'probability distribution' for four-dimensional universes embedded in a larger dimensional multiverse. One might find, for example, that the bulk of such universes that had small vacuum energy also had three families of elementary particles and four different forces. Or one might find that only in universes with small vacuum energy could there exist a long-range force of electromagnetism. Any such result might provide reasonably compelling evidence that a probabilistic anthropic explanation of the energy of empty space makes solid physical sense.

Needless to say, such mathematical conditional probabilities have not resulted thus far. That does not mean they do not exist however. Nevertheless, in the meantime particle physics have taken anthropic reasoning a step further.

Particle physicists are way ahead of cosmologists. Cosmology has produced one totally mysterious quantity: the energy of empty space, about which we understand virtually nothing. However, particle physics has not understood many more quantities for far longer!

For example: Why are there three generations of elementary particles? Why is gravity so much weaker than the other forces in nature? Why is the proton 2000 times heavier than the elecdtron? And so on.

Some particle physicists have now jumped on the anthropic bandwagon in the extreme. For perhaps not just one fundamental quantity in nature is an environmental accident. Maybe all of the mysteries of particle theory can be solved by invoking the same mantra: If the Universe were any other way, we could not live in it!

One might wonder if such a solution of the mysteries of nature is any solution at all, or more importantly, whether it describes science as we understand it. After all, the goal of science, and in particular physics, over the past 450 years has been to explain why the universe must be the way we measure it to be, rather than why in general the laws of nature would produce universes which are quite different.

I have tried to explain why this is not quite the case, namely why many respectable scientists have turned to the anthropic principle, and why a number have worked quite hard to see if we might learn something new about our universe based on it.

Let me now go further and try and explain how the existence of forever undetectable universes, either removed from us by virtually infinite distances in space, or right beyond the tip of our noses, removed from us by microscopic distances in possible extra dimensions, might nevertheless be subject to some kind of empirical testing.

Imagine, for example, that we devised theory based on unifying at least three of the four forces of nature in some 'Grand Unified Theory', a subject of continued intense interest in particle physics (among those who have not given up looking for fundamental theories in four dimensions). Such a theory would make predictions about the forces of nature that we measure and about the spectrum of elementary particles that we probe at our accelerators. Should such a theory make a host of predictions that are subsequently verified in our experiments we would have very good reason to suspect that it contains a germ of truth.

Now, suppose this theory imagine such a theory also predicts a period of inflation in the early universe, and in fact predicts that our inflationary epoch is merely one of a host of such episodes in an eternally inflating multiverse. Even if we could not directly explore the existences of such regions beyond our horizon, then, as I have said earlier, if it walks like a duck and quacks like a duck... well you know.

Possible empirical support for the ideas surrounding extra dimensions is more far-fetched, but not impossible. There are many bright young theorists who are devoting their professional careers to the hope of developing the theory to the point where there might be some evidence, even indirect, that it is correct. Their hopes might be misplaced, but they have voted with their feet.

So, after a century of remarkable, truly unprecedented progress in our understanding of nature, we have found ourselves able to probe the universe on scales which were previously unimaginable, we have understood the nature of the Big Bang expansion back to its earliest microseconds, and have discovered the existence of hundreds of billions of new galaxies, with hundreds of billions of new stars. We have discovered that 99% of the Universe is actually invisible to us, dominated by dark matter that is most likely some new form of elementary particle, and dark energy, whose origin remains a complete mystery at the present time.

And after all of this, it may be that physics will become an 'environmental science'. It could be that the fundamental constants of nature, so long assumed to take on special importance, could just be environmental accidents. If we tend to take ourselves too seriously, maybe we have taken our universe too seriously too. Maybe literally, as well as metaphorically, we are making much ado about nothing, or at least the nothing that dominates our universe!. Maybe our universe is rather like a tear buried in a vast multiversal ocean of possibilities. Maybe we will never find a theory that describes why the universe has to be the way it is.

Or maybe we will.

That, finally, is the most accurate picture of reality as we now understand it that I can paint. It is based on work of tens of thousands of dedicated minds over the past century, building some of the most complex machines ever devised, and discovering some of the most beautiful and also the most complex ideas humanity has ever had to grapple with. It is a picture whose development emphasizes the best about what it is to be human. And we owe it to ourselves to draw wisdom from it. To do otherwise would do a disservice to all the brilliant and brave individuals who helped us reach our current state of knowledge.

If we wish to draw philosophical conclusions about our own existence, our significance, and the significance of the universe itself, our conclusions should be based on empirical truths. A truly open mind means forcing our imaginations to conform to the evidence of reality, and not vice-versa, whether or not we like the implications.

I don't mind not knowing. It doesn't scare me.

Richard Feynman

Isaac Newton, perhaps the greatest physicist of all time, profoundly changed the way we think about the universe in many ways. But perhaps the most important contribution he made was to demonstrate the possibility that the entire universe is explicable. With his Universal Law of Gravity, he demonstrated for the first time that even the heavens might bend to the power of natural laws. A strange, hostile, menacing and seemingly capricious universe might be nothing of the sort.

If immutable laws governed the Universe, the mythical Gods of Ancient Greece and Rome would have been impotent. There would have been no freedom to arbitrarily bend the world to create thorny problems for mankind. What held for Zeus would also apply to the God of Israel. How could the Sun stand still at midday if the Sun did not orbit the earth but it's motion in the sky was actually caused by the revolution of the Earth, which, if suddenly stopped, would produce forces on its surface that would destroy all human structures, and humans along with them?

Of course, supernatural acts are what miracles are all about. They are after all, precisely those things that circumvent the laws of nature. A God who can create the laws of nature can presumably also circumvent them at will. Although why they would have been circumvented so liberally thousands of years ago, before the invention of modern communication instruments that could have recorded them, and not today, is still something to wonder about.

In any case, even in a Universe with no miracles, when one is faced with a profoundly simple underlying order, two different conclusions can be drawn. One, drawn by Newton himself, and earlier espoused by Galileo, and a host of other scientists over the years, was that such order was created by a divine intelligence, responsible not only for the Universe, but for our own existence, and that we were created in her image. The other conclusion is that the laws themselves are all that exist. They themselves require our universe to come into existence, to develop and evolve, and that we are an irrevocable by product of these laws. The laws may be eternal, or they too may have come into existence, again by some as of yet unknown, but purely physical cause.

