retarded waves took out. The effect would be to produce a slight difference in the energy drain from the antenna when it is beamed at the screen as opposed to space. In spite of the high sensitivity of the measurements, however, Partridge found no evidence for advanced waves.

Beguiling though the time-symmetric universe may be, it is very hard to argue for it plausibly. Statistically, the overwhelming majority of possible initial states of the universe will *not* produce reversal, so only if the state of the universe is selected to belong to a very peculiar and special set will 'the tide turn.' The situation can be compared to a bomb exploding inside a steel container. It is possible to imagine all the fragments of the bomb rebounding in unison from the walls of the container and coming back together to reconstitute the bomb. That sort of conspiratorial behavior is not strictly impossible, but it requires an incredibly contrived set of circumstances.

Nevertheless, the time-symmetric universe idea has proved sufficiently compelling that even Stephen Hawking recently flirted with it as part of his quantum cosmology program, which I shall explain shortly. However, following more detailed investigation, Hawking admitted that his proposal was misconceived.



## Continuous Creation

Thomas Gold tells the story that one evening in the late 1940s he and Hermann Bondi were walking back from the cinema, having seen a movie called *Dead of Night*, about dreams within dreams that formed an endless sequence. On the way home it suddenly occurred to them that the theme of the film might be an allegory for the universe. Perhaps there *was* no beginning, no big bang even. Maybe the universe instead has a means of continuously replenishing itself so that it can keep going forever.

In the subsequent months Bondi and Gold fleshed out their idea. The central feature of the Bondi–Gold theory is that there was no big-bang origin of the universe at which all matter was created. Instead, as the universe expands, new particles of matter are continuously created to fill up the gaps so that the average density of matter in the universe remains unchanged. Any individual galaxy will pass through a life cycle of evolution, culminating in its death when the stars burn out, but new galaxies are able to form from the newly created matter. At any given time there will be a mixture of galaxies of various ages, but the very old galaxies will be very sparsely distributed, because the universe will have expanded a lot since their birth. Bondi and Gold envisaged the rate of expansion of the universe to remain constant, and the rate of matter creation to be just such as to maintain a constant average density. The situation is similar to that of a river which looks the same overall, even though water is continuously flowing through it. The river is not static, but in a steady state. The theory therefore became known as the 'steady-state theory' of the universe.

The steady-state universe has no beginning or end, and looks the same on average at all cosmic epochs, in spite of the expansion. The model avoids the heat death, because the injection of new matter also injects negative entropy: to return to the watch analogy, it continuously rewinds the watch. Bondi and Gold

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gave no detailed mechanism to explain how matter is created, but their colleague Fred Hoyle had been working on just this problem. Hoyle investigated the possibility of a 'creation field' that would have the effect of producing new particles of matter. Because matter is a form of energy, Hoyle's mechanism might be construed as violating the law of conservation of energy, but this need not be so. The creation field itself carries negative energy, and by arranging things carefully, it is possible for the positive energy of the created matter to be compensated exactly by the enhanced negative energy of the creation field. From a mathematical study of this interplay, Hoyle discovered that his creation-field cosmological model automatically tended toward, and then remained in, the steady-state condition required by the theory of Bondi and Gold.

Hoyle's work gave the necessary theoretical underpinning to ensure that the steady-state theory was taken seriously, and for a decade or more it was considered to be an equal contender with the big-bang theory. Many scientists, including the originators of the steady-state theory, felt that by abolishing the big bang they had once and for all removed the need for any sort of supernatural explanation for the universe. In a universe with no beginning there is no need for a creation event or a creator, and a universe with a physical creation field to make it "self-winding" doesn't require any divine intervention to keep it running.

Actually, the conclusion is a *non sequitur*. The fact that the universe might have no origin in time does not explain its existence, or why it has the form it does. Certainly it does not explain why nature possesses the relevant fields (such as the creation field) and physical principles that establish the steady-state condition. Ironically, some theologians have actually welcomed the steady-state theory as a *modus operandi* for God's creative activity. After all, a universe that lives forever, avoiding the heat death, has considerable theological appeal. Around the turn of the century the mathematician and philosopher Alfred North Whitehead founded the so-called process school of theology. Process theologians reject the traditional Christian concept of creation out of nothing in favor of a universe that had no beginning. God's creative activity manifests itself instead as an ongoing process, a creative advance in nature's activity. I shall return to the topic of creative cosmology in chapter 7.



