John Polkinghorne, SO FINELY TUNED A UNIVERSE of atoms, stars, quanta & God

John Polkinghorne is the president of Queens' College, University of Cambridge, and an ordained Anglican priest. Formerly he was a professor of Mathematical Physics, also at Cambridge University. He has written a number of books on the relationship between science and religion including Science and Creation, Science and Providence, and The Faith of a Physicist. He is also the recipient of the 2002 Templeton Prize, awarded to persons who use scientific research to make substantial contributions to the understanding of spiritual realities. The award was established in 1972 by Sir John Templeton, who was a pioneer in the development of value-based, globally diversified mutual funds.

Polkinghorne is one of the major voices in today's ongoing conversations between theologians and sciences, viewing theology as the integrating discipline for the sciences. Science asks questions like "What?," "When?," "Where?," and "How?" Theology takes all of these questions and places them in a larger framework of understanding, asking the question "Why?" This essay, published in the journal Commonweal, was adapted from a lecture given at Connecticut College in New London, Connecticut.

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I have spent most of my working life as a theoretical physicist and all of my consciously remembered life as part of the worshiping and believing community of the church. I want to take absolutely seriously the possibility of religious belief in a scientific age. I believe that science and religion are friends and not foes.

To see that, we must recognize two things:

1. We must take account of what science has to tell us about the pattern and history of the physical world. Of course, science itself can no more dictate to religion what it is to believe than religion can prescribe for science what the outcome of its inquiry is to be. The two disciplines are concerned with the exploration of different aspects of human experience: in the one case, our impersonal encounter with a physical world that we transcend; in the other, our personal encounter with the One who transcends us. They use different methods: in the one case, the experimental procedure of putting matters to the test; in the other, the commitment of trust which must underlie all personal encounter, whether among ourselves or with the reality of God. They ask different questions: in the one case, how things happen, by what process? In the other: why things happen, to what purpose?

Though these are two different questions the ways we answer them must bear some consonant relationship to each other. The fact that we now know that the universe did not spring into being ready made a few thousand years ago but that it has evolved over a period of 15 billion years

from its fiery origin in the Big Bang, does not abolish Christian talk of the world as God's creation, but it certainly modifies certain aspects of that discourse.

2. We must understand that religious belief, just like scientific belief, is *motivated* understanding of the ways things are. Of course, a religious stance involves faith, just as a scientific investigation starts by commitment to the interrogation of the physical world from a chosen point of view. But faith is not a question of shutting one's eyes, gritting one's teeth, and believing the impossible. It involves a leap, but a leap into the light rather than the dark. It is open to the possibility of correction, as God's ways and will become more clearly known.

Scientists do not ask "Is that reasonable?" as if we knew beforehand what the world is going to be like. They know that when we move into regimes far away from everyday experience, all sorts of surprising things can happen. Common sense will not be the measure of all things. We are not clever enough to see very far ahead. Therefore, the scientific question is "What makes you think this might be the case?" That is a different question from "Is that reasonable?" and a question that is open to the possibility of enlarging our understanding of how things are.

Let me give an example of the surprises that the physical world has proved to have in store for us. If I were to say, "Bill is at home and he is either drunk or sober;" you would expect either to find Bill at home drunk or to find him at home sober. It seems trivial and obvious; the learned would say that you have used the distributive law of logic. Oddly enough, the corresponding argument applied to a quantum entity like an electron does not work. The elusive, unpicturable quantum world is found to obey a different kind of logic.
May the same not also be true of encounter with divine reality?

My Christian belief in this age of science has to be motivated belief, based on evidence that I can point to. The center of my faith lies in my encounter with the figure of Jesus Christ, as I meet him in the Gospels, in the witness of the church, and in the sacraments. That is the heart of my Christian faith and hope. Yet, at a subsidiary but supportive level, there are also hints of God's presence which arise from our scientific knowledge. The actual way we answer the question "How?" points on to the question "Why?" so that science by itself is found not to be sufficiently intellectually satisfying. I want to sketch out these encouragements to religion.

A characteristic of scientific thought is the drive for synthesis. We want to have as unified an understanding as we possibly can. That is the drive behind the present activity in particle physics, which is looking for a grand unified theory—a GUT, as scientists say in our acronymic way. So, it's the instinct of a scientist to seek as economic and as extensive an understanding of the world as possible.

I believe that the grandest unified theory that you could ever conceivably reach is a theological understanding of the world. Theology is the drive to find the most profound and comprehensive understanding of our encounter with reality. If we're going to look for such a total theory, there are basically two alternative strategies, for if we are looking for a total explanation we won't get it for nothing. Every explanation depends upon certain basic unexplained assumptions. *Ex nihilo nihil fit*, nothing comes from nothing. That's true intellectually. Any theory of the world proceeds from some set of basic assumptions. One way to look at the world is to take the brute fact of the physical world as your starting point. That's how somebody like David Hume would proceed. Start with the brute fact of matter as your unexplained basis. But another way to proceed is to start with the brute fact (if that's the word to use) of God. In other words, one can appeal to the will of an agent, the purpose of a Creator, as the basic unexplained starting point for understanding the world.

