The Fire in the Equations

Science, Religion, and the Search for God

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Contents

Preface to 2004 Edition

In the years since *The Fire in the Equations* first appeared, I have taken part in many conversations about it, both with interviewers and informally among friends and acquaintances, and there have been many reviews and comments in print. Because certain questions about the book and the way I wrote it have cropped up repeatedly, it seems to me that it might be useful for me to address those questions in a preface to this new edition.

First, did I have a personal agenda when I began the book? The answer is yes, but not the sort one might expect. My 'agenda' was to undertake a journey of exploration, without knowing where it would take me or where it would end. My present views on science-religion issues were not in place when I began the book. They were forged in the writing of it. If readers were and are surprised at some of the twists in the line of argument, so was I.

A related issue that some readers and commentators have found unsettling is that I do not 'come clean' in the book and state my personal conclusions about God. I chose to write from an agnostic point of view. But AM I an agnostic? Am I a 'believer'? Am I an atheist? Whatever I am, I must have hidden it well, for my mail has been about equally divided between letters trying to convert me to belief and letters accusing me of being a religious apologist. Should this preface, ten years after *The Fire in the Equations* was first published, reveal where I stand on the question of whether there is a God? I do have strong convictions of my own and willingly talk about them in personal conversations, but I have decided, once again, not to do so in the context of this book. It was written on the principle—unfashionable, I know, in the current intellectual climate—that it is a valuable exercise and not a futile one to attempt to set aside for a while any preconceived notions and beliefs and approach a subject open-mindedly and objectively. This exercise was helped by a natural inclination to play 'devil's advocate' on all sides of issues and by a personal rule that one should never feel comfortably convinced of anything unless one has heard and understood the strongest arguments against it.

As I wrote the book, I tried to be equally diligent in exposing any arguments that seemed to me to be facile or logically flawed, no matter which 'side' they came from, but I also adhered to the principle that a splendid, logically impeccable argument does not necessarily create 'truth.' In the course of this exploration, it has been an unexpected pleasure to win the friendship, or at least the respect, of people whose views are far from my own, as I sent off various pieces of the book with the questions, 'Have I represented your point of view fairly and convincingly? Can you fault the way I have used your thoughts and your words and your work? If so, would you help me revise this passage until you can't fault it?'

A third issue that needs addressing in this Preface is whether, given the rapid progress of scientific discovery, a ten-year-old book like *The Fire in the Equations* is out of date. Regular attendees at meetings of cosmologists, other scientists, and leading thinkers in the science-religion field will, I believe, agree with me that we still headline the same problems that are featured in this book, raise the same questions, worry over the same arguments, invoke the same scientific discoveries and theories. The reason is not that these fields have failed to progress. *The Fire in the Equations* was ahead of its time in the 1990s. It dealt with cutting-edge science, with fields such as chaos and complexity theory that were just beginning to be understood and valued, with proposals such as the Higgs field for which potentially definitive experimental work is only now taking place, with speculative mathematical theories (such as Stephen Hawking's and Andrei Linde's) that still remain outside the limits of experiment or observation. In some cases the ideas, or slants on them, were so new that I had to rely on conversations and interviews because nothing had yet been published about them. In only three instances have

I felt it necessary to add to the discussion to bring it completely up to date. If I were writing the book today I might spend more time on the anthropic principle and the 'fine-tuning' of the universe, simply because they are so much in vogue, but the treatment of these in Chapter 5, as it stands, needs no apology or correction. It is also the case that *The Fire in the Equations* is not a book that juxtaposes only academic theology with science. The 'religion' represented here includes grass-roots religion—what people who attend church or synagogue and believe in God actually *do* believe. This has not changed dramatically. Not that they all agree, but then neither do the academic theologians or the scientists.

In closing this Preface, I should point out that my modus operandi in writing *The Fire in the Equations* was not to attempt to discover or forge reconciliation between science and religion. My exploration was not even based on the assumption that reconciliation is lacking or needed. It seemed best to go in search of conflict, not resolution, determinedly to those areas where the heart of the conflict was reputed to lie. I invite readers to join me on this journey and to draw their own conclusions from the arguments and evidence I have presented as fairly, straightforwardly, and accurately as I know how.

1

'They Buried Him in Westminster Abbey'

At 8 o'clock in the evening of Tuesday, 25 April 1882, the horse-drawn funeral car carrying Charles Darwin's coffin arrived at Westminster Abbey. The sixteen-mile journey in the rain from the Kentish village of Downe had taken all day. The coffin was borne through the cloisters of the Abbey and placed in the Chapel of St Faith, a spare, sepulchral, vaulted chamber, ice-cold and lit only by two flickering lanterns. It was a magnificent coffin, but not the coffin he and his family had wanted. That had been an oak box, 'all rough, just as it left the bench, no polish, no nothin,' said John Lewis, the Downe village carpenter who built it. 'When they agreed to send him to Westminster . . . my coffin wasn't wanted. This other one you could see to shave in.'[1] But Charles Darwin belonged to the nation now and to history, not to his family and his village, and at noon the following day he would be buried in state in the Abbey.

On the previous Sunday the news of Darwin's death had brought forth paeans of praise for him and his scientific discoveries from the pulpits of London, and the newspapers had continued the theme: 'Darwin's doctrine is in no wise inconsistent with strong religious faith and hope,' proclaimed the *Daily News*.[2] 'True Christians can accept the main scientific facts of Evolution just as they do of Astronomy and Geology, without any prejudice to more ancient and cherished beliefs,' pontificated the *Standard*.[3] Canon H. P. Liddon, in an afternoon sermon in St Paul's Cathedral, compared Darwin to St Thomas—'doubting' Thomas. Canon

Liddon chose not to condemn Darwin's religious scepticism but to commend 'the patience and care with which he observed and registered minute single facts'. St Thomas had refused to believe in Christ's resurrection unless he could put his hand into the wounds inflicted during the crucifixion. Darwin, like Thomas, had insisted on evidence, what Canon Liddon called 'the clearly ascertained report of the senses'.[4] The *Guardian* reassured its readers that they should not have 'any misgivings lest the sacred pavement of the Abbey should cover a secret enemy of the Faith'. The honour of burial there should be seen as 'a happy trophy of the reconciliation between Faith and Science'.[5]

What? Hadn't Darwin ended any possibility of believing strongly in both science and the Judaeo-Christian God without indulging in intellectual dishonesty? Extremes of opinion among both scientists and religious people ever since would certainly have it so. Darwin demolished the literal interpretation of the biblical Creation story and undermined one of the most eloquent arguments for the existence of God, that the world was a place perfectly designed for the survival and sustenance of human beings. Evolution and survival of the fittest provided a natural explanation for what had seemed a miracle. Yet there have been many scientists since Darwin, and there are many now in the twenty-first century, who are devout believers in God. Do they, as someone said of physicist Max Planck, forget their faith when they go into the lab, and forget their science when they go into church?

On 26 April 1882, the skies were still leaden. The gas-lit Abbey was dank and gloomy, thronged with sombrely dressed luminaries of government and science as well as middle-class citizens who came without black-bordered tickets and were allowed to fill the less desirable seats. The funeral was a religious service with readings and anthem texts from the Gospels and the Psalms. The Abbey organist, J. Frederick Bridge, had composed an anthem to be sung for the occasion. He had chosen words from the Book of Proverbs: 'Happy is the man that findeth wisdom, and getteth understanding.'[6] Later the chief mourners and the public filed past the grave to the accompaniment of the 'Dead March' from Handel's *Saul,* a march which in the original was a dirge for a king who had torn himself away from the love of God to rely on the power of himself.