In the event, the steady-state theory fell out of favor not on philosophical grounds, but because it was falsified by observations. The theory made the very specific prediction that the universe should look the same on average at all epochs, and the advent of large radio telescopes enabled this prediction to be tested. When astronomers observe very distant objects, these do not appear as they are today, but as they were in the remote past, when the light or radio waves left them on their long journey to Earth. These days, astronomers can study objects that are many billions of light-years away, so that we see them as they were many billions of years ago. Thus a deep space survey can provide 'snapshots' of the universe at successive epochs, for comparison. By the mid-1960s it became clear that several billion years ago the universe would have looked very different from the way it does now, in particular vis-à-vis the numbers of various types of galaxies.

The final nail in the coffin of the steady-state theory came in 1965 with the discovery that the universe is bathed in heat radiation at a temperature of about three degrees above absolute zero. This radiation is believed to be a direct relic of the big bang, a sort of fading glow of the primeval heat that accompanied the birth of the cosmos. It is hard to understand how such a radiation bath could have arisen without the cosmic material having once been highly compressed and exceedingly hot. Such a state does not occur in the steady-state theory. Of course, the fact that the universe is not in a steady state does not mean that continuous creation of matter is impossible, but the motivation for Hoyle's creation field is largely undermined once it is established that the universe is evolving. Nearly all cosmologists

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now accept that we live in a universe that had a definite beginning in a big bang, and is developing toward an uncertain end.

If one accepts the idea that space, time, and matter had their origin in a singularity that represents an absolute boundary to the physical universe in the past, a number of puzzles follow. There is still the problem of what caused the big bang. However, this question must now be seen in a new light, for it is not possible to attribute the big bang to anything that happened *before* it, as is usually the case in discussions of causation. Does this mean the big bang was an event without a cause? If the laws of physics break down at the singularity, there can be no explanation in terms of those laws. Therefore, if one insists on a reason for the big bang, then this reason must lie beyond physics.

### *Did God Cause the Big Bang?*

Many people have an image of God as a sort of pyrotechnic engineer, lighting the blue touch-paper to ignite the big bang, and then sitting back to watch the show. Unfortunately, this simple picture, while highly compelling to some, makes little sense. As we have seen, a supernatural creation cannot be a causative act in time, for the coming-into-being of time is part of what we are trying to explain. If God is invoked as an explanation for the physical universe, then this explanation cannot be in terms of familiar cause and effect.

This recurring problem of time was recently addressed by the British physicist Russell Stannard, who draws the analogy between God and the author of a book. A completed book exists in its entirety, although we humans read it in a time sequence from the beginning to the end. 'Just as an author does not write the first chapter, and then leave the others to write themselves, so God's creativity is not to seem as uniquely confined to, or



even especially invested in, the event of the Big Bang. Rather, his creativity has to be seen as permeating equally all space and all time: his role as Creator and Sustainer merge.'[4]

Quite apart from the problems of time, there are several additional pitfalls involved in invoking God as an explanation for the big bang. To illustrate them I shall relate an imaginary conversation between a theist (or, more properly, a deist), who claims that God created the universe, and an atheist, who 'has no need of this hypothesis.'

Atheist: At one time, gods were used as an explanation for all sorts of physical phenomena, such as the wind and the rain and the motion of the planets. As science progressed, so supernatural agents were found to be superfluous as an explanation for natural events. Why do you insist on invoking God to explain the big bang?

Theist: Your science cannot explain everything. The world is full of mystery. For example, even the most optimistic biologists admit that they are baffled by the origin of life.

Atheist: I agree that science hasn't explained everything, but that doesn't mean it can't. Theists have always been tempted to seize on any process that science could not at the time explain and claim that God was still needed to explain it. Then, as science progressed, God got squeezed out. You should learn the lesson that this 'God of the gaps' is an unreliable hypothesis. As time goes on, there are fewer and fewer gaps for him to inhabit. I personally see no problem in science explaining all natural phenomena, including the origin of life. I concede that the origin of the universe is a tougher nut to crack. But if, as it seems, we have now reached the stage where the only remaining gap is the big bang, it is highly unsatisfying to invoke the concept of a supernatural being who has been displaced from all else, in this 'last-ditch' capacity.