The first approach is the strategy of atheism. The second approach is the strategy of theism. I want to defend the second strategy and to explain why I believe that, if we are driven by the desire to have as comprehensive and unified an understanding as possible, we shall find it in a scheme of things that has a place for belief in God.

If we were to start with the brute fact of the physical world, that world is described for us at least in part by the laws of science. But if we take the laws of nature as discerned by science seriously, and if we look at them carefully, we will find that they are not sufficiently intellectually satisfying in themselves. In fact, they seem to have a certain character which actually points beyond themselves. In other words, out of the scientific understanding of the world arise questions which seem to direct us beyond science itself to a deeper level of intelligibility. Here are two examples.

The first example is a fact about the physical world which is very familiar to us, a fact indeed that makes science possible. It is simply this: that we can understand the physical world, that it is intelligible to us in its rational transparency. Not only is that so, but it is mathematics which is the key to the understanding of the basic structure of the physical world. Moreover, we look for theories in physics which in their mathematical expression are economic and elegant. In other words, we seek theories which have about them an unmistakable character of mathematical beauty. It is our expectation that it is precisely theories characterized by mathematical beauty which will describe the structure of the world.

When we use mathematics as a key to unlock the secrets of the universe, something very peculiar is happening. Mathematics is the free exploration of the human mind. Our mathematical friends sit in their studies, and out of their heads they dream up the beautiful patterns of mathematics. Inexplicably, some of the most beautiful patterns thought up by the mathematicians are found actually to occur in the structure of the physical world. In other words, there is some deep-seated relationship between the reason within (the rationality of our minds—in this case mathematics) and the reason without (the rational order and structure of the physical world around us). The two fit together like a pair of gloves. That is a rather significant fact about the world, or so thought Einstein. Einstein once said, “The only incomprehensible thing about the universe is that it is comprehensible.” Why, we should ask, are our minds so perfectly shaped to understand the deep patterns of the world around us?

You can always just shrug your shoulders and say, “Well, that’s just the way it happens to be, and a bit of good luck for you chaps who are good at mathematics.” But my instincts as a scientist, as someone who is searching for understanding, is not to be as intellectually lazy as that. A famous theoretical physicist, Eugene Wigner, once asked: “Why is mathematics so unreasonably effective in understanding the physical world?” One popular answer is that evolutionary biology explains it all. If our minds didn’t fit the world around us, we just wouldn’t have survived in the struggle for existence. That is obviously true, but it’s only true up to a point. It’s true about our experience of the everyday world of rocks and trees where we have to dodge the rocks and miss the trees. It’s also true of our mathematical thinking of that world, which I suppose amounts to a little elementary arithmetic and a little elementary Euclidean geometry.

But the power of mathematics to illuminate and give understanding of the physical world is not just confined to the everyday world. For example, mathematics also describes the counter-intuitive, unpicturable quantum world. That is a world that we can’t visualize, but we can understand it using very abstract mathematics, ultimately the mathematics of spontaneously broken, gauge-field theories. The theoretical physicist Paul Dirac discovered something called quantum field theory which is fundamental to our understanding of the physical world. I can’t

believe Dirac's ability to discover that theory, or Einstein's ability to discover the general theory of relativity, is a sort of spin-off from our ancestors having to dodge saber-toothed tigers. Something much more profound, much more mysterious, is going on. Why do the reason within and the reason without fit together on a deep level? Religious belief provides an entirely rational and entirely satisfying explanation of that fact. It says that the reason within and the reason without have a common origin in that deeper rationality which is the reason of the Creator, whose will is the ground of both my mental and my physical experience. Theology has the power to answer a question, namely the intelligibility of the world, that arises from science but goes beyond science's ability to answer. Remember, science simply assumes the intelligibility of the world. Theology can take that striking fact and make it profoundly comprehensible.

When we look at the rational order and transparent beauty of the physical world, revealed through physical science, we see a world shot through with signs of mind. To a religious believer, it is the mind of the Creator that is being discerned in that way.

Let me give another example, a scientific discovery of a more specific character that's been made in the last thirty or forty years. We live in a universe that started about 15 billion years ago and it started extremely simple. One of the reasons why cosmologists can talk with great confidence about the very early universe is that the very early universe was so simple, just an expanding ball of energy. Yet, the world that started so simple has become very rich and complex through its evolving history, with human life being the most interesting consequences of that history. Human beings are the most complicated physical systems that we have encountered in our explorations of the world. The history of the universe has been astonishingly fruitful, and we understand many steps in that evolving, fruitful process. When we think about those steps and our understanding of them, we reach a very surprising conclusion.