What did they make of it, the mourners, the dignitaries, and the merely curious at the funeral of Charles Darwin? Is the Wisdom of science the Wisdom of Proverbs? Proverbs also describes a single-minded human struggle which ends in the gift of 'the knowledge of God'.[7] A century after Darwin's death, another great English scientist, Stephen Hawking, wrote that the ultimate triumph of human reason would be to know the Mind of God. He said science could get us almost there, but not the whole way. Is the Knowledge of God in Proverbs the Mind of God in *A Brief History of Time*? Or is Hawking's a metaphor for our becoming God-like in our complete knowledge? Is there a Person waiting for us at the end of the quest, or is that Person *us,* reasoning humanity triumphant, evolution's masterpiece?

Ultimate reality, whatever that turns out to be, is the end of the quest. Paradoxically, it must also be the beginning. We must ask whether there is anything about our universe, about ourselves, that we can take for granted—any fundamental we can use as a starting place for the exploration of everything else. If it is difficult to find such a 'still point'—and we shall find that it is indeed difficult—then the quest for ultimate truth must begin with a leap of faith. Not faith that we are capable of complete understanding. Faith that we can know anything at all.

2

Seeing Things

Kick at the rock, Sam Johnson, break your bones,
But cloudy, cloudy is the stuff of stones.
—FROM *EPISTEMOLOGY* BY RICHARD WILBUR

THERE IS AN OLD straight-backed oak chair standing against the wall across from my desk. It was made by hand about a century ago in the Texas hills, when that hill country was still a frontier. I inherited the chair from my grandparents. When my grandmother and grandfather looked at it in the dining room of their Mason County parsonage, they saw the same chair I see here today in my study, or so I assume. Maybe the wood has darkened a little with age. Someone visiting me today will see the same chair my grandparents saw and that I see, or so I assume. Common sense tells me I'm right.

My faith in common sense is a faltering faith. In writing my previous book, *Stephen Hawking: Quest for a Theory of Everything,* I explored a world that was not on any level a common-sense world. A man of extraordinary genius condemned to live out his years locked in a useless body without movement or speech, whose sheer bloody-minded courage nevertheless allows him to be one of the pre-eminent physicists of our time as well as an international celebrity—Hawking is not a common-sense figure. Quantum mechanics and Einstein's general relativity are not common-sense subjects. Nevertheless, having made that journey through the looking glass and back, having seen for myself how absurd and counter-intuitive the world is, I still sit here and say, Yes, the reality of that oak chair was the same for my grandparents as it is for me today.

I recently re-read Sir Arthur Eddington's introduction to his book *The Nature of the Physical World,*[1] in which he speaks of a table as I am writing about my chair. There is a story about Eddington that when someone remarked that only three people in the world understood Einstein's theory of relativity, he muttered, 'I'm trying to think who the third could be.' But Eddington, for all his remarkable intellect, also had a talent for taking complicated scientific concepts and explaining them in simple English. In the paper I've been reading he describes a piece of furniture like my chair as seen through the eyes of physics. It is not a description my grandparents would have recognized.

My chair is made up of atoms, and atoms are almost entirely empty space. That means my chair consists in very large part of emptiness. My chair is a blur of uncertainty, which I'm allowed to think of as unimaginably tiny particles whizzing around in a fuzzy manner. I know I mustn't think of these particles as 'things' in exactly the sense I think of the chair as a 'thing'—something that can be pinned down in the accurate way we expect to pin 'things' down. I wonder whether a chair consisting of 'non-things' can itself fairly be called a 'thing', and why I see it as such. Is my familiar chair more real than the same chair as Eddington describes it? Or must I consider the smallest level of the universe the most 'real'? We shall get back to those questions later. My chair looks real enough to me.

A perfectly common-sense, familiar Texas oak chair. That seems to be the only interpretation anyone's five senses can make of it. If I touch the chair seat, a swarm of electronic impulses bats against my hand, which is also a swarm of electronic impulses. The combined bulk of these impulses is less than a billionth of the bulk of the chair itself. Thus all that empty space. But somewhere between the electronic impulses and my consciousness a mysterious transformation occurs which causes me without any effort to interpret all of this as a solid piece of oak.

Perhaps that interpretation is the only possible interpretation on our level of the universe, but I am curious as to whether you really would see and feel the same chair if you were here in my study. We would describe it to one another in more or less the same way, but our descriptions would have to consist of words and would have to depend entirely upon the mental images each of us has learned to associate with those words. Have you perhaps learned to associate the word 'brown' in your mind's eye with a different hue from that which my mind conjures up when 'brown' is mentioned? My chair in my mind's eye is surely not precisely my chair in your mind's eye.

What do you and I really know about chairs or anything else? How do we know it? We humans have gone a long way beyond such modest observations of the world around us. We trust not only our five senses but a wealth of accumulated findings and a spectacularly complex system of mathematics and logic. From all of this we hope to find out the truth about far, far more than chairs and tables. What is the universe? How did it begin? What happened before that? How and when will it end? What is space and, even more puzzling, what is time? We hope to be able to answer Hawking's question 'Why does the universe go to all the bother of existing?'[2] We hope, with him, to know the mind of God.

We also would like to know the answers to questions left unspoken in Hawking's *A Brief History of Time,* questions that nevertheless cry out from its pages for answers. Why? Why should a man be dealt such a preposterously unbalanced fate—appalling disease, extraordinary genius, bloody-minded courage? It isn't just Stephen Hawking's dilemma. In a sense, the cynic might suggest, it sums up the situation of the entire human race. It is the human condition, a mockery of rationality, a theatre of the absurd.

My grandparents would have bowed to all of it as the work of a God whose activities are far beyond our understanding, a God whose 'tough love' goes beyond that of any human parent. That is how they dealt with the absurdity of their youngest son being blown up with his boat in the English Channel, not by enemy fire but by a stray American shell. Some of the rest of us aren't willing to take that sort of explanation lying down, and neither, really, were my grandparents—not without complaint and some rebellion and more than a few demands for clearer explanations, demands directed to a God they were quite sure could give the explanations if he chose. The mind of God to my grandparents was not something to be learned through physics, though my grandfather was avidly interested in whatever scientists could tell him, and certainly didn't think such information irrelevant to his own personal spiritual quest.

Hawking does not share my grandparents' faith in God. But he shares their curiosity about ultimate truth, ultimate explanation. Like them he longs to have all illusions swept away, to know the unveiled truth behind everything, no holds barred. To act on such longing involves great risk. Does the atheist want to know the truth if the truth is that there is a God? Does the believer want to know the truth if the truth is that there is not? Are we that open-minded?

There is a further element of risk for anyone on a search for truth. You cannot start in a vacuum. You must begin by trusting some ideas about the universe that have never been proved, may never be proved, and might turn out to be wrong. To be simplistic about it, you have to assume that you exist and that you are sane. Those may not be such difficult assumptions. Common sense supports them. Of course you have to believe they are true in order to trust your common sense. You see what sort of mental maze we get ourselves into!

The search for truth in science is based on agreement concerning just such basic assumptions. It is a gamble, if you will; a gamble that certain articles of faith that cannot be proved by science are nevertheless well-founded enough to provide a springboard for all scientific investigation. It is intriguing to find that religion shares much of science's basic view of reality. How is it that two approaches, science and religion, both claiming to be avenues to truth but in many ways reputed to clash with one another, should be in agreement on so basic a level?

The explanation could be quite simple—that we are all looking at the same universe, and what is obvious to one reasonable person is equally obvious to the next. If that is so, it should not surprise us to find all reasonable people more or less in agreement about certain fundamental aspects of the universe. However, the agreement is not unanimous. We are speaking of a world-view shared by science (since the seventeenth century) and Western religion, with exceptions even here, but not shared by all of humanity who presumably experience and have experienced the same universe.

Perhaps the explanation lies in the origins of science as we know it today. Scientists of the seventeenth century, most but not all of whom had religious views closer to my grandparents than to Hawking (many of the first Fellows of the Royal Society in England were Puritans), developed a procedure to be used in the search for scientific knowledge, a procedure that would systematically separate what is true from what is not true. That is the procedure we call the scientific method. It has served us splendidly ever since its birth and made our spectacular technology possible. Whatever the scientific method's origins or its philosophical foundations, we have no cause to doubt its usefulness.