These possibilities continue to be debated by philosophers, theologians, and sometimes scientists. We do not know for certain which of them actually describes our universe, and perhaps we shall never know. But the point is, as I emphasized at the very beginning of this book, the final arbiter to this question will not come from hope, desire, revelation or pure thought. It will come, if it ever does, from an exploration of nature. Dream or Nightmare, as Jacob Bronowski said in the opening quote in the book—and one person's dream in this case can easily be another's nightmare—we need to live our experience as it is and with our eyes open. Or, as I have put it, universe is the way it is, whether we like it or not.

And here, I think it is *extremely significant* that 'a universe from nothing', arising naturally, and even inevitably, is increasingly consistent with everything we have learned about the world. This learning has *not* come from philosophical or theological musings about morality or other speculations about the human condition. It is instead based on the remarkable and exciting developments in empirical cosmology and particle physics that I have described thus far.

I want to now return to the question I described at the beginning of this book: "Why is there something rather than nothing?". We are now presumably in a better position to address this, having now reviewed our modern picture of the universe, its history, and its possible future in the preceding pages.

As I also alluded to at the beginning of this book, like almost all such philosophical questions, this one too has been informed by science. Far from providing a framework which forces upon us the requirement of a creator, the very meaning of the words involved have so changed that the sentence has lost much of its original meaning, as I shall describe.

At the same time, in science we have to be particularly cautious about "why" questions. When we say "why", we usually mean "how". If we can answer the latter, that generally suffices for our purposes. For example, we might ask: 'Why is the Earth 93 million miles from the Sun?', but what we really probably mean is, 'How is the Earth 93 million miles from the Sun?'. That is, we are interested in what physical processes led to the Earth ending up in its present position. 'Why' implicitly suggests purpose, and when we try and understand the solar system in scientific terms we do not generally ascribe purpose to it.

So, I am going to assume what is meant by this question is really: "How is there something rather than nothing?". Because this sentence sounds much stranger to the ear, I hope I will be forgiven if I sometimes fall into the trap appearing to discuss the more standard formulation when I am really trying to respond to the more specific "how" question.

Even here, from the perspective of actual *understanding*, this particular 'how' question has been supplanted by a host of operationally more fruitful questions, such as, 'What might have produced the properties of the universe that most strikingly characterize it at the present time?', or perhaps more importantly, 'How can we find out?'. The answers to these questions involve theoretical predictions that can be compared to experiments to drive our knowledge of the universe forward more directly. It is for this reason in part that I have focused on such questions up to this point in this book. Nevertheless, the 'something from nothing' question continues to have great currency, and therefore needs to be confronted.

Whatever view one adopts about any inherent rationality to the universe, it became clear already with Newton's work that possible domain of God's actions was dramatically reduced. Newton's laws may not only have severely constrained the freedom of action of a deity, they dispensed with various requirements for supernatural intervention. Newton discovered that the motion of planets around the sun does not require them to be continually pushed along their paths, but rather, and highly non-intuitively, requires them to be pulled by a force acting toward the

Sun, thus dispensing for the need for the Angels who were often previously invoked to guide the planets on their way. While dispensing with this particular use of angels has had little impact on people's willingness to believe in them (polls suggest far more people believe in Angels in the US than believe in evolution), it is fair to say that progress in science since Newton has even more severely constrained the available opportunities for the hand of God to be manifest in his implied handiwork.

We can describe the evolution of the universe back to the earliest moments of the big bang without specific need for anything beyond known physical laws, and we can hope to do so for the future history as well. There are certainly puzzles about the universe we don't understand, but I am going to assume that readers of this book are not wedded to a "God of the Gaps" picture, whereby God is invoked whenever there is something specific about our observations that seems puzzling or not fully understood. Even theologians recognize that such recourse not only diminishes the grandeur of their supreme being, it also opens her up to being removed or further marginalized, whenever further work explains or removes the puzzle.

In this sense, the 'something from nothing' argument really tries to focus on the original 'act of creation', and asks whether a scientific explanation can ever be logically complete and fully satisfying in addressing this specific issue.

It turns out that, given our current understanding of nature, there are three different, separate meanings for the "something from nothing" question. The short answer to each is 'quite plausibly yes', and I shall discuss each in turn in the rest of this book as I attempt to explain why, or, as I have argued just now, better yet, how.

Occam's razor then suggests that if it is physically plausible—or, as I shall argue, often required—that something will come from nothing, then we don't need recourse to more extraordinary claims, which, as Carl Sagan would say, would require more extraordinary evidence. Surely, the requirement of an all powerful deity who somehow exists outside of our universe, or multiverse, while at the same time governing what goes on inside of it, is one such claim.

The Origins Project that I direct just ran a workshop on the Origin of Life, and I cannot help but view the present cosmological debate in this context. We do not yet fully understand how life originated on Earth. However, we not only have plausible chemical mechanisms by which this might be conceivable, we are honing in closer and closer every day to specific pathways that might have allowed biomolecules, including RNA, to naturally arise. Moreover, Darwinian evolution, based on natural selection, provides a compellingly accurate picture of how complex life emerged on this planet following whatever specific chemistry produced the first faithfully self replicating cells with a metabolism that captured energy from their environment. (As good a definition of life as I can come up with for the moment.)

Just as Darwin, albeit reluctantly, removed the need for Divine intervention in the evolution of the modern world, teaming with diverse life throughout the planet, (though he left the door open the possibility for God to have helped breath life into the first forms), our current understanding of the Universe, its past, and its future, make it appear more and more plausible that 'something' arose without the need for any divine guidance. I expect we will never achieve more than plausibility in this regard. But that itself, in my view, is a tremendous step forward as we continue to marshal the courage to live meaningful lives in a universe that most likely came into existence, and may fade out of existence, without purpose and without us at its center.

Let's now return to one of the most remarkable features of our Universe: It is as close to being flat as we can measure. I remind you of the unique facet of a flat universe, at least on scales where it is dominated by matter in the form of galaxies, and where a Newtonian approximation remains valid: In a flat universe, and only in a flat universe, the average gravitational energy of every object participating in the expansion is precisely zero.

I emphasize that this was a falsifiable postulate. It didn't have to be this way. Nothing required this a prior except theoretical speculations based on considerations of a universe that could have arisen naturally from nothing, or at the very least, *almost nothing*.

One cannot overstress the importance of the fact that once gravity is included in our considerations of nature, one is no longer free to arbitrarily define the energy of a system, nor the fact that there are both positive and negative contributions to this energy. Determining the total gravitational energy of objects being carried along by the expansion of the Universe is *not* subject to arbitrary definition, any more than the geometric curvature of the universe is a matter of definition. It is a property of space itself, according to general relativity, and this property of space is determined by the energy contained within it.