Theist: I don't see why. Even if you reject the idea that God can act directly in the physical world once it has been created, the problem of the ultimate origin of that world is in a different category altogether from the problem of explaining natural phenomena once that world exists.

Atheist: But unless you have other reasons to believe in God's existence, then merely proclaiming 'God created the universe' is totally *ad hoc*. It is no explanation at all. Indeed, the statement is essentially devoid of meaning, for you are merely defining God to be that agency which creates the universe. My understanding is no further advanced by this device. One mystery (the origin of the universe) is explained only in terms of another (God). As a scientist I appeal to Occam's razor, which then dictates that the God hypothesis be rejected as an unnecessary complication. After all, I am bound to ask, what created God?

Theist: God needs no creator. He is a necessary being – he must exist. There is no choice in the matter.

Atheist: But one might as well assert that the universe needs no creator. Whatever logic is used to justify God's necessary existence could equally well, and with an advantageous gain in simplicity, be applied to the universe.

Theist: Surely scientists often follow the same reasoning as I have. Why does a body fall? Because gravity acts on it. Why does gravity act on it? Because there is a gravitational field. Why? Because space-time is curved. And so on. You are replacing one description with another, deeper description, the sole purpose of which is to explain the thing you started with, namely, falling bodies. Why do you then object when I invoke God as a deeper and more satisfying explanation of the universe?

Atheist: Ah, but that's different! A scientific theory should amount to much more than the facts it is trying to explain. Good theories provide a simplifying picture of nature by establishing connections between hitherto disconnected phenomena. Newton's gravitational theory, for example, demonstrated a connection between the ocean tides and the motion of the moon. In addition, good theories suggest observational tests, such as predicting the existence of new phenomena. They also provide detailed mechanistic accounts of precisely how the physical processes of interest happen in terms of the concepts of the theory. In the case of gravitation, this is through a set of equations that connect the strength of the gravitational field with the nature of the gravitating sources. This theory gives you a precise mechanism for how things work. By contrast, a God who is invoked only to explain the big bang fails in all three criteria. Far from simplifying our view of the world, a Creator introduces an additional complicating feature, itself without explanation. Second, there is no way we can test the hypothesis experimentally. There is only one place where such a God is manifested – namely, the big bang – and that is over and done with. Finally, the bald statement 'God created the universe' fails to provide any real explanation unless it is accompanied by a detailed mechanism. One wants to know, for example, what properties to assign this God, and precisely how he goes about creating the universe, why the universe has the form it does, and so on. In short, unless you can either provide evidence in some other way that such a God exists, or else give a detailed account of *how* he made the universe that even an atheist like me would regard as deeper, simpler, and more satisfying, I see no reason to believe in such a being.

Theist: Nevertheless, your own position is highly unsatisfactory, for you admit that the reason for the big bang lies outside the scope of science. You are forced to accept the origin of the universe as a brute fact, with no deeper level of explanation.



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Atheist: I would rather accept the existence of the universe as a brute fact than accept God as a brute fact. After all, there has to be a universe for us to be here to argue about these things!

I shall discuss many of the issues raised in this dialogue in the coming chapters. The essence of the dispute is whether one is simply to accept the explosive appearance of the universe as a bald, unexplained fact – something belonging to the 'that's-that' category – or to seek some more satisfying explanation. Until recently it seemed as if any such explanation would have to involve a supernatural agency who transcended the laws of physics. But then a new advance was made in our understanding of the very early universe that has transformed the entire debate, and recast this age-old puzzle in a totally different light.

### *Creation without Creation*

Since the demise of the steady-state theory, scientists have seemed to be faced with a stark choice concerning the origin of the universe. One could either believe that the universe is infinitely old, with all the attendant physical paradoxes, or else assume an abrupt origin of time (and space), the explanation for which lies beyond the scope of science. What was overlooked was a third possibility: that time can be bounded in the past and yet not come into existence abruptly at a singularity.