Depending upon whether we believe in God, you or I might leave God out of the following articles of faith, but otherwise we would find little in this seventeenth-century world-view with which to disagree. In the seventeenth century a scientist could have had it both ways without risking charges of contradiction. What he learned from his religion and his direct experience of the universe led him to believe the following:

- The universe is *rational,* reflecting both the intellect and the faithfulness of its Creator. It has pattern, symmetry, and predictability to it. Effect follows cause in a dependable manner. For these reasons, it is not futile to try to study the universe.
- The universe is *accessible* to us, not a closed book but one open to our investigation. Minds created in the image of the mind of God can understand the universe God created.
- The universe has *contingency* to it, meaning that things could have been different from the way we find them, and chance and/or choice have played a role in making them what they are. Whether this is contingency in the sense that chance and choice play an on-going role within the universe, or merely in the sense that there was an initial chance occurrence or choice which brought about this universe instead of a different one or none at all, one cannot learn about the universe by pure thought and logic alone. Knowledge comes by observing and testing it.
- There is such a thing as *objective* reality. Because God exists and sees and knows everything, there IS a truth behind everything. Reality has a hard edge to it and does not cave in or shift like sands in the desert

in response to our opinions, perceptions, preferences, beliefs, or anything else. Reality is not a democracy. There is something definite, some raw material, out there for us to study.

- There is *unity* to the universe. There is an explanation—one God, one equation, or one system of logic—which is fundamental to everything. The universe operates by underlying laws that do not change in an arbitrary fashion from place to place, from minute to minute, or even millennium to millennium. There are no loose ends, no real contradictions. At some deep level, everything fits.

Divorced now from the assumption that there is a God, these five assumptions about the universe, these five articles of faith, if you will—rationality, accessibility, contingency, objectivity, and unity—continue to underlie the practice of science. Some would argue that upon them depends all possibility of doing science as we know it. The best argument for their validity is not that they are obvious but that the scientific method seems to work so well! The proof (dangerous word) is in the pudding.

Nevertheless, we are left with some questions. Is the scientific method, which serves us so admirably in our quest for knowledge about the physical universe, also a reliable source of complete understanding about the events around us and of our own existence? If the scientific method and the approach of constructing mathematical models cannot answer Hawking's question 'Why does the universe go to all the bother of existing?', what can? Is there a meaning and is there a God (or 'mind of God') beyond the reaches of the scientific method but not beyond the reaches of human reason?

Human reason cannot be divorced from common sense, which says: I can see that the universe has rationality and accessibility and contingency and objectivity, and so can most of the people I know . . . If other cultures look at the same universe and draw different conclusions, well, that's certainly mysterious but I can't be too much bothered by it . . . Maybe they're wrong . . . I have to trust my senses.

If you feel that way you may be accused of being naive. However, some very un-naive people would back you up to the extent of saying that the argument 'This is what I make of it all, and I don't have any stronger reference point than that' is in fact very hard to refute. Sir Brian Pippard of Cambridge University, the physicist who introduced me to the Eddington book I mentioned earlier, tells me there are more chairs across from me in my study than just the common-sense chair and the chair-as-seen-by-physics. We've already mentioned a third, but we didn't give it quite the importance Brian Pippard wants us to. It is the chair in my mind's eye, an image I can't share with Pippard or you or anybody, because I can't let you into my mind to see whether 'brown' or anything else looks the same in my mind as in yours. We can discuss my chair, even compare it with a description my grandfather wrote in an inventory of his furniture, and come easily to the conclusion that we are all talking about the same object, but our mind's-eye chairs will not all be identical. Our interpretations of whatever it is out there across from my desk will not be exactly the same.

Perhaps the mind's-eye chair seems to you less substantial, representing a fuzzier and more subjective viewpoint, than Eddington's chair-as-viewed-by-physics or the common-sense chair we thought was there before we began all this talk about it. Evidence coming from one person is not so dependable as something you and I and others could agree upon precisely. The scientific method cannot accept such individual, uncorroborated evidence. But Pippard argues, and it is hard to take exception with him, that the *one and only* certainty each of us has is the certainty of his or her own existence. What this means is that 'Come what may, it is the [chair] in the mind of each of us to which all else we believe in must conform.'[3] Of course even the certainty of my own existence is questionable. Philosophically it is possible to argue that I do not exist. But I notice that I do, and that is the only reference point I have to go on. I am, by default, my unique authority in the matter. I also have only my presumption of my existence and my mind's-eye images to go on if I want to come to any conclusions at all about my chair or the rest of the universe.

What has happened to objective truth if truth in my mind's eye may be different from truth in yours? Pippard isn't saying that what my mind's eye leads me to believe is truth. What your mind's eye leads you to believe isn't necessarily truth either. Pippard is saying that the one and only certainty *I* have is of *my* own existence. The only certainty *you* have is of *your* own existence. Each of us has only that as a starting point. The question is, how does what begins with my certainty of my existence, and continues with my mind's-eye view of the universe, end with the discovery of objective truth—even perhaps with that ultimate distillation of objective truth, the Theory of Everything or the Mind of God? What makes me think I can begin HERE and arrive THERE where ultimate, objective truth is in my mind's-eye view?

One of the articles of faith listed above was that truth does exist in a way that is independent and 'other' from myself or yourself, unchanged whether or not it is studied by a physicist or a common-sense observer and not affected by how it is viewed in anyone's mind's eye. Pippard tells me there is a fourth chair across the room from me—the 'chair-as-it-is-in-itself', the most bed-rock solid of all views of my chair and the most elusive.

I *would* like to know whether my perception of my grandparents' chair and the rest of the universe has any relation to ultimate reality. If there is a God, I would like to know what it all looks like from God's vantage point. Sir Brian Pippard says my chair-as-it-is-in-itself—and, by extension, the universe-as-it-is-in-itself—might turn out to be 'something quite other, outside the range of our thought.'[4] How much more 'other' might be the Mind of God?

To bring us down out of the clouds to a more practical level, suppose you decide, on a quest for knowledge, to attach particular importance to what scientists have discovered about the universe by means of the scientific method, which does after all seem to be a very reliable method for finding out what is what. If you proceed along these lines you may be in for a shock. You will learn not only that science has not proved the assumptions that the universe is rational, accessible, contingent, objective, and has unity to it, but also that there have been scientific discoveries and theories which lead us to question seriously whether those assumptions are correct. Where does that leave us? Are the foundations of all our knowledge crumbling? Is the search for truth about to self-destruct? Can we know ANYTHING?

Is the Rational Universe an Illusion?

We speak of a universe that is rational and logical, a universe that makes sense and has pattern to it. Strong evidence of this rationality is the dependability of cause and effect. Everyone knows that nothing happens without something causing it to happen. The cause may be obvious or it may be hidden beyond our ability ever to discover what it is, but it is always there, or so we assume. We conduct lengthy and expensive investigations to find the cause of a disaster like the explosion of the United States space-shuttle *Challenger.* Extremely cold weather, a problem with the O-ring seals. No-one thinks seriously of concluding 'It just happened, nothing more to be said about it.' Every effect has a cause, and that means there are chains of cause and effect, chains which we don't expect to come to a dead end.

Even if chance played a part—the perhaps unlikely instance of weather conditions and O-ring problem coinciding—no one would claim that the 'law' of cause and effect had been broken. The weather conditions had a history of cause and effect behind them and so did the O-rings and the adhesive that secured them. Too complicated to follow, perhaps, but still there. A story was involved, and if we could find out what the story was, we could explain the disaster. If we had failed to find some link in the story, we still wouldn't have leapt to the conclusion that no such link existed. It would not occur to us to do that. We say the evidence is insufficient.