I say this because my statement that the average total gravitational energy of every galaxy in our expanding universe is zero has been attacked, for example during debates Christopher Hitchens has had with Dinesh [redacted], as being merely something scientists have defined to be the case in order to support naturalistic explanations of nature.

Nothing could be further from the truth. The effort to determine the curvature of the Universe was an undertaking carried out over half a century by scientists who have devoted their lives to determining the truth about the universe, not to imposing their a priori desires upon it. I remember, even well after the theoretical arguments about why the Universe should be flat were first proposed, how my observational colleagues, during the 1980's and even early 1990's remained bent on proving otherwise. For after all, in science one achieves the greatest impact not by going along with the herd, but by bucking against it.

Nevertheless, it is the data that has had the last word, and the last word is in. Our observable universe is as close to being flat as we can measure. The gravitational energy of galaxies moving along with the Hubble expansion *is* zero, like it or not.

I would now like to describe how, if our universe arose from nothing, a flat universe, one with zero total gravitational energy of every object, is precisely what we should expect. The argument is a little subtle—subtler than I have been able to describe in my lectures on the subject—so I am happy to have the space here to carefully try and lay it out.

First, I want to be clear about what kind of 'nothing' I am discussing here. I first want to assume the existence of space itself, but purely empty space, nothingness, along with laws of physics that we might hope to understand by extrapolating what we currently can measure and hopefully involving predictions that we may one day test at particle accelerators or via observable signatures in the cosmos today.

In this case, as I have described in chapter 6, Alan Guth already explained to us precisely in this case how we can get something from nothing—the ultimate free lunch,. As we have seen, empty space can have a non-zero energy associated with it, even in the absence of any matter or radiation. In this case, general relativity tells us that space will expand exponentially, so that even the tiniest region at early times could quickly encompass a size more than large enough to contain our whole visible universe today.

What happens during such a rapid expansion? As we have also seen, what will eventually encompass our universe gets flatter and flatter as its size grows. During the period, while the energy density of empty space remains precisely constant (so that the total energy stored in the empty space which is growing itself grows exponentially!), the total gravitational energy of any small region within the space gets driven closer and closer to zero.

We have also seen that these miracles happen without the need for any hocus pocus. Gravity has the remarkable property that gravitational energy can be negative, while at the same time, the gravitational properties of empty space endowed with energy are very peculiar. Solving Einstein's equations tells us that such gravity is gravitationally repulsive, and, as I have also described, that the gravitational 'pressure' associated with such energy is actually negative as well

I know of no heuristic physical explanation that explains the negative pressure associated with the energy of empty space. Nevertheless, this negative pressure is vital because it also means that as the Universe expands, the expansion itself continues to pour energy into space. It is precisely in this way that space can keep growing at a faster and faster rate.

When Inflation ends, in this picture, the energy stored into empty space gets turned into an energy of real particles and radiation, creating effectively the traceable beginning of our present Big Bang expansion. I say the traceable beginning because Inflation effectively erases any memory of the state of the Universe before it began. All complexities and inhomogeneities on initially large scales (if the initial universe or metaverse were large, even infinitely large) get smoothed out and/or driven so far outside our horizon today that we observe a uniform universe after many many expansion periods of inflation have completed. (Quantum mechanics produces some residual fluctuations during inflation, as I have described, and these can, in principle be responsible for all the structure we observe in the universe today.)

Moreover, after all the dust is settled, the generic configuration of the matter and radiation, unless one very very carefully fine tunes the amount of inflation, will be that of a flat universe, one in which the average Newtonian gravitational energy of all objects will appear to be zero.

As I have described earlier, therefore, our observable universe can start out microscopically small and effectively empty and grow to enormous scales, all without costing a drop of energy, yet producing enough matter and radiation to account for everything we see today!

The important point worth stressing in at this time as I have briefly reviewed inflationary dynamics is that something can arise from nothing in this case *precisely* because the energetics of nothing, in the presence of gravity, are *not* what common sense would have guided us to suspect before we discovered the underlying laws of nature.

But no one ever said that the Universe is guided by what we, in our petty myopic corners of space and time, might have originally thought was sensible, just as we might have thought it was not sensible that nothing can produce something. The beauty of science has been that it forces us to revise what is sensible to accommodate the universe, rather than vice versa.

The observation that the Universe is flat, that the local Newtonian gravitational energy is zero today is strongly suggestive that our Universe arose though a process like that of Inflation, a process whereby the energy of nothing gets converted into the energy of something.

While Inflation demonstrates how nothing can effectively create something, the discussion I have just given will not completely satisfy those who may feel that creating something out of empty space which has energy stored in it, along with laws of physics like general relativity mixed into the brew is not really creating something, namely the universe in which we inhabit, from truly nothing. After all, space exists before Inflation, as does energy, as does time.

Such people are correct. However, once again, as we expand our understanding of nothing, we will see that Inflation can represent simply the tip of a cosmic iceberg of nothingness.

Dust to Dust, ashes to ashes..

The Common Book of Prayer.

The existence of energy in empty space—the discovery that rocked our cosmological universe and the idea that forms the bedrock of Inflation—only reinforces something about the quantum world that was already well established in the context of the kinds of laboratory experiments I have also already described.. Empty space is complicated. It is a boiling brew of virtual particles that pop in and out of existence in a time so short we cannot see them directly.

Virtual particles are manifestations of a basic property of quantum systems. At the heart of Quantum Mechanics is a rule that sometimes governs politicians or CEOs—as long as no one is watching, anything goes. Systems continue to move, if just momentarily, between all possible states, including states that would not be allowed if the system were actually being measured. These 'quantum fluctuations' imply something essential about the quantum world: *nothing* is unstable. Nothing always produces something, if only for an instant.

But here's the rub. The conservation of energy tells us that quantum systems can only misbehave for so long. Like embezzling stockbrokers, if the state that a system fluctuates into requires sneaking some energy from empty space, then the system has to return that energy in a time short enough so that no one measuring the system can detect it.

As a result, one might presume to safely argue that this 'something' that is produced by quantum fluctuations is ephemeral—not measurable, unlike, say you or I or the Earth on which we live.

But this too is subject to the circumstances associated with our measurements. For example, consider the electric field emanating from a charged object. It is definitely real . You can feel the static electric force on your hair or watch a balloon stick to a wall. However, in the quantum theory of electromagnetism suggests that the static field is due to the emission, by the charged particles involved in producing the field, of virtual photons that have essentially zero total energy. These virtual particles, because they have zero energy, can propagate across the universe without disappearing, and the field due to the superposition of many of them is so real it can be felt.