Before getting into the details of this, let me make the general point that the essence of the origin problem is that the big bang seems to be an event without a physical cause. This is usually regarded as contradicting the laws of physics. There is, however, a tiny loophole. This loophole is called quantum mechanics. As explained in chapter 1, the application of quantum mechanics is normally restricted to atoms, molecules, and subatomic particles. Quantum effects are usually negligible for macroscopic objects. Recall that at the heart of quantum physics lies Heisenberg's uncertainty principle, which states that all measurable quantities (e.g., position, momentum, energy) are subject to unpredictable fluctuations in their values. This unpredictability implies that the microworld is indeterministic: to use Einstein's picturesque phraseology, God plays dice with the universe. Therefore, quantum events are not determined absolutely by preceding causes. Although the probability of a given event (e.g., the radioactive decay of an atomic nucleus) is fixed by the theory, the actual outcome of a particular quantum process is unknown and, even in principle, unknowable.



By weakening the link between cause and effect, quantum mechanics provides a subtle way for us to circumvent the origin-of-the-universe problem. If a way can be found to permit the universe to come into existence from nothing as the result of a quantum fluctuation, then no laws of physics would be violated. In other words, viewed through the eyes of a quantum physicist, the spontaneous appearance of a universe is not such a surprise, because physical objects are spontaneously appearing all the time – without well-defined causes – in the quantum microworld. The quantum physicist need no more appeal to a supernatural act to bring the universe into being than to explain why a radioactive nucleus decayed when it did.

All of this depends, of course, on the validity of quantum mechanics when applied to the universe as a whole. This is not clear-cut. Quite apart from the astonishing extrapolation involved in applying a theory of subatomic particles to the entire cosmos, there are deep questions of principle concerning the meaning to be attached to certain mathematical objects in the theory. But many distinguished physicists have argued that the theory can be made to work satisfactorily in this situation, and thus was the subject of 'quantum cosmology' born.

The justification for quantum cosmology is that, if the big bang is taken seriously, there would have been a time when the universe was compressed to minute dimensions. Under these circumstances quantum processes must have been important.

In particular the fluctuations described by Heisenberg's uncertainty principle must have had a profound effect on the structure and evolution of the nascent cosmos. A simple calculation tells us when that epoch was. Quantum effects were important when the density of matter was a staggering $10^{94}$ gm $cm^{-3}$. This state of affairs existed before $10^{-43}$ seconds, when the universe was a mere $10^{-33}$ cm across. These numbers are referred to as the Planck density, time, and distance respectively, after Max Planck, the originator of the quantum theory.

The ability of quantum fluctuations to 'fuzz out' the physical world on an ultramicroscopic scale leads to a fascinating prediction concerning the nature of space-time. Physicists can observe quantum fluctuations in the laboratory down to distances of about $10^{-16}$ cm and over times of about $10^{-26}$ seconds. These fluctuations affect such things as the positions and momenta of particles, and they take place within an apparently fixed space-time background. On the much smaller Planck scale, however, the fluctuations would also affect space-time itself.

To understand how, it is first necessary to appreciate the close linkage between space and time. The theory of relativity requires that we view three-dimensional space and one-dimensional time as parts of a unified four-dimensional space-time. In spite of the unification, space remains physically distinct from time. We have no difficulty in distinguishing them in daily life. This distinction can become blurred, however, by quantum fluctuations. At the Planck scale the separate identities of space and time can be smeared out. Precisely how depends on the details of the theory, which can be used to compute the relative probabilities of various space-time structures.

It may happen, as a result of these quantum effects, that the most probable structure for space-time under some circumstances is actually four-dimensional space. It has been argued by James Hartle and Stephen Hawking that precisely those circumstances prevailed in the very early universe. That is, if we imagine going backward in time toward the big bang, then,



when we reach about one Planck time after what we thought was the initial singularity, something peculiar starts to happen. Time begins to 'turn into' space. Rather than having to deal with the origin of space-time, therefore, we now have to contend with four-dimensional space, and the question arises as to the shape of that space – i.e., its geometry. In fact, the theory permits an infinite variety of shapes. Which one pertained in the actual universe is related to the problem of choosing the right initial conditions, a subject that will be discussed in more detail shortly. Hartle and Hawking make a particular choice, which they claim is natural on grounds of mathematical elegance.