We've grown accustomed to the way cause and effect operate on our level and in the part of the universe we can observe, and so it seems safe to assume, though we have no way of demonstrating it beyond a certain point, that cause and effect similarly operate in areas of the universe that we cannot observe directly. We rely on this being so. We think that cause and effect will continue to operate in the future, with no real guarantee that today isn't the last day they will be in operation. If an experiment gives one result today, it ought to give the same result tomorrow. If it fails to do so, we question the experiment or our interpretation of it, not the reliability of the concept of cause and effect.

We also assume with no way of testing it that cause and effect operated at the very earliest stages of the universe. Even at the moment of creation? So strong is our belief that it is difficult to imagine that the universe itself could exist without a cause; that it could just BE. We want to know how it happened, and we want to find the answer to the question 'Why?' Or even 'Who?'

Belief in cause and effect is a cornerstone of the scientific method. Nevertheless some scientists keep reminding us that the 'law' of cause and effect is an 'article of faith', not a law at all. It can't be proved to operate in all cases. Indeed, there is a major subfield of modern physics that requires us to reconsider our assumption that every event has an unbroken history of cause and effect leading up to it.

'Quantum mechanics' is not a name like 'black hole' or 'quasar' to light the fires of our imagination. Yet the study of the quantum level of the universe is an area of physics which seems as exotic as anything ever dreamed of in science fiction. It is the study of the smallest size levels in the universe, of atoms and elementary particles. Some of what happens on that level is extremely difficult to explain in a way that satisfies our wish for a common-sense description. One of the oddities is that we observe individual events that are, in a sense, 'uncaused' events, happenings without a history of the sort we normally assume any event must have.

The quantum level of the universe will crop up repeatedly in this book. For the benefit of those who haven't already learned something about it, or have forgotten what they used to know, let us pay it a preliminary visit before proceeding further:

Picture something relatively familiar, our solar system. The planets orbit the sun in orbits that we have learned to predict. At any given moment each planet in relation to the others has a definite position and is travelling in a definite direction at a definite speed. We can see that Saturn is THERE today, and, because we also know its speed and direction of movement, we can figure out what path it followed to get there and where it's going next. A space vehicle could plot a course and know that at a certain time, at certain space coordinates, it would intercept the planet Saturn.

Early in our century scientists thought atoms were something like miniature solar systems with electrons orbiting the nucleus as predictably as planets orbit the sun. That made for excellent science fiction possibilities—our solar system as an atom in a superbeing's thumbnail—intelligent beings living on electrons, as we live on the earth. You were not taught in school that any such possibilities existed, but you probably had a diagram of an atom in your physics book that looked something like the solar system, and you very likely carry that picture around in your mind even now to trundle out whenever the word 'atom' is spoken. In the 1920s physicists found that this is not an accurate picture of an atom (which shows the time lag between scientific discoveries and textbook publication). Though no mental picture really suffices, we do better to visualize electrons blurred in a cloud around the nucleus. With this revelation, science outdid science fiction.

As far as anyone has been able to discover, unlike a planet in a solar system, an electron (and this applies to all other particles as well) never has a definite *position* AND a definite *momentum* at the same time. We may measure very precisely the position of a particle, but we cannot at the same time measure very precisely its momentum. Or we may choose to measure its momentum very precisely, but we cannot at the same time precisely measure its position. It's as though the two measurements—position and momentum—ride at opposite ends of a see-saw. As the precision of one measurement rises, the other inevitably goes down, and vice versa. This is the Heisenberg Uncertainty Principle of quantum physics. No-one has been able to find a way around it. There probably is none. We cannot under any circumstances find out where a particle is AND the speed and direction of its movement. The answer to that question with regard to any individual particle at any given moment in time seems not simply unknown—not simply unknowable—non-existent.

There are a few physicists who still refuse to believe that such a bizarre situation, such a block to our further investigation, should be the end of the story. They hope that some future development in physics will increase our understanding and make it possible to ask and answer the two questions precisely at the same time: 'Where is the particle and how is it moving?' But most have concluded that this question has no answer, that quantum uncertainty does not result from our ineptitude as observers, that things on the quantum level really are uncertain.

The drama of this situation may not strike you immediately. It's obvious that no scientist likes to be frustrated in his or her investigations, but why should this uncertainty have so profoundly disturbed the scientific community when it was discovered early in our century, and in the years following that discovery? It has been disturbing in part because it seems to undermine our faith in the reliability of cause and effect, a concept which has traditionally supported the assumption of a rational universe.

In the case of the *Challenger* explosion, we had a definite series of events, a history (though perhaps not entirely known to us) that happened in one way and not in any other. In the case of the planets in the solar system, a definite path, a definite history brought Saturn to the position in which we observe it tonight. Even in the case of an amnesia patient who remembers nothing at all, whom no-one else can identify, and whose past cannot be traced, the patient is *assumed* to have a history which happened in one way and not in any other.

In the case of an individual elementary particle, that definite series of events, that definite history, is missing. The particle doesn't even have an unknown or an unknowable history. What it has is a blur of possible histories, a blur that does not focus itself on one historical track rather than another. Studying the quantum world from our level, we see that some histories for a particle are more likely than others, have a greater probability. Nevertheless (to state the case in its most extreme form) any history is possible and there is *no* answer to the question 'What history brought this one particle to the position or momentum we, at this moment, measure it to have?' In this sense, 'causality' is lost.

In case you are thinking that all this, though fascinating, is not very relevant to the world of everyday existence, let me remind you of the chair with which we began this chapter. All ordinary matter in the universe is made of atoms. That goes for this book, ourselves, planets, air, microbes, as well as chairs. Every atom consists of particles, and the uncertainty principle applies to all particles. You and I and chairs and tables and all other matter in the universe are at one level a quantum blur—on any level an amalgam of uncaused events!

But does a loss of causality on the level of particles and atoms really call into question the rationality of the universe? You may raise your eyes from this book and reassure yourself that day does follow night and night follows day, the seasons come round as expected, the moon and the planets keep to their appointed orbits, the galaxy retains its shape, the room in which you sit has the same dimensions it had an hour ago. Whatever nonsense is going on, it all sorts itself out into the familiar and, given the circumstances, surprisingly dependable world we perceive. In Chapter 6 we will examine reasons why this is so. But scientists still don't completely understand how and why the sorting out takes place, how and why the world of quantum uncertainty is transformed into the common-sense world of our daily experience. They cannot tell us how large a part human perception and consciousness play in the sorting out, how much 'interpretation' by the human mind has to go into the transformation, how much what we see is what we expect to see rather than what is really there.

We know we aren't directly conscious of everything that goes on around us. Our five senses are our only contact with the world, and there is much news they don't transmit. In the room with us there are many types of electromagnetic radiation that we aren't aware of. All of these are forms of light which human eyes can't see. Some of them we sense as heat. Others not at all. Some are in the form of radio waves, which we can't know are there unless we turn on a radio. What else is going on around us? Suppose the universe is really a place of nonsense—anarchical, meaningless, patternless, directionless in both space and time. Is there a possibility *that* is what reality is like? If so, why do we see so much pattern?

The theory of evolution tells us that certain capabilities give certain individuals within a species a survival advantage. These individuals are more successful than others at making the best of the situation in their environment; they live long enough to have more offspring. Their traits, including those which gave them the survival advantage, are passed down to more descendants than the traits of those individuals without the survival advantage. We'll discuss evolution in more detail in Chapter 6. Meanwhile, we are all probably familiar with examples of survival advantage. If lizards appear in green and brown, and green is a good camouflage among leaves—so that the predators of lizards can't find the green ones to eat them—after a few generations (all other things being equal) brown lizards are likely to be extinct and green lizards flourishing.