Sometimes conditions are such so that real, massive particles can actually pop out of empty space with impunity. One well-known example involves two charged plates that are brought close together. Once the electric field gets strong enough between them, it becomes energetically favorable for a real particle antiparticle pair to 'pop' out of the vacuum, with the negative charge heading toward the positive plate and the positive charge toward the negative one. In so doing, it is possible that the reduction in energy by so reducing the electric field can be greater than the energy associated with the rest mass of the two particles. Of course, the strength of the field has to be huge in real life for such a condition to actually be possible.

There is actually a place where strong fields of a different kind might allow a phenomenon something like that described above to occur, but in this case due to gravity. It is the case that made Stephen Hawking famous among physicists. He showed in 1974 that it might be possible for black holes, out of which classically nothing can ever escape, to actually radiate particles quantum mechanically.

There are many different ways to try and understand this phenomenon but one of these is strikingly familiar to the situation I described above with electric fields. Outside of the core of black holes is a radius, called the 'event horizon', inside of which no object can classically escape, because the escape velocity exceeds the speed of light. Thus, even light emitted inside of this region will not make it outside of the event horizon.

Now, however, imagine a particle-antiparticle pair nucleates out of empty space just outside of the event horizon, due to quantum fluctuations in that region. It is possible, if one of the particles actually falls within the event horizon, for it to lose enough gravitational energy by falling into the black hole that this energy exceeds twice the rest mass of either particle. In this case, the partner particle can fly off to infinity without any violation of energy conservation. The black hole can therefore radiate particles!

The situation is even more interesting because since the infalling particle loses more energy due to gravity than its rest mass contribution would be to the resulting black hole plus the particle, the net system after the particle falls in actually has less energy than it did before! Namely the particle being radiated out to infinity carries energy away from the black hole, and the black hole gets lighter as a result. Eventually the black hole may radiate away entirely. At this point we do not know because the final stages of black hole evaporation involve physics on scales where quantum gravitational considerations become important, and where, therefore, mere general relativity alone cannot tell us the final answer.

Nevertheless, what all of these phenomena imply is that under the right conditions, not only can nothing become something, it is required to.

The first example I know of in cosmology of the fact that 'nothing' can be unstable to forming something comes from efforts to understand why we live in a universe of matter.

Most of you probably don't wake up each morning wondering about this, but the fact that our universe contains matter, and essentially no antimatter, is remarkable. Any sensible universe at its inception, one might think, would contain equal amounts of both. After all, matter and antimatter both have the same mass. Only the charges, and some other more subtle 'quantum numbers' of particles and antiparticles may differ. What we call antimatter would be called, no doubt, in the hypothetical antimatter universe I described earlier with anti-lovers and anti-moons, matter. Such a universe would be almost indistinguishable from the one we live in.

But if our universe began sensibly, with equal amounts of matter and antimatter, and stayed that way, we wouldn't be around to ask 'why?', or 'how?'. This is because all particles of matter would have annihilated with all particles of antimatter in the early universe, leaving nothing left but pure radiation. No matter or antimatter for stars, or galaxies, or for lovers or antilovers who might otherwise one day gaze out and be aroused by the spectacle of the night sky in each other's arms. No drama. History would consist of emptiness, a radiation bath which would slowly cool, leading ultimately to a cold, dark, hollow universe. Nothingness would reign supreme.

However, we began to understand in the 1970's how it is possible for plausible quantum processes to create something from nothing in this case—namely how a small asymmetry could be established between matter and antimatter in the early universe where none had existed before. This may sound like a small accomplishment, but in my opinion, and indeed I have written about it as so, it might as well be considered the moment of creation. Because once an asymmetry between matter and antimatter was created, nothing could later put asunder. The future history of a universe full of stars and galaxies was essentially written. For now, antimatter particles would annihilate with the matter particles in the early universe, but the remaining excess of matter particles due to the small asymmetry would be unable to find any remaining antimatter to annihilate with, and as a result would survive until the present day.

Even if the asymmetry were even 1 part in a billion there would be enough matter left over to account for everything we see in the universe today. In fact, an asymmetry of 1 part in a billion or so is precisely what was called for, because today there are roughly 1 billion photons in the cosmic microwave background for every proton in the universe. The CMB photons are the remnants, in this picture, of the early matter-antimatter annihilations near the beginning of time.

A definitive description of how this process may have happened in the early universe is currently lacking because we have not yet fully empirically established the detailed nature of the microphysical world at the scales where this asymmetry was likely to have been generated. Nevertheless, a host of different plausible scenarios have been explored based on the current best ideas we have about this physics. While they differ in the details they all have the same general characteristics. Quantum processes associated with either elementary particles in the primordial heat bath, or more likely that help determine the quantum character of empty space can inexorably drive either an empty universe or an initially matter-antimatter symmetric universe almost imperceptibly toward a universe that will be dominated by either antimatter or matter.

If it could go either way, was it just a circumstantial accident that our universe became dominated by matter? Could it have gone the other way? Imagine standing on top of a tall mountain and tripping. The direction you fall was not pre-ordained, but rather is an accident, depending upon which direction you were looking at, or at what point in your stride you trip. Perhaps our universe is like that, and the fundamental parameter or parameters that determine the ultimate direction of the asymmetry between matter and antimatter are randomly determined from some underlying probability distribution, or perhaps not, and the fundamental underlying physics only allows one value.

Independent of this uncertainty, however, is the remarkable fact that there can be a feature of the underlying laws of physics that can allows quantum processes to drive the universe away from either an empty or featureless state. The physicist Frank Wilczek, who was one of the first groups of theorists to explore these possibilities, has reminded me that he utilized precisely the same language I have used previously in this chapter, in the 1980 *Scientific American* article he wrote on the matter-antimatter asymmetry of the universe: After describing how a matter-antimatter asymmetry might be plausibly generated in the early universe based on our new understanding of particle physics, he added a note that this provided one way of thinking about the answer to the question of why there is something rather than nothing: nothing is unstable.

While the instability Frank was referring to was quite specific, the central point here is that such instabilities are a generic feature of the quantum universe, and, as I shall now describe, can, in the context of the question we are trying to address here, involve not just particles and fields within our universe, but our whole universe itself.