It is possible to give a helpful pictorial representation of their idea. The reader is cautioned, however, not to take the pictures too literally. The starting point is to represent space-time by a diagram with time drawn vertically and space horizontally (see figure 4). Future is toward the top of the diagram, past toward the bottom. Because it is impossible to represent four dimensions properly on the page of a book, I have eliminated all but

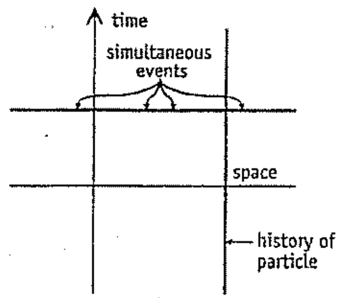


**Figure 4.** Space-time diagram. Time is drawn vertically and space horizontally. Only one dimension of space is shown. A horizontal section in the diagram represents all space at one instant of time. A vertical line represents a fixed point in space (e.g., the position of a stationary particle) throughout time.

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one dimension of space, which is nevertheless adequate to make the essential points. A horizontal slice through the diagram represents all space at one instant of time, and a vertical line represents the history of a point in space at successive times. It is helpful to imagine having this diagram drawn on a sheet of paper on which certain operations can be performed. (The reader may find it instructive actually to carry these out.)

If space and time were infinite, we would, strictly speaking, need an infinite sheet of paper for our diagram to represent space-time properly. However, if time is bounded in the past, then the diagram must have a boundary somewhere along the bottom: one can imagine cutting a horizontal edge somewhere. It may also have a future boundary, demanding a similar edge along the top. (I have denoted these by the wiggly horizontal lines in figure 5.) In that case we would have an infinite strip representing all of infinite space at successive moments from the beginning of the universe (at the bottom edge) to the end (at the top edge).

At this stage one can entertain the possibility that space is not, after all, infinite. Einstein was the first to point out that

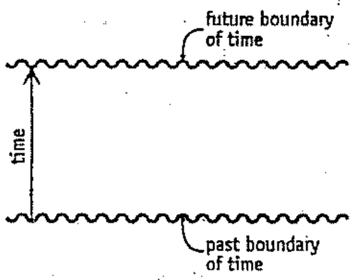


**Figure 5.** It may be that time is bounded by singularities in the past and/or future. This is represented on a space-time diagram by truncating the diagram at the bottom and top respectively. The wiggly lines denote the singularities.



space might be finite yet unbounded, and the idea remains a serious and testable cosmological hypothesis. Such a possibility is readily accommodated in our picture by rolling the sheet around to make a cylinder (figure 6). Space at each instant is now represented by a circle of finite circumference. (The two-dimensional analogue is the surface of a sphere; in three dimensions it is a so-called hypersphere, which is hard to imagine but mathematically perfectly well defined and understood.)

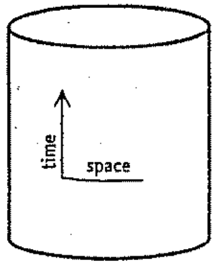


**Figure 6.** It may be that space is finite yet without boundary. This is represented by rolling the space-time diagram into a cylinder. A horizontal section, representing space at one instant, is then a circle.

A further refinement is to introduce the expansion of the universe, which may be represented by letting the size of the universe change with time. As we are concerned here with the origin of the universe, I shall ignore the top edge of the diagram, and show only that portion near the bottom. The cylinder has now become cone-shaped; a few circles are drawn to represent the expanding volume of space (figure 7). The hypothesis that the universe originated in a singularity of infinite compression is depicted here by allowing the cone to taper to a single point at the base. The singular apex of the cone represents the abrupt appearance of both space and time in a big bang.

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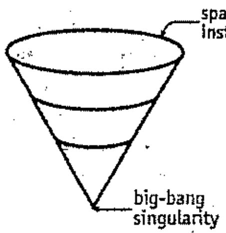


**Figure 7.** Expanding universe. The effect of cosmological expansion can be represented on our space-time diagram by making the cylinder of figure 6 into a cone. The apex of the cone corresponds to the big-bang singularity. Horizontal sections through the cone are now circles of successively greater diameter, denoting space growing larger.

The essential claim of quantum cosmology is that the Heisenberg uncertainty principle smears out the sharpness of the apex, replacing it by something smoother. Just what that something is depends on the theoretical model, but in the model of Hartle and Hawking a rough guide is to round off the apex in the way shown in figure 8, where the point of the cone is replaced by a hemisphere. The radius of this hemisphere is the Planck length ($10^{-33}$ cm), very small by human standards, but infinitely large compared with a point singularity. Above this hemisphere the cone opens out in the usual way, representing the standard nonquantum development of the expanding universe. Here – in the upper portion, above the join to the hemisphere – time runs vertically up the cone as usual, and is physically quite distinct from space, which runs horizontally around the cone. Below the join, however, the situation is dramatically different. The time dimension starts to curve around into the space direction (i.e., the horizontal). Near the base of the hemisphere one has a two-dimensional, roughly horizontal curved surface.