It isn't hard to imagine that in the evolution of living beings there was a survival advantage for those who could discover pattern in their surroundings and experiences. Brains would have evolved in such a way that as generations passed they were better and better able to find such pattern. We know that the human mind has become a superb device for compressing the wealth of information it receives from the five senses into useful, meaningful, abbreviated form. Thought and memory could not work as they do if we were not equipped to do this compressing. It doesn't seem far-fetched to think that our brains, having been wired this way by evolution, might continue with this process out of habit, even to the extent of finding pattern where there is no inherent pattern to be found.

But could the human or pre-human brain have created the very concept of pattern if there had been no pattern at all to be found in the universe? Is that perhaps how we have come to interpret a quantum blur as a chair? Are there in reality an infinite number of dimensions, only four of which our senses and our consciousness allow us to know about? Does time perhaps *not* flow chronologically in a way which allows us to remember the past but not the future? Can we prove anything about this at all? A good argument against an absence of all pattern is that evolution itself is a pattern. If *that* pattern exists only in our minds, could anything have done any evolving?

It's difficult to see how *all* pattern could be merely *our* invention. But could it be that human beings have come to attribute more importance to the pattern found in nature than nature herself does? Consider the symmetry we find in nature. We have only to look around us to see that there is far more to the picture than simple symmetry. Symmetry seems to be an ideal which much of the universe fails to live up to, at least on the levels most obvious to us.

When she was ten years old, my daughter did a school project about geometric shapes in the natural and built environment. Collecting photographs, she discovered it was easy to find examples in the built environment. Here were squares, pyramids, even dodecahedrons aplenty. Collecting the photographs of the natural environment was much more difficult. Circles were there in the pupils of our eyes and the ripples when we drop a stone in still water. But other shapes presented a problem. Columnal basalt formed *roughly* hexagonal shapes in a natural 'giant's pavement'. The hexagons in DNA spirals, in beehives, and in the eye of a horsefly also seemed carelessly drawn, without regard for exact geometry. The diamond shapes in a sunflower seed-head were lop-sided. One had to give tree-trunks the benefit of the doubt in most cases to call them cylinders. The earth bulges and is not a perfect sphere. Natural crystals are not perfect geometric shapes either. As for mirror symmetry, one side of a human face is not the true mirror image of the other.

It seemed at first to a ten-year-old that all the wealth of geometric shapes and figures that lie waiting in mathematics, which is arguably a thing of nature, not human-made, is largely unrealized in nature itself. Nature has not taken advantage of many of the possibilities. Humans have. The things we build and the art we create exhibit much more geometry and symmetry than we can find in nature. Are we bettering nature, imposing rationality on a less rational universe, when we design a building or draw a pleasing design?

Even my young daughter soon realized that the situation was really more subtle than that. There is geometry hidden in nature. The way we see, the way we judge distance and perspective is all bound up with triangles and cones. The frequency of vibration of the stretched membrane of a timpani head involves circles and wedges of circles. Radiation waves move out spherically from an underground explosion. The imaginary line drawn through time by a planet (not only its orbit, the pattern of many superimposed orbits, in time-lapse photography if you will) is beautifully geometric. The rules of geometry help dictate how a building can be made to stand and what cannot be built. Whether we choose to carry that geometry and symmetry into the more visual level of decor and design, we *must* adhere to nature's geometry-related rules in the structure. We shall see later that there is also symmetry hidden in the fundamental laws of nature.

But if symmetry and geometry go deeper than what we most readily see in the natural world, the digression from ideal geometry and symmetry also goes deeper. Matter in the universe, in the form of stars, planets and galaxies, is distributed unevenly. It is clumped in a way not yet understood by science, leaving enormous, mysterious voids. At the level of elementary particles, we discover a right- and left-handedness about the universe, slightly favouring the left. In the early universe there may have been an infinitesimal imbalance between the amount of matter and the amount of antimatter, an imbalance which has resulted in the universe of matter we see today.

If we were somehow able to take the natural world, straighten out the lines, correct the asymmetries and irregularities, make all the tree-trunks into true cylinders, the picture that would emerge would be unnatural, unbeautiful, impossible. If someone or something had taken the asymmetries found in physics and 'corrected' them, we and our universe could not exist. As important as the concept of pattern in nature is, there is also a powerful requirement for a pulling out of shape, a deviation from plumb, a tipping of the balance. There is a tension everywhere between ideal pattern and deviation from it. Can we call this tension itself a symmetry, a pattern, a balance? Such a subtle symmetry, such a tension, is familiar to artists and musicians. It is part of their craft to use it, to make it work for them. It is less familiar, perhaps, to scientists, except for those engaged in the study of chaos and complexity.

The rationality of the universe goes beyond its manifestation in obvious symmetry, pattern, and cause and effect. It would appear to include the ability to make judgments as to when the symmetry must be broken, when the geometry must be pulled out of shape, when cause and effect must not apply. Is that the rationality of the Mind of God?

Perhaps we have underestimated the amount of apparent asymmetry and 'irrationality' that can be accommodated without contradiction in a rational universe. Perhaps there is no contradiction between a rational God and a range of human experience that seems to stretch any conventional notion of rationality beyond the breaking point. Or are such suggestions merely a rearguard action engaged in so that we can preserve our assumptions that the universe is rational and that there is a Mind of God?

'In Nature's Infinite Book of Mysteries . . .' Can We Read Very Much at All?

'We don't know a millionth of one percent about anything,' said the American inventor Thomas Edison.[5] Of course it's been at least seventy years since he uttered those words. We ought to know a little more by now. Even so, just a casual look around us would indicate that there is incredibly much to know.

We've already called into question the trustworthiness of our five senses, through which any information about the universe must come to us. Nevertheless we have a gut feeling (which isn't quite the same thing as common sense) that the universe is open to our study and our understanding, and this feeling certainly isn't new with our generation or our century. However, it is possible to conceive of a universe which would be rational yet somehow blocked off, veiled, difficult to find out about, as our everyday world must be to one who is born blind and deaf. It is even possible to conceive of a universe in which this blocking off would be for our benefit. T. S. Eliot wrote that 'Humankind cannot bear very much reality.'[6] Perhaps he was right.

Nevertheless, we yearn to know the truth about everything and behind everything, to see further and further with our telescopes, to probe closer and closer with our microscopes, to know all the answers. We are hard to discourage and not particularly humble in assessing our capabilities or our achievements.

In April of 1980 Hawking had the audacity to suggest we had come so far that before the end of the twentieth century we might find the theory that would explain everything that is happening, has happened, or ever will happen in the universe. Eight years later he wrote that after we have that theory in hand we might just go on (not scientists alone, but all of humanity) to know the mind of God. Which calls to memory an ironic piece of history trivia. In the late 1890s Prussia closed its patent office on the grounds that all possible inventions had been invented. It wasn't long afterwards that Albert Einstein, in a Swiss patent office, began toying with ideas which would revolutionize science.

In the children's party game 'Pass the Parcel', a colourfully wrapped package goes round the circle of children while the music blares. When the music stops, the child holding the parcel unwraps the first layer of tissue paper. A piece of candy tumbles out, the reward for this child. The music begins, the parcel starts round once more, and the game goes on. With each pause in the music another layer of paper is pulled off and the parcel gets smaller. At the heart of the parcel there is a prize more exciting than any of the candy rewards that have come before.

Science plays a game like Pass the Parcel, unwrapping layer after layer of knowledge to reveal deeper knowledge, more complete understanding. For instance, unwrap atoms and you find electrons, protons, and neutrons. Unwrap protons and neutrons and you find quarks. Perhaps there are, after all, layers of structure more basic than electrons and quarks. As the game goes on, we hold our breath to see what will emerge when the last wrapping comes off. We might have to hold our breath for a very long time.