Before I proceed, however, I am again reminded the similarities between the discussion I have just given of a matter-antimatter asymmetry and the discussions I we had at our recent Origins workshop to explore our current understanding of the nature of, and origin of life in the universe. The words were different, but the fundamental issues were remarkably similar: What specific physical process in the early moments of the earth's history could have led to the creation of the first replicating biomolecules and metabolism? Here, as in the case of the 1970's in physics, the recent decade has seen incredible progress. We learned of natural organic pathways for example that could produce, under plausible conditions, Ribonucleic acids, long thought to be the precursers to our modern DNA based world. Until recently it was felt that no such direct pathway was possible and that some other intermediate forms must play a key role.

So now few biochemists and molecular biologists doubt life can naturally arise from non-life. The specific are yet to be discovered. But, as we discussed all of this a common subtext permeated our proceedings: Did the life that first formed on Earth *have* to have the chemistry that it did or are there many different, equally viable possibilities?

Einstein once asked a question which he said was the one thing he really wanted to know about nature, and I admit it is the most profound and fundamental question that many of us would like answered. He put it as follows: "What I want to know is whether *God* [sic] had any choice in the creation of the universe.".

I have annotated this because Einstein's God was not the God of the Bible. For Einstein the existence of order in the universe provided a sense of such profound wonder that he felt a spiritual attachment to it, which he labeled, motivated by Spinoza by the moniker 'God'. In any case, what Einstein really meant in this question was the issue I have just described in the context of several different examples: Are the laws of nature (and the universe we inhabit that has resulted from them) unique? If one changes one facet, one constant, one force, however slight, would the whole edifice crumble? (And so, in a biological sense,, is the biology of life unique? Are we unique in the Universe?) We will return to discuss this most important question later in this book.

While such a discussion will cause us to further refine and generalize notions of 'nothing' and 'something', I want to complete this chapter by taking an intermediate step in making the case for inevitable creation of something.

As I have defined it thus far, the relevant 'nothing' from which our observed something arises is 'empty space'. However once one allows for the merging of quantum mechanics and general relativity, it is possible to extend this argument to the case where space itself is forced into existence.

General Relativity as a theory of gravity is, at its heart, a theory of space and time. As I described on the very first page of this book, this means that it was the first theory that could address the dynamics not merely of objects moving through space, but also how space itself evolves.

Having a quantum theory of gravity would therefore mean that the rules of quantum mechanics would apply to the properties of space and not just to the properties of objects existing in space, as in conventional quantum mechanics.

How to extend quantum mechanics to include such a possibility is tricky, but it turns out that the formalism Richard Feynman developed which led to a modern understanding of the origin of antiparticles is well suited to the task. Feynman's methods focus on the key fact which I alluded to at the beginning of this chapter:

that quantum mechanical systems explore, if briefly, all possible trajectories, even ones which are classically forbidden, as they evolve in time.

In order to explore this Feynman developed a 'sum over paths formalism' to make predictions. In this method one considers, for example, all possible trajectories between two points that a particle might take. One then assigns a probability to each trajectory, based on well-defined principles of quantum mechanics, and then performs a sum over all paths in order to determine final (probabilistic) predictions for the motion of particles.

Stephen Hawking was one of the first people to fully exploit this idea to the possible quantum mechanics of space-time. The virtue of Feynman's methods was that focusing on all possible paths ends up meaning that the results can be shown to be independent of the specific labeling one applies to each space-time point on each path. Because relativity tells us that different observers in relative motion can assign different positions in space and time to points, having a formalism that was independent of the different frames of reference for different observers was particularly useful.

Nowhere more useful perhaps than in considerations of general relativity, where the specific labeling of space and time points becomes completely arbitrary, and all that ultimately determines the behavior of systems are geometric quantities like curvature, that turn out to be independent of all such labeling schemes.

As I have alluded to several times, general relativity is not fully consistent with quantum mechanics, at least as far as we can tell, and therefore there is no completely unambiguous method to define Feynman's sum over paths technique in general relativity. Thus, one has to make some guesses in advance based on plausibility, and check to see if the results make sense.

If one is to consider the quantum dynamics of space-time itself then, one must imagine that in the Feynman 'sums', one must consider every different configuration possible for space to occupy during the intermediate stages of the calculation, when quantum indeterminacy reigns supreme. This means one must consider spaces with arbitrarily curved surfaces on small scales, and many other configurations one would not expect to actually observe when one measures the properties of space over large distances and times.

But let's consider even stranger possibilities. Remember that in the quantum theory of electromagnetism particles can pop out of empty space at will, as long as they disappear again on a timeframe determined by the Uncertainty Principle. By analogy, then, in the Feynman quantum sum over possible space-time configurations should one consider the possibility of small, possibly compact spaces that themselves pop in and out of existence? More generally, what about spaces with different topologies? Should one allow arbitary 'handles' to be attached to space, like donuts dunking into space-time?

These are frankly open questions. However, unless one can come up with a good reason for excluding such configurations from the quantum mechanical sum that determines the properties of the evolving universe, and to date no such good reason exists that I know of, then under the general principle which holds everywhere else I know of in nature—namely that anything that is not proscribed by the laws of physics must actually happen—it seems most reasonable to consider these possibilities.

As Stephen Hawking has then emphasized, a quantum theory of gravity allows for the creation, albeit perhaps momentarily, of space itself where none existed before.

"Virtual" universes are fascinating theoretical constructs, but they would seem to no more explain how something can arise from nothing than do the virtual particles that populate otherwise empty space.

However, just as a non-zero real electric field can result from the unsuppressed possible emission of zero-energy photons from a charge that can propagate out to infinite distances, one can imagine one specific type of universe that should be possible to spontaneously appear, and need not disappear. You guessed it: A Universe with zero total energy!

Now, I would like nothing better than to suggest that this is precisely the Universe we live in. This would be the easy way out, but I am more interested here in being true to our current understanding of the Universe than to make an apparently easy and convincing case for creating it from nothing.

I have argued, hopefully, compellingly, that the average Newtonian gravitational energy of every object in our flat universe is zero. And it is. But that is not the whole story. Gravitational energy is not the total energy of any object. To this energy we must add its rest energy, associated with its rest mass. Put another way, the gravitational energy of an object at rest isolated from all other objects by an infinite distance is zero. However, as Einstein told us, its total energy in this case is $E=mc^2$.

In order to take this rest energy into account we have to move from Newtonian Gravity to General Relativity, which, by definition, incorporates the effects of special relativity into a theory of gravity. And here things get both more subtle and more confusing. On small scales compared to the possible curvature of a universe, and as long as all objects within these scales are moving slowly compared to the speed of light, the general relativistic version of energy reverts to the definition we are familiar to from Newton. However, once these conditions no longer hold, all bets are off, almost.