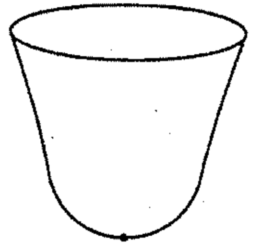


**Figure 8.** Creation without creation. In this version of the origin of the universe the apex of the cone of figure 7 is rounded off. There is no abrupt beginning: time fades gradually away toward the base of the diagram. The event P looks like the first moment, but this is only an artifact of the way the diagram is drawn. There is no well-defined beginning, although time is still finite in the past.

This represents a two-dimensional space rather than one space and one time dimension. Notice that the transition from time to space is gradual; it must not be thought to occur abruptly at the join. Expressing it another way, one might say that time emerges gradually from space as the hemisphere curves gradually into the cone. Note also that in this scheme time is still bounded from below – it does not stretch on back into the infinite past – yet there is no actual 'first moment' of time, no abrupt beginning at a singular origin. The big-bang singularity has, in fact, been abolished.

One might still be tempted to think of the base of the hemisphere – the 'South Pole' – as the 'origin' of the universe, but, as Hawking emphasizes, this is mistaken. A portion of a spherical surface is characterized by the fact that, geometrically, all points on it are equivalent. That is, no point is singled out as privileged in any way. The base of the hemisphere looks special to us because of the way that we have chosen to represent the curved sheet. If the cone is tipped over a bit, some other point becomes the 'base' of the structure. Hawking points out that the situation is somewhat analogous to the way we represent the spherical surface of the Earth geometrically. Lines of latitude converge on the North and South poles, but the Earth's surface at these places is the same as anywhere else. We could equally well have picked Mecca or Hong Kong as the focus for these circles. (The actual choice has been dictated by the axis of rotation of the Earth, a feature which is irrelevant to the present discussion.) There is no suggestion that the surface of the Earth comes to an abrupt stop at the poles. There is, to be sure, a singularity in the coordinate system of latitude and longitude there, but not a physical singularity in the geometry.

To make this point clearer, imagine making a little hole at the 'South Pole' of the hemisphere in figure 8, then opening the sheet out around the hole (suppose it is elastic) to make a cylinder, then unwrapping the cylinder and spreading it out to form a flat sheet. We would end up with a picture just like figure 5. The point is that what we formerly took to be a singular origin to time (the bottom edge) is really just the coordinate singularity at the South Pole, infinitely stretched out. Exactly the same thing happens with maps of the Earth in Mercator's projection. The South Pole, which is really just a perfectly ordinary point on the Earth's surface, is represented by a horizontal boundary line, as though the Earth's surface has an edge there. But the edge is purely an artifact of the way we have chosen to represent the spherical geometry by a particular coordinate system. We are free to redraw a map of the Earth using a different coordinate system, with some other point chosen as the focus for circles of latitude, in which case the South Pole would appear on the map as it really is – a perfectly normal point.

The upshot of all this is that, according to Hartle and Hawking, there is no origin of the universe. Nevertheless, that does not mean that the universe is infinitely old. Time is limited



in the past, but has no boundary as such. Thus centuries philosophical anguish over the paradoxes of infinite versı finite time are neatly resolved. Hartle and Hawking ingenious manage to pass between the horns of that particular dilemma. Hawking expresses it: 'The boundary condition of the universe that it has no boundary.'[5]

The implications of the Hartle–Hawking universe for theo ogy are profound, as Hawking himself remarks: 'So long as tl universe had a beginning, we could suppose it had a creato But if the universe is completely self-contained, having n boundary or edge, it would have neither beginning nor end: would simply be. What place, then, for a creator?'[6] The argumer is therefore that, because the universe does not have a singul origin in time, there is no need to appeal to a supernatural a of creation at the beginning. The British physicist Chris Ishan himself an expert on quantum cosmology, has made a study c the theological implications of the Hartle–Hawking theor 'There is no doubt that, psychologically speaking, the existenc of this initial singular point is prone to generate the idea of Creator who sets the whole show rolling,' he writes.[7] But thes new cosmological ideas remove the need, he believes, to invok a God-of-the-gaps as the cause of the big bang: 'The new theorie would appear to plug *this* gap rather neatly.'