If our game is 'Infinite Pass the Parcel', it will never end. We will grow old and die sitting in that circle, listening to that tinny march! New generations will take our place in the circle. We will discover more and more refined theories, each one describing the universe more accurately than the last. Devise a way to take more sensitive measurements or make a new observation, and we discover things that are not accounted for by existing theory. Develop a more advanced theory. With each advance a layer of the parcel is unwrapped. The 'unknown' seems to become smaller. But if knowledge is infinite, the 'unknown' will never truly grow smaller. Every layer will reveal a deeper layer, and there will be another beyond that. Even if there is such a thing as complete knowledge, our way of doing science might mean that an infinite number of refinements would be needed for us to touch bed-rock. We may pass the parcel for all eternity. Einstein, for one, believed that 'this process of deepening the theory has no limits.'[7]

Whether or not nature's book of mysteries is infinite, science has already encountered some specific pages of the book which seem to be unreadable. We have already mentioned the quantum level of the universe and how the uncertainty principle limits us there. Physicist and author Paul C. W. Davies described scientific work on elementary particles as 'learning more and more about less and less.' Hawking calls quantum mechanics the 'theory of what we do not know and cannot predict.' Einstein didn't want to accept quantum uncertainty as inherent uncertainty. 'God does not play dice,' he declared. But Niels Bohr, the Danish physicist, who was convinced that the quantum world was intrinsically uncertain, answered, 'Albert, don't tell God what he can do!' In the 1930s Einstein devised an experiment which he hoped would show that events, even on the quantum level, have distinct causes. It wasn't until the 1960s that the technical capability was available to carry out Einstein's experiment. The results showed that Einstein had been wrong.

The quantum world does not provide the only unreadable passage in the book of the universe. For a time in the late sixties and seventies, it seemed as though singularities of infinite density and spacetime curvature might end all hope of our learning about how the universe began. If singularities exist, they are a serious road-block. Relativity theory predicts that we should find them at the centre of black holes, at the beginning of the universe, and possibly at the end of the universe. Physicists do not want to find singularities. It is no small matter to discover a door slammed in their faces.

First, a look at singularities which might be at the centre of black holes. Black-hole theory has it that a massive star, quite a bit more massive than our sun, after successfully supporting itself for millions or even billions of years against the inexorable collapsing pull of gravity, runs out of the fuel necessary to continue this support. To be more specific, the fuel is hydrogen, and the star has been producing energy by transforming this hydrogen into helium and then into some heavier elements. When the energy the star can produce is no longer enough to balance the pull of gravity, the star begins to collapse. If the star is massive enough, it will go on collapsing until it becomes a black hole.

What exactly is a black hole? The classical textbook definition is an area of the universe from which nothing can escape unless it is capable of travelling faster than the speed of light. Only the ability to exceed the speed of light could allow something to escape the gravitational pull of a black hole. Nothing that we know of can exceed the speed of light, and so it follows, by this definition, that nothing, not even light itself, can escape from a black hole.

If you aren't familiar with the concept of black holes you may be picturing an invisible solid sphere (the remains of the star) out in space, emitting no light and allowing no escape from its surface, but that isn't quite correct. A black hole is not an object but includes an area of space surrounding the collapsing star—roughly spherical but probably bulging like the earth does around its midriff. Relativity theory predicts that the star itself, within this area of no escape, goes on collapsing until all the matter in it is compressed to an area of zero volume and infinite density, which is known as a singularity.

Physical theories can't really handle infinite numbers. When Einstein's theory of general relativity predicts a singularity of infinite density and infinite spacetime curvature, that theory is also predicting its own breakdown. All the theories of classical physics break down at a singularity. We lose our ability to predict anything.

Some of you may be wondering why we don't label the entire interior of a black hole, rather than just the singularity, as *terra incognita,* one of the unreadable pages. If no light or anything else can come out of a black hole, then surely no information can come out. How do we know what goes on in there?

Black holes are indeed mysterious, but we do know mathematically and theoretically a great deal about them, including the dynamics of their interiors. Furthermore, it isn't entirely inconceivable that we may some day have the technology to travel to a black hole. Then if anyone is *really* curious, he or she can jump in, and if the black hole is large enough, so that gravitational tidal effects don't tear the explorer to spaghetti immediately, he or she can find out first-hand about what goes on inside a black hole, at least in its outermost areas. This expert witness won't be able to return to report on the experience to the rest of us, but at least one person's curiosity will be satisfied. The interior of a black hole is not unknowable.

However, it isn't the singularities that might lie at the heart of black holes that trouble physicists most. The really serious unreadable page is the singularity at the beginning of the universe. First we had better discuss why there should be any singularity there at all.

In the 1920s American astronomer Edwin Hubble made one of the most revolutionary discoveries of the twentieth century: The universe is expanding. The distant galaxies are all increasing in distance from us and from each other. If this is true, and no-one today seriously contests it, then unless something has changed dramatically in the past, the galaxies used to be much closer together. It follows that at some moment in the distant past everything that we might ever be able to observe in the universe would have been in exactly the same place. All that enormous amount of mass and energy would have been packed in a single point, infinitely dense.

We'll return to the events and controversies leading up to and following upon Hubble's discovery in Chapter 4. For the moment suffice it to say that although general relativity predicts the existence of singularities, it was not until 1970 that Roger Penrose of Oxford University and Stephen Hawking (both experts on black holes) used what they had learned from black holes, reversed the direction of time, and showed that the universe must have begun as a singularity. This was good news for their careers as physicists. In another way it was bad news.

If Hawking and Penrose were correct, the singularity at the beginning of the universe would mean that the beginning of the universe is beyond our science—an unreadable page. As is true at a singularity in a black hole, the laws and theories of classical physics, including Einstein's theory of relativity which predicts the singularity, all break down at the singularity at the beginning of the universe. We couldn't use these laws to predict what would emerge from the singularity. It could be any sort of universe. And the question of what happened before the singularity probably has no meaning at all. All we could say about the beginning is that time began, because we observe that it did.

It wasn't long before physicists, with Hawking in the lead, began to attack this ultimate Gordian knot. We shall see the results of that venture in Chapter 4.

There is another category of information about the universe which seems closed to our investigation. We have not yet found a way to predict 'constants of nature' such as the mass and charge of the electron and the speed of light in a vacuum. To say these are unknown would be incorrect. We can, in fact, measure the mass and charge of the electron and the speed of light. What we don't know about them is more subtle than that: If we couldn't measure these values directly, we wouldn't be able to find out what they are from any theory we have. These are 'arbitrary elements' in all our theories. An alien who had never seen our universe would have no way of finding out by using any present theory what these values would be in our universe. And that, for a physicist, is an unsatisfactory situation.

Will we ever know these answers? Some hopeful avenues are currently being explored. However, if our universe began as a wormhole tunnelling out of another universe, as one speculative theory we encounter in Chapter 4 suggests, we may never be able to predict all the constants of nature —though we will understand better why we must remain frustrated.

Relatively new branches of science called chaos and complexity, which we shall examine in detail in Chapter 6, lead us to believe we've been over-confident about human ability to predict even the orbits of the solar system very far into the future. With most, perhaps all, systems in nature, only infinite knowledge of present details (and perhaps not even that) would allow us to calculate precisely what will happen in the future of the system or what has happened in the past. We never have infinite knowledge of details. Where does that leave us in our gallant attempts to trace the history of the universe to its origin and to predict its future?

Chaos and complexity also point up a significant road-block between us and the fundamental laws of nature. When we try to understand the structure of the universe, we discover many instances where it is difficult, perhaps impossible, to determine whether what we see is the result of fundamental laws or the result of chance. If we are observing a chance outcome, one among many outcomes the fundamental laws would have allowed, then it would be misleading to suppose our observation is a clue to the fundamental, underlying laws of the universe. For example, if the way galaxies cluster is attributable to the laws of nature, we can study that clustering and learn something about those basic laws. On the other hand, if the way galaxies cluster is a matter of chance, with the underlying laws permitting a variety of results, we won't learn much about the basic laws by studying the way galaxies are clustered. It's a Catch-22. Not understanding what the fundamental laws actually determine, and where they are flexible, renders us incapable of finding out what those laws are.