Part of the problem is that it turns out that Energy as we normally think of it elsewhere in physics is not a particularly well-defined concept on large scales in a curved universe. Different ways of defining coordinate systems to describe any underlying space-time (namely different frames of reference) can lead, on large scales, to different determinations of the total energy of the system. In order to accommodate this effect one has to generalize the concept of energy, and moreover if one is to define the total energy contained in any universe one must consider how one adds up the energy in universes that may be infinite in spatial extent.

To say that there is debate over precisely how to do this is also an understatement. The scientific literature is replete with claims and counter-claims in this regard.

One thing is certain, however, there is one universe in which the total energy is definitely and precisely zero. It is not, however a flat universe, which is in principle infinite in spatial extent, and therefore the calculation of total energy becomes problematic. It is a closed universe, one in which the density of matter and energy is sufficient to cause space to close back upon itself. As I have described, in a closed universe, if you look far enough in one direction, you will eventually see the back of your head!

The reason the energy of a closed universe is zero is really quite simple. It is easiest to consider the result by analogy with the fact that in a closed universe the total electric charge must also be zero.

Since the time of Michael Faraday we think of electric charge as being the source of an electric field. Pictorially, we imagine 'field lines' emanating out radially from the charge, with the number of field lines being proportional to the charge, and the direction of field lines being outward for positive charges and inward for negative charges, as shown below:

We imagine these field lines going out to infinity, and as they spread out, getting farther apart, this implies the strength of the electric field gets weaker and weaker.

However, in a closed universe, the field lines associated with a positive charge, for example, may start out spreading apart but eventually, just like the lines of longitude on a map of the earth come together at the north and south poles, the field lines from the positive charge will end up come together again on the far side of the universe. When they converge, the field will get stronger and stronger again, until there is enough energy to create a negative charge which can 'eat' the field lines at this antipodal point of the universe.

It turns out a very similar argument, in this case associated not with the 'flux' of field lines, but with the 'flux' of energy in a closed universe tells us that the total positive energy, including that associated with the rest masses of particles, must be exactly compensated for by a negative gravitational energy, so that the total energy is precisely zero.

So, if the total energy of a closed universe is zero, then if the sum over paths formalism of quantum gravity is appropriate, then quantum mechanically, such universes could appear spontaneously with impunity, carrying no net energy. I want to emphasize that these universes would be completely self contained space-times, disconnected from our own.

There is a hitch, however. A closed universe filled with matter will in general expand to a maximum size, and then recollapse just as quickly, ending up in a space-time singularity where the no-man's land of quantum gravity at present cannot tell us what its ultimate fate will be. The characteristic lifetime of tiny closed universes will therefore be microscopic, perhaps on the order of the 'Planck time', the characteristic scale over which quantum gravitational processes should operate, about 10^{-44} seconds or so.

Note however that there is a way out of this dilemma. If, before such a universe can collapse, the configurations of fields in such a universe produces a period of inflation, then even an initially tiny closed universe can rapidly exponentially expand, becoming closer and closer to an infinitely large flat universe during this period. After 100 or so doubling times of such inflation, the universe will be so close to flat that it could easily last much longer than our universe has been around without collapsing.

Another possibility actually exists.. one which always gives me a slight twinge because it represented an important learning experience for me. When I was first a postdoc at Harvard, I was playing with the possible quantum mechanics of gravitational fields, and I learned of a result by a good friend from graduate school, Ian Affleck, another Canadian who had been a graduate student at Harvard when I was at MIT, and joined the Society of Fellows a few years before I did, who had used the mathematical theory of Feynman that we now use for dealing with elementary particles and fields, called quantum field theory, to calculate how particles and antiparticles could be produced in a strong electric field.

I realized that the form of the solution that Ian had described, something called an 'instanton', resembled very much, if one took over his formalism to the case of gravity, an inflating universe. But it looked like an inflating universe that began from nothing! I was confused about how to interpret what physics such a mathematical solution might correspond to, when I learned that just down the road a very creative cosmologist who has since become a friend, Alex Vilenkin, had actually just written a paper which described how quantum gravity indeed might create an inflating universe directly from nothing. I was scooped, but I couldn't be that upset because (a) I frankly didn't understand in detail at that point what I was doing, and (b) Alex had the boldness to propose something which at the time I didn't. I have since learned that one doesn't have to understand all the implications of one's work in order to publish. Indeed there are several of my own most important papers that I only fully understood well after the fact.

In any case, while Stephen Hawking and his collaborator Jim Hartle have proposed a very different scheme for trying to determine the 'boundary conditions' on universes that may begin from nothing at all, the important facts are these:

(1) In quantum gravity, universes can, and indeed always will, spontaneously appear from nothing. Such universes need not be empty, but can have matter and radiation in them, as long as the total energy, including the negative energy associated with gravity, is zero.

(2) In order for the closed universes that might be created from such mechanisms to last for longer than microscopic times, something like Inflation is necessary. As a result, the only long-lived universe one might expect to live in in such a scenario is one that today appears flat, just as the Universe in which we live appears.

The lesson is clear: quantum gravity not only appears to allow universes to be created from nothing, it may require them. 'Nothing', in this case no space, no time, no anything, *is* unstable.

Moreover, the general characteristics of such a universe, if it lasts a long time, would be expected to be those we observe in our universe today.

Does this prove our Universe arose from nothing? Once again, of course not. But it does take us one rather large step closer to the plausibility of such a scenario. And, it removes one more of the objections that one might have been leveled against the argument of creation from nothing as described in the last chapter.

There, 'nothing' included pre-existing space, and fixed laws of physics. Now, the requirement of space has been removed.

But, as we shall next discuss, even the laws of physics may not be necessary, or required.

It was the best of times. It was the worst of times.

Charles Dickens

The central problem with the notion of creation is that it appears to require some externality, something outside of the system itself, to *pre-exist*, in order to create the conditions necessary for the system to come into being. This is usually where the notion of God comes in, because as I have mentioned, the buck has to appear to stop somewhere.

But as I have also noted, this can be viewed as a purely a semantic solution to the problem of creation. I think this is best explained within the context of a slightly different example: the origin of morality, which I first learned from my friend Steven Pinker.

Is morality external and absolute, or is it derived solely within the context of our biology and our environment, and thus can it be determined by science? During a debate on this subject organized by the institute that I run at Arizona State University, Pinker pointed out the following conundrum.

If one argues that without God, there can be no ultimate right and wrong, namely that God determines for us what is right and wrong, one can then ask the question: What if God decreed that rape and murder were morally acceptable? Would that make them so?