Although Hawking's proposal is for a universe without definite origin in time, it is also true to say in this theory tha the universe has not always existed. Is it therefore correct to sa that the universe has 'created itself'? The way I would rathe express it is that the universe of space-time and matter i internally consistent and self-contained. Its existence does no require anything outside of it; specifically, no prime mover i needed. So does this mean that the existence of the univers can be 'explained' scientifically without the need for God Can we regard the universe as forming a closed system containing the reason for its existence entirely within itself The answer depends on the meaning to be attached to the word 'explanation.' Given the laws of physics, the universe can, so to speak, take care of itself, including its own creation. But where do these laws come from? Must we, in turn, find an explanation for *them*? This is a topic I will take up in the next chapter.

Can these recent scientific developments square with the Christian doctrine of creation *ex nihilo*? As I have repeatedly emphasized, the idea of God bringing the universe into existence from nothing cannot be regarded as a temporal act, because it involves the creation of time. In the modern Christian viewpoint, creation *ex nihilo* means sustaining the universe in existence at all times. In modern scientific cosmology, one should no longer think of space-time as 'coming into existence' anyway. Rather, one says that space-time (or the universe) simply is. 'This scheme does not have an initial event with a special status,' remarks the philosopher Wim Drees. 'Hence, all moments have a similar relation to the Creator. Either they are all 'always there,' as a brute fact, or they are all equally created. It is a nice feature of this quantum cosmology that that part of the content of creation *ex nihilo* which was supposed to be the most decoupled from science, namely the 'sustaining,' can be seen as the more natural part in the context of the theory.'[8] The image of God conjured up by this theory, however, is rather far removed from the twentieth-century Christian God. Drees perceives a close resemblance to the pantheistic picture of God adopted by the seventeenth-century philosopher Spinoza, where the physical universe itself takes on aspects of God's existence, such as being 'eternal' and 'necessary.'

One can, of course, still ask: Why does the universe exist? Should the (timeless) existence of space-time be regarded as an (atemporal) form of 'creation'? In this sense creation 'from nothing' would not refer to any temporal transition from nothing to something, but would merely serve as a reminder that there could have been nothing rather than something. Most scientists (though perhaps not all – see page 129 would agree that the existence of a mathematical scheme for a universe is not the same thing as the actual existence of that universe. The scheme still has to be implemented. Thus there remains what Drees calls 'ontological contingency.' The Hartle–Hawking theory fits this more abstract sense of 'creation' rather well, because it is a quantum theory. The essence of quantum physics, as I have remarked, is uncertainty: prediction in a quantum theory is prediction of *probabilities* rather than certainties. The Hartle–Hawking mathematical formalism supplies the *probabilities* that a particular universe, with a particular arrangement of matter, exists at each moment. In predicting that there is a nonzero probability for some particular universe, one is saying that there is a definite chance that it will be actualized. Thus creation *ex nihilo* is here given the concrete interpretation of 'actualization of possibilities.'



### *Mother and Child Universes*

Before leaving the problem of the origin of the universe, I should say something about a recent cosmological theory in which the question of origin enters in a radically different way. In my book *God and the New Physics* I floated the idea that what we call the universe might have started out as an outgrowth of some larger system, which then detached itself to become an independent entity. The basic idea is illustrated in figure 9. Here space is represented as a two-dimensional sheet. In accordance with the general theory of relativity, we can imagine this sheet as curved. In particular, one can conceive of a localized bump forming on the sheet, and rising into a protuberance connected to the main sheet by a thin throat. It may then happen that the throat becomes progressively narrower, until it pinches off completely. The protuberance has then turned into a completely disconnected 'bubble.' The 'mother' sheet has given rise to a 'child.'