Is Objective Reality a Mirage?

If we ask ourselves what we believe about the existence of objective reality, objective truth, the answer for most of us is probably that we think it exists, and we tend also to believe that science and the scientific method are the best way to get at it—to settle what is the truth and what is not.

However, science doesn't make any claim to have discovered the ultimate truth about anything. Scientists speak instead of discovering predictability—of seeking deeper understanding of nature. They don't speak of 'the verdict of science', but of 'the standard model', which means the model that nearly all experts agree on at the present time. They speak of 'approximate theories', which means theories that work satisfactorily in a certain area but do not claim to be the whole truth as it might apply to all areas. They speak of 'effective theories', which means something we can work with for the present while knowing that it isn't absolutely and unequivocally correct.

It is generally agreed that in science nothing can ever be 'proved'. The best anyone can say of a theory is that it has not been disproved. No matter how many times something is confirmed by testing, there is still an infinite number of times it may be tested in the future. That means the number of chances left for it to be disproved will always outnumber the number of times it has been tested and verified. Scientists are sceptical people when it comes to anything which claims to be ultimate, unassailable truth. It may be this scepticism that keeps some scientists away from a belief in God, not the notion that science disproves God. The idea of anyone actually finding ultimate, unassailable truth has in a sense become foreign to the minds of many scientists, and to some of the rest of us as well, even though we may believe such truth exists.

In other areas besides science, truth is even more elusive. Where questions of religion, morality, and human behaviour are involved, we are prone to say that it is a matter of opinion, a matter of belief. What happens to the notion of objective reality then? It is certainly very tolerant of Hawking, for example, to say that whether God operates in our lives is 'a matter of belief', but surely he doesn't mean that objective reality is different for the atheist from what it is for the person who believes in God. Does the Christian or Jew live in a universe that was created and is sustained by God and the atheist in a universe for which there is no God? If there is such a thing as objective truth, some of us are dead right and others dead wrong. Tolerance is necessary not because everybody is equally right, but because we have no way of proving once and for all which of us is right.

That is, IF there is such a thing as objective reality. It is not inaccurate to say that on the quantum level of the universe the objective truth seems to be that we lose objective reality.

Recall the two ways we have mentioned of explaining the uncertainty we find on the quantum level of the universe. One way is to say that things there seem uncertain because we haven't yet found an adequate way of observing and measuring. However, the majority of physicists have become convinced that quantum uncertainty is something deeper than merely a matter of observation and measurement. When we measure precisely a particle's momentum, that particle does not at the moment of our measurement *have* any definite position to be measured.

That raises the question of whether anything that isn't located somewhere is a real 'thing'. Does it actually exist as an independent entity? If it does, wouldn't it *have* to have a definite location and a definite motion?

Even more troubling, there is a sense in which we as observers change reality on the quantum level. We said earlier that, as far as anyone has been able to discover, a particle or even an atom never has a definite position AND a definite momentum at the same time. If you look for an atom's position, that's what you get, an atom in a definite place—with a blur as to its motion. If you look for an atom's motion, that's what you get, an atom moving in a definite manner—with a blur as to its location. A very predictably unpredictable little fellow, this atom. But what happens when you aren't measuring anything at all about it? It seems that when an atom isn't being observed it lapses into a state that can be described as ghostlike, with no concrete reality to it at all. Only under observation does it resolve itself into either an atom with a location or an atom with a definite momentum, and which atom it will be depends entirely upon what the observer is trying to measure. To put it bluntly, the observer seems to create reality by observing it.

John Wheeler of Princeton and the University of Texas is the physicist who coined the name 'black hole', which was fortunate because the name 'collapsar' was the best anyone else had suggested. Besides inventing good names, Wheeler has a remarkable talent for finding analogies that make it possible for nonphysicists to understand physics. Here is his version of Twenty Questions, Quantum Style.

Professor Wheeler is IT. We all assume that he has chosen a secret word, but he decides to play a trick on us. He doesn't choose any word at all. The game begins. 'Animal, vegetable, or mineral?' we ask. Prof. Wheeler, having no secret word in mind, just a blur of every noun in his English vocabulary, is free to choose any of the three categories. 'Animal,' he answers. As we all shift our attention to the animal kingdom, the blur of possibilities becomes smaller. 'Mammal?' someone asks. 'No,' answers Prof. Wheeler, though he could just as honestly have answered 'Yes.' 'Reptile?' is the next question. 'Yes,' says Prof. Wheeler with a congratulatory nod, although he might just as truthfully have said 'No.' Now we all think of snakes and lizards and the like, a blur of reptilian life in our minds. A blur of reptilian life in Prof. Wheeler's mind too. There is no definite reptile lurking there in his mind's eye. As the game goes on Prof. Wheeler may have to be very clever in order to keep each answer consistent with all his previous answers, but if he does, can you see that in the end we will arrive at a definite word, although there was not one waiting to be found in Prof. Wheeler's mind? The avenue our questions have taken has helped create the hidden word.

In an analogous way, Wheeler tells us, it is our probing that determines what reality is on the quantum level. It isn't a reality that exists 'out there', independent of us, waiting to be found, the same regardless of whether or not anyone is looking. Our act of observation creates a real situation where otherwise there would be only ghostly uncertainty. We can't separate this reality from the person doing the observing or from his or her choice of how to do the measuring.

If we as observers manipulate and even create reality on the quantum level, what effect might we be having on the universe as a whole? It is Wheeler again who presents us with a mind-boggling suggestion. Perhaps it may be impossible for a universe to exist without observers. Does it follow that the universe did not exist before there were thinking beings in it? Does it follow that our observations create a history of the universe before our own appearance, a history that in a certain sense did not exist before we began to ask questions about the early universe? What meaning does our expertise and our technology have if all we are able to do with it is discover answers we are creating ourselves? And if we become extinct, will the universe vanish?

In a parallel line of thought, can God exist without believers? If the existence of God is a matter of belief, then if nobody believed in God we wouldn't have a lonely God, we'd have no God at all. Is it possible to conceive of a situation in which the answer to the question 'Is there a God?' is indefinite in the way particles are indefinite on the quantum level? Would belief then, not observation, create an affirmative answer? This would not be the same as saying the believer is deluded, any more than the physicist who locates an electron at a definite position is deluded. Unbelief would create a negative answer, and that also would not be a delusion. Can truth be contrary to truth?

Suffice it to say that most of us do not take kindly to the notion that it is possible to have contradictory truths. Contradictory opinions—all right. Contradictory evidence—that's OK too. Somebody's mistaken. Somebody's lying. Compromise—fine. But contradictory truth? No. Most of us feel instinctively that there is a definite answer to every question, even the question of whether God exists. We feel that our opinions and our beliefs do not make something real or unreal. We do not manipulate reality, whether that reality is the existence of a chair or the existence of God. In spite of hints to the contrary coming from the quantum level of the universe, when it comes to decisions about ultimate reality, I don't think my vote gets counted.

This is not a reaction confined to the ordinary, common-sense-oriented person-on-the-street. Most scientists feel there must be something 'real' or else what they study about the physical world would not fit together in such amazing and unexpected ways. We hear almost identical words from people regarding their belief in God. But isn't this 'fitting together', which we interpret to mean that there is some raw material out there against which we can stub our toes and bang our heads, just the sort of pattern that evolution has so superbly conditioned us to find—and to feel good about finding? Perhaps we even consciously or unconsciously single out problems for our scientific study which are likely to have that sort of satisfying resolution, while ignoring those which do not.

Are We Really Free Agents?