While some might answer yes, I think most believers would say, no, God would not make such a decree. But why not? Presumably because God would have some reason for not making such a decree, presumably because reason suggests that rape and murder are not morally acceptable. But if God would have to appeal to reason, then why not eliminate the middleman entirely?

We may wish to apply similar reasoning to the creation of our Universe. All of the examples I have provided thus far indeed involve creation of something from nothing, but the *rules* for that creation, i.e. the laws of physics, were pre-ordained. Where do the rules come from?

There are two possibilities. Either God, or some divine being who is not bound by the rules, who lives outside of them, determines them—either by whim or with malice aforethought—or they arise by some less supernatural mechanism.

The problem with God determining the rules, is that one can at least ask what, or who, determined God's rules. Traditionally the response to this is to say that God is, among her many other spectacular attributes, the *cause of all causes*, in the language of the Roman Catholic Church, or the *first cause* (as per Aquinas), or in the language of Aristotle, the *Prime Mover*.

Interestingly, Aristotle recognized the problem of a first cause, and decided that for this reason the universe must be eternal, and moreover, God, who he identified as the Prime Mover, himself had to be eternal, not causing motion by creating it, but rather by establishing the end purpose of motion, which itself Aristotle deemed had to be eternal.

Aristotle felt that equating *first Cause* with God was less than satisfying, in fact that the Platonic notion of first cause was flawed, specifically because Aristotle felt every cause must have a precurser—hence the requirement that the universe be eternal. Alternatively if one takes the view of God as the cause of all causes, herself eternal, even if our universe is not, the reductio ad absurdum sequence of 'why' questions does terminate, but as I have stressed, only at the expense of introducing a remarkable all powerful entity for which there is simply no other evidence.

In this regard, there is another important point to stress here. While the apparent logical necessity of first cause is a real issue for any universe which is has a beginning, and therefore on the basis of logic alone one cannot rule out such a deistic view of nature, it is vital to realize that this bears no logical connection to the personal deities of the world's great religions, in spite of the fact that it is often used to justify them. A deist who finds the need for some overarching intelligence to establish order in nature compelling cannot be driven to the personal God of the scriptures by the same logic.

These issues have been debated and discussed for millennia, by brilliant and not-so-brilliant minds. We can return to them now, because we are simply better informed. Neither Aristotle nor Aquinas knew about the existence of our galaxy, much less the Big Bang, or quantum mechanics. Hence the issues they, and later medieval philosophers grappled with, as I have argued, must be interpreted and understood in the light of new knowledge.

Consider, in the light of our modern picture of cosmology, for example, Aristotle's suggestion that there are no first causes, or rather that causes indeed go backward (and forward) infinitely far in all directions. There is no beginning, no creation, no end.

When I have thus far described how something almost always can come from nothing, I have focused on either the creation of something from pre-existing empty space, or the creation of empty space from no space at all. I have not addressed directly the issues of what might have existed, if anything, before such creation, what laws governed the creation, or put more generally, I have not discussed what some may view as the question of 'first cause'. A simple answer is of course that either empty space, or the more fundamental nothingness from which empty space may have arisen, pre-existed and has been eternal. However, to be fair, this begs the questions of what fixed the rules that governed such creation and how.

To posit a God who could resolve this conundrum, as we have seen numerous times thus far, has generally required that God exist outside of the Universe and be either timeless or eternal.

Our modern understanding of the universe provides another plausible, more physical solution, however, that has some of the same features.

I refer here to the multiverse. The likelihood that our Universe is one of a possibly infinite set of Universes, in each of which any number of fundamental aspects of physical reality are different, opens up a vast new possibility for understanding our existence.

As I have already described, for me one of the more distasteful, but potentially true, implications of these pictures is that physics, at some fundamental level, is merely an environmental science. The fundamental forces and constants of nature in this picture are no more fundamental than the Earth-Sun distance. We find ourselves living on Earth rather than Mars not because there is something profound and fundamental about the Earth-Sun distance, but rather simply if Earth were located at a different distance, then life as we know it could not have evolved on our planet.

I want to emphasize that Anthropic arguments are notoriously slippery, and it is almost impossible to make specific predictions based on it, without knowing explicitly both the probability distribution among all possible universes of the various fundamental constants and forces, namely which may vary and which don't, and what possible values and forms they may take, and also exactly how "typical" we are in our universe. If we are not 'typical' life-forms then anthropic selection, if it occurs at all, may be based on different factors then we would otherwise ascribe.

Nevertheless a multiverse, either in the form of a Landscape of Universes existing in a host of extra dimensions, or in the form of an infinitely replicating set of Universe in a three dimensional space, as in the case of eternal inflation, changes the playing field when thinking about the creation of our own universe, and the conditions that may be required for that to happen.

In the first place, the question of what determined the laws of nature that allowed our universe to form and evolve now becomes less significant. If the laws of nature are themselves stochastic and random, then there is no prescribed 'cause' for our universe. Under the general principle that anything that is not forbidden is allowed, then we would be guaranteed, in such a picture, that some universe would arise with the laws that we have discovered. No mechanism, and no entity, is required to fix the laws of nature to be what they are. They could, in principle, be almost anything. Since we don't currently have a fundamental theory that explains the detailed character of the landscape of a multiverse we cannot say. In fact, there may be no fundamental theory at all. While I became a physicist because I hoped there was, and that I might one day help contribute to discovering it, this hope could easily be misplaced. In this regard I take solace in the statement by Richard Feynman that I summarized briefly before, but want to present in its entirety here, and which precedes the quote that begins the epilogue of this book:

> *"People say to me, 'Are you looking for the ultimate laws of physics?' No, [redacted] not. [redacted] just looking to find out more about the world, and if it turns out there is a simple ultimate law that explains everything, so be it. That would be very nice to discover. If it turns out it's like an onion with millions of layers, and we're sick and tired of looking at layers, then that's the way it is....My interest in science is to simply find out more about the world, and the more I find out the better it is. I like to find out."*

One can carry the argument further, and in a different direction which also has implications for the arguments at the core of this book. In a multiverse, of any of the types that have been discussed, there could be an infinite number of regions, potentially infinitely big or infinitesimally small as well, in which there is simply 'nothing', and there could be regions where there is 'something'. In this case, the response to why there is something rather than nothing becomes almost trite: There is something simply because if there was nothing, we wouldn't find ourselves living there!

I recognize the frustration inherent in such a trivial response to what has seemed such a profound question throughout the ages. But science has told us that what is profound, or trivial, can be dramatically different than what one might suppose at first glance.