Amazingly, there is good reason to expect something like this

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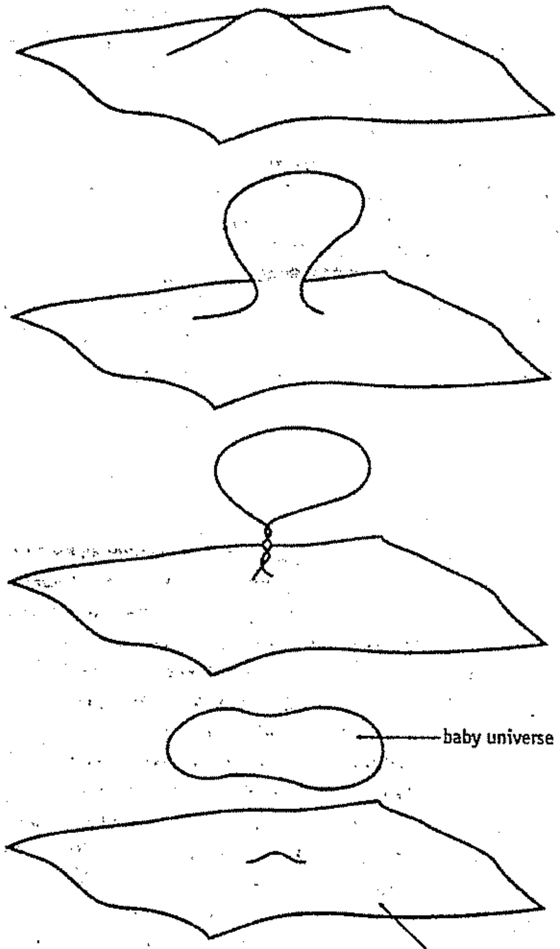




to be going on in the real universe. The random fluctuations associated with quantum physics imply that, on an ultramicroscopic scale, all manner of bumps, wormholes, and bridges should be forming and collapsing throughout space-time. The Soviet physicist Andrei Linde has the idea that our universe started out this way, as a little bubble of space-time, which then 'inflated' at a fantastic rate to produce a big bang. Others have developed similar models. The 'mother' universe which spawned ours is also continuously inflating at a fantastic rate, and spewing out baby universes for all it is worth. If this state of affairs is correct, it implies that 'our' universe is only part of an infinite assemblage of universes, although it is self-contained now. The assemblage as a whole has no beginning or end. There are problems in any case in using words like 'beginning' and 'end,' because there is no suprauniversal time in which this spawning process takes place, although each bubble has its own internal time.

An interesting question is whether our universe is also capable of being mother, and producing child universes. Might it be possible for some mad scientist to create his or her very own universe in the laboratory? This question has been investigated by Alan Guth, the originator of the inflationary theory. It turns out that, if a large amount of energy is concentrated, a space-time protuberance might indeed form. At first sight this seems

**Figure 9.** Hatching a baby universe. The mother universe is represented by a two-dimensional sheet. Curvature in the sheet arises from gravitational effects. If gravity is intense enough, the curvature can produce a protuberance that forms a mini-universe connected by an umbilical cord or throat known as a 'wormhole.' From the mother universe the throat can appear as a black hole. Eventually the hole evaporates, severing the cord and dispatching the baby universe onto an independent existence.

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to raise the alarming prospect that a new big bang would be triggered, but in fact what happens is that the formation of the protuberance looks from our region of space-time to be just like the creation of a black hole. Although there may be an explosive inflation within the protuberance-space, we see only a black hole that steadily shrinks. Eventually the hole evaporates away completely, and at that moment our universe becomes disconnected with its child.

In spite of the appeal of this theory, it remains highly speculative. I shall return to it briefly in chapter 8. Both the mother-and-child and the Hartle–Hawking theories adroitly circumvent the problems associated with a cosmic origin by appealing to quantum processes. The lesson to be learned is that quantum physics opens the door to universes of a finite age, the existence of which does not demand a well-defined prior cause. No special act of creation is needed.

All of the physical ideas discussed in this chapter have been based on the assumption that the universe as a whole complies with certain well-defined laws of physics. These laws of physics, which underpin physical reality, are woven into a fabric of mathematics, itself founded on the bedrock of logic. The path from physical phenomena, through the laws of physics, to mathematics and, ultimately, logic, opens up the beguiling prospect that the world can be understood through the application of logical reasoning alone. Could it be that much, if not all, of the physical universe might be as it is as the result of logical necessity? Some scientists have indeed claimed that this is so, that there is only one logically consistent set of laws and only one logically consistent universe. To investigate this sweeping claim, we must inquire into the nature of the laws of physics.

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