A friend of mine, Jim Morgan, tells me that on a summer day in 1990, as he sat in a camp chair in his garden reading *A Brief History of Time,* a yellow leafhopper about a quarter-inch long landed at the top of page 9 and remained there for about six seconds. Jim stopped reading to ponder. Was it determined irrevocably at the instant of the creation of the universe 10 to 20 billion years ago that he and the leafhopper and Hawking's page 9 would meet, precisely thus, on this quiet summer afternoon? Not a second earlier, not a second later, not on page 8 or 10? Hawking, of course, has said he is of the opinion that everything that happens, has happened, or will happen in the universe *has* been determined either by a Theory of Everything or by God. Jim Morgan says he would like to think Hawking is right. If he is, any assumption that chance and choice play a role as events unfold in the universe is a false assumption.

What is a Theory of Everything? It isn't really correct to say *a* Theory of Everything. That would imply that there is more than one such theory. It must be *the* Theory of Everything—the simple set of rules that would underlie all the enormous complexity and trivial detail of the universe. A formula that could be written on a T-shirt? Maybe.

It isn't easy for a non-physicist to see how such a formula could exist. A glance out of almost any window or the thought of the working of our own bodies is enough to tell us there are far too many things going on in the universe to be explained so succinctly. But scientists have for centuries been finding that nature is often less complicated than it first appears. Richard Feynman, the American physicist and Nobel laureate, describes the way the process works. There was a time, he reminds us, when we had something we called motion, and something called heat, and something else again called sound.

> But it was soon discovered [Feynman writes] after Sir Isaac Newton explained the laws of motion, that some of these apparently different things were aspects of the same thing. For example, the phenomena of sound could be completely understood as the motion of atoms in the air. So sound was no longer considered something in addition to motion. It was also discovered that heat phenomena are easily understandable from the laws of motion. In this way, great globs of physics theory were synthesized into a simplified theory.[8]

Hawking, in his inaugural lecture as Lucasian Professor of Mathematics at Cambridge, suggested that we may soon be able to synthesize *all* of physics theory into one simplified theory, but he was not suggesting that we will soon have a theory with which we human beings can predict everything that happens in the universe. We won't be able to use it to decide which horse to back in the Kentucky Derby. There are too many billions upon billions of details involved in tracing the history of every particle that makes up every horse, the turf on which it is running, not to mention the weather, from the instant the universe began to the day of the race. We have no computer capable of doing such calculations. There are other insuperable problems with predicting everything. Hawking thinks that's for the best. Otherwise, we'd place our bet and change the odds! Even our reaction to our prediction and the repercussions from our reaction would have to have been predicted in the theory.

Hawking was suggesting something less dramatic. He said that physics was well on the way to finding a theory which would give a unified explanation of the activities of the elementary particles and the working of the four forces by which they interact. These interactions underlie everything that happens in the physical universe. Hawking said in his inaugural lecture that the complete theory to explain the universe would also have to answer the question of what the 'initial conditions' of the universe were, conditions at the instant of beginning, before any time whatsoever had elapsed. We will see that a complete theory may have to do more than that, depending partly upon whose definition of Theory of Everything you are using.

However, the question we are asking here is not whether we can find such a theory, or what we humans could or could not predict with it, but rather does such a complete theory exist either within reach of us or beyond our comprehension. And if it exists, does it only *explain* everything, or does it actually *predict* or even *determine* everything? Is free will an illusion? Do chance and choice simply not exist? Perhaps even the Theory of Everything could not possibly have been different.

Although Hawking has said he believes everything is determined, he has also said that free will is 'a good approximate theory of human behaviour'.[9] We defined 'approximate theory' above as a theory which is useful in a limited context, but which may not be correct in all contexts. What Hawking means is that whether or not everything is determined, we do best to assume that we have free will and choices. And that's what most of us do. Even those with a strong belief in predestination still look both ways before crossing the street. Of course, one might argue that these people were predestined to look both ways.

Hawking is not alone in his belief that everything is determined, though there are probably fewer scientists who would agree with him today than there were in the eighteenth and early nineteenth centuries. The difference in Hawking's theories, as we shall learn in more detail later, is that they can be seen to undermine even the more fundamental assumption of contingency, that choice and/or chance were involved in the origin of the universe.

Other current science presents us with a different picture. Chaos and complexity studies reveal a delicate balance in the universe between predictability and unpredictability, allowing us to understand better why it is that we experience both in the common-sense world. We must save our discussion of chaos and complexity for Chapter 6 and a different context. For now, suffice it to say that they cast a strong vote against determinism, encouraging us to keep our assumption of contingency. However, there are also hints in chaos and complexity that the question 'Is everything determined?' can never be answered definitively by human beings.

The question of whether or not everything is determined appears repeatedly in science and religion and has profound implications for human morality. On the one hand, God is supposed to have foreknowledge. On the other, we are told we have free will and will be held accountable for our actions. How can both be true? On the one hand, the Theory of Everything may have determined the future from the instant of the beginning of the universe. On the other, we are told we do best to assume we live in a contingent universe, a not-entirely-predictable universe—a universe that can be studied only by looking at it, not by pure thought, no matter how advanced and well-informed that thought. The enormous paradox that lies at the heart of Western religion seems to lie at the heart of science as well.

Is the Universe a Uni-verse?

The assumption that the universe has a unified description is less easy than the other four assumptions to support from everyday experience, which often seems to imply the opposite of unity. It might appear that only by limiting our scientific inquiry to what does fit into a unified picture could we possibly go on claiming such unity exists. Similarly, there are those who insist that only by shutting our eyes to contradictions and conflicting claims can we sustain a belief in one God.

Nevertheless, in science, our faith in this unprovable assumption of unity keeps us searching for deeper, simpler explanations in which the fragmented picture resolves itself into something of great simplicity, elegance, and beauty. If 'laws' break down, then what we have been calling 'laws' must be only approximations and we must look further beyond them for those laws which are truly fundamental and unchanging—an underlying symmetry. This way of proceeding has indeed proved fruitful. 'Beauty' is a strong guide in physics—a beauty which has to do in part with this falling into place of previously disparate elements. As our understanding deepens, contradictions often do seem to resolve.

Often . . . but not always. In mathematics, that area of thought where we most expect completeness and a relatedness without contradictions, we find contradictions. The mathematics worked out one way leads to one conclusion, and worked out another leads to a contradictory conclusion. We have learned to trust mathematics as a guide to what the real world is like—all of us in simple ways, theoretical physicists in ways they think will lead them to fundamental understanding of the universe. Could it be that our mathematics sometimes builds houses of cards? Or should we give the strongest interpretation to the way mathematics always seems to match nature and conclude that if there are contradictions in mathematics, there are contradictions in nature? What happens to our unity then?

Our assumption that there are laws which hold at all times and in all places leads us to believe that by studying a small part of the universe we can make great strides toward understanding the whole universe and its entire history—even predict its future. When the breakdown of physical laws at a singularity called into question the assumption that unchanging laws held even at the origin of the universe, this provided a strong motive to look for theories which undermine singularities. But if we favour theories which uphold our assumption of unity, do we risk a circular argument, letting our assumption pick our theory while our theory upholds our assumption?

What shall we conclude? Can we learn anything meaningful about the universe by means of science? Are not the assumptions which underlie the scientific method called into question by twentieth-century scientific theories and discoveries? Should we trust even those theories and discoveries? Haven't they also emerged from a structure which may be no more than a dubious inheritance from seventeenth-century religious dogma?

It may be an act of faith alone, a flying in the face of some contrary evidence, but few of us would succumb to complete pessimism or abandon the scientific quest. Few of us would say that the human race and individuals among the human race can't know anything meaningful about the universe. Some of us do go on doing science, and others search for God, and still others do both, or keep their options open, or merely cope on a day-to-day basis—continuing to assume that the universe is rational, contingent, open to our scrutiny, has underlying unity, and that there is such a thing as objective truth. Beyond that shared mind-set, we are a diverse and rather motley crew, like knights on a quest with many different motives and hidden agendas and varying degrees of commitment. In the chapters to follow we shall see where this adventure has led us so far, and where it might still take us.