The universe is far stranger, and far richer, than our meager human imaginations can anticipate in advance. The ideas that modern cosmology have driven us to consider could not even have been formulated a century ago. The great discoveries of the 20th and 21st centuries have not only changed the world that we operate in, they have revolutionized our understanding of the world, or worlds that exist, or may exist just under our noses, the reality that lies hidden until we are brave enough to search for it.

This is why philosophy and theology are ultimately incapable of addressing by themselves the truly fundamental questions that perplex us about our existence. Until we open our eyes and let nature call the shots, we are bound to wallow in myopia.

Why is there something rather than nothing? Ultimately this question may be no more significant or profound than asking why some flowers are red and some are blue. 'Something' may always come from nothing. It may be required, independent of the underlying nature of reality. Or perhaps 'Something' may not be very special, or even very common in the multiverse. Either way, what is really useful is not pondering this question, but rather the exciting voyage of discovery that may reveal specifically how the Universe in which we live evolved and is evolving and the processes that ultimately operationally govern our existence. That is why we have science. We may supplement this understanding with reflection, and call that Philosophy. But only via continuing to probe every nook and cranny of the Universe that is accessible to us will we truly build a useful appreciation of our own place in the cosmos.

Before concluding this discussion, there is one aspect of this question that I haven't touched upon, but which strikes me as worth ending with. Implicit in the question of why there is something rather than nothing is the myopic expectation that something will persist. That somehow the Universe has 'progressed' to the point of our existence, as if that is the pinnacle of creation. However, far more likely, based on everything we know about the universe, is the possibility that the future, perhaps the infinite future is one in which nothingness will once again reign.

If we live in a universe whose energy is dominated by the energy of nothing, as I have described, the future is indeed bleak. The heavens will become cold and dark and empty. But things are actually worse. In my debates with Freeman Dyson about the future of life, we agreed upon one thing. A Universe dominated by the energy of empty space is the worst of all universes for the future of life. Any civilization is guaranteed to ultimately disappear in such a universe, starved of energy to survive. After a virtually infinite amount of time, some quantum fluctuation, or some thermal agitation may produce a local region where once again life can evolve and thrive. But that too will be ephemeral. The future will be dominated by a universe with nothing in it to appreciate its vast mystery.

Alternatively, if matter was created at the beginning of time by some quantum processes, we are virtually guaranteed that it will disappear once again. Physics is a two way street, and beginnings and endings are linked. Far far into the future, protons and neutrons will decay, matter will disappear, and the Universe will approach a state of maximum simplicity and symmetry. Mathematically beautiful perhaps, but devoid of substance.

Finally, there are arguments based on the very ideas that are now leading physicists to explore the possibilities of extra dimensions that suggest a universe like ours, with a positive energy of empty space, must of necessity be unstable. It will decay to a state with negative energy, which will necessarily collapse inwards to a point, returning to the quantum haze from which our own existence may have once spawned. Our universe will disappear as abruptly as it might have begun.

The answer to the question, 'Why is there something rather than nothing?' in this case will then simply be: There won't be for long.

I don't mind not knowing. It doesn't scare me.

Richard Feynman

I began this book with a quote from one of my very favorite scientific public intellectuals, Jacob Bronowski:

> *"Dream or nightmare, we have to live our experience as it is, and we have to live it awake. We live in a world which is penetrated through and through by science and which is both whole and real. We cannot turn it into a game simply by taking sides."*

As I have also argued, one person's dream is another person's nightmare. A Universe without purpose or guidance may seem to some to make life itself meaningless. For others of us, such a Universe is invigorating. It seems even more amazing that we exist, and it motivates us to draw meaning from our own actions, and to make the most of our brief existence in the Sun, simply because we are here, blessed with consciousness, and with the opportunity to do so.

Bronowski's point, however, is that it doesn't really matter either way, and what we would like for the Universe is irrelevant. Whatever happened, happened, and on a cosmic scale whatever will happen will happen. We cannot affect the former, and are unlikely to affect the latter.

What we can do however, is try to understand the circumstances of our existence. I have described in this book one of the most remarkable journeys humanity has taken in exploring and understanding the cosmos on scales that simply were unknown a century ago. The journey has pushed the limits of the human spirit, combining the willingness to follow evidence wherever it might lead, with the courage to devote a lifetime exploring the unknown with the full knowledge that the effort might go nowhere, and finally requiring a mixture creativity and persistence to address the often tedious tasks of sorting through endless equations or endless experimental challenges.

I have always been attracted to the Myth of Sisyphus, and have likened the scientific effort at times to his eternal task of pushing a boulder up a mountain, only to have it fall each time before he reaches the top. As Camus imagined, Sisyphus was smiling, and so should we. Our journey, whatever the outcome, provides its own reward.

The phenomenal progress we have made in the past century has brought us to the cusp, as scientists, of operationally addressing the deepest questions that have existed since humans took their first tentative steps to understand who they were and where they came from.

As I have described here, in the process the very meaning of these questions has evolved along with our understanding of the Universe. "Why is there something rather than nothing?" must be understood in the context of a cosmos where the distinction between something and nothing has begun to disappear, and where transitions between the two in different contexts are not only common, but required.

As such the question itself becomes less important, at least in driving our quest for knowledge. Instead we are driven to understand the processes that govern nature in a way that allow us to make predictions and, whenever possible, to impact upon our own future. In so doing we have discovered that we live in a Universe in which 'nothing', namely empty space, has a new dynamics that dominates the current evolution of the cosmos. We have discovered that all signs suggest a Universe that could and plausible did arise from nothing, and which may one day return to nothing, via processes that may not only be comprehensible—itself certainly not something that could have been anticipated—but also processes that may not require any external control or direction. In this sense, science, as Steven Weinberg has emphasized, does not make it impossible to believe in God, but rather makes it possible to not believe in God. Without science, everything is a miracle. With science, there remains the possibility that nothing is.

The choice is each of ours, of course, and I don't expect the ongoing debate to die down any time soon. But as I have stressed, I believe that if we are to be intellectually honest in our choice, it must be an informed one, informed not by revelation, but fact.

That has been the purpose of this book, to provide an informed picture of the Universe as we understand it, and to describe the theoretical speculations that currently are driving physicists, and physics, forward as we attempt to weed out the wheat from the chaff.

I have made my own predilections clear. I find the case for a Universe from Nothing by far the most compelling intellectual alternative at the current time. Readers will draw their own conclusions.

I want to end my discussion by returning to a question that I personally find much more intellectually fascinating than the question of something from nothing. It is the question Einstein asked about whether God had any choice in the creation of