Scientists play intellectual games, and they play those games with a serious intent. The sort of game they play is this: when we think of the universe we live in, it is characterized by certain types of scientific laws and certain types of basic forces that go with those laws. For example, we live in a universe which has gravity in it; not just any old gravity, but gravity of a particular type and a particular strength. There is an intrinsic strength to the force of gravity built into the fabric of our universe, into the specification of what sort of world we live in. In fact, gravity is a very weak force. That might surprise you if you have ever walked out of a second story window, but the force of gravity is intrinsically very weak. We can play intellectual games and say, "I wonder what the universe would be like, and what its history would have been like, if gravity had been a bit different—if it had been much stronger, or even a little bit weaker than it is." And we can play similar games with all the other fundamental forces of nature. We can take electromagnetism, the force that holds matter together. We can sit on our chairs because electromagnetism holds them together, and it holds us together as well! We can again say, "What would the universe be like if electromagnetism were weaker, or if it were stronger?" We can play these intellectual games and, when we do that, a very surprising conclusion follows: Unless the fundamental physical laws were more or less precisely what they actually are, the universe would have had a very boring and sterile history. In other words, it's only a very special universe, a finely tuned universe, a universe in a trillion, you might say, which is capable of having had the amazingly fruitful history that has turned a ball of energy into a world containing human life. This insight is called the anthropic principle: a world capable of producing *anthropoi* (complicated "consequences" comparable to men and women) is a very special finely tuned universe. That's a very surprising discovery!

Let me illustrate why. If you are to have a fruitful universe, one of the things you've got to have in it are stars. And, you've got to have stars of the right sort. The stars have two jobs that are absolutely indispensable to the fruitful history of the universe. One is, they have to act as

long-term, steady energy sources. Essentially all energy here on earth comes from the sun, either directly or indirectly through fossil fuels. The sun has been burning steadily for about 5 billion years and it will continue to burn steadily for about another 5 billion years more. Long-term energy sources are indispensable because it takes billions of years for life to develop, and you must have what physicists call main sequence stars which are steadily-burning, long-lived stars.

We understand what makes stars burn in that sort of way. Basically it's the balance between the force of gravity and the electromagnetic forces. If you were to alter either of those forces, you would put the stars out of kilter. You'd have stars that either burned up very rapidly, that lived just for millions of years rather than billions of years, or you'd have stars that were very turbulent and unstable and flared up and died down, and that would be disastrous. No life could develop in a universe of that character. It is difficult to design a fruitful universe. You've got to get the right balance between gravity and electromagnetism to make the stars act as acceptable energy sources for life.

But that's only part of the story, because the stars have another tremendously important thing to do. The nuclear furnaces that burn inside the stars are the source of the chemical elements which are the raw materials of life. The early universe was very simple, and because the early universe was very simple it produced only very simple consequences. In fact, the very early universe made only the two simplest chemical elements, hydrogen and helium. And they are just not rich enough in their chemistry to make life possible. For life you need a much more complicated chemistry than hydrogen and helium by themselves could sustain. In particular, you need the chemistry of carbon, which has the ability to make those immensely complicated macro-molecules which are the basis of the possibility of life.

Every atom of carbon inside your body was once inside a star. We're all made from the ashes of dead stars. The only place you can make those heavier elements is inside the right sort of stars, and it's pretty difficult to make the stars do that. First, you've got to make carbon by making three helium nuclei stick together. That's actually quite hard to do and it depends upon very delicate aspects of the nuclear forces. Now, suppose you've figured out how to do that. You can't sit back and feel satisfied, because carbon is not enough. You've got to make lots more elements. You've got to make oxygen for example. That means making another helium nucleus stick to the carbon you already made and turn the carbon into oxygen. But, wait a minute. You've got to do that, but you must not over do it. You mustn't turn all the carbon into oxygen; otherwise you've lost the carbon. So, you've got to get all these balances right, and so on, and so on, up to iron. If you can just tune the nuclear forces right, you can make all the elements up to iron inside the stars, but iron is the most stable of all the nuclear species, and you can't get beyond iron inside the stars. You've still got two problems left that you've got to solve. One is you'll need to make some of the heavier elements beyond iron, and you also have to make accessible for life the elements you've already made. It's no good making carbon, oxygen, and all that, and leaving them locked up, useless, inside the cooling core of a dying star. You'll have made the elements, but they won't be of any use to bring about life. You've got to make sure that your stars are such that when they come to the end of their natural life, which is about 10 billion years, some of them will explode as supernovae and so will scatter out into the environment those chemical elements that they've made. If you're made from stardust, there's got to be some dust from stars around for you to be made of. You've got to have stellar explosions. And, if you're very clever, you can arrange in the explosion that the neutrinos, as they blow off the outer layer of the star, then make those heavier elements like zinc and so on that you couldn't make inside the star itself.

I hope I've given some idea of how making elements is a very complicated process, which depends for its fruitfulness on a very delicate, fine-tuned balance between the nuclear forces that

control these processes. If those nuclear forces were in any way slightly different from the way they actually are, the stars would be incapable of making the elements of which you and I are composed.

What are we to make of all this? What do we make of the fact that the world we live in is fruitful only because its basic scientific constitution is of a very special, very finely tuned character?

Once again, you can shrug your shoulders and say, "Well, that's just the way it happens to be. We're here because we're here and that's it." That doesn't seem to me to be a very rational approach to this issue. John Leslie, a philosopher at Guelf University in Canada, writes about these questions. He has written the best book about the anthropic principle, called *Universes*. He's a beguiling philosopher because he does his philosophy by telling stories, which is a very accessible way for those of us who are not professionally trained in philosophy to get the hang of it. He tells the following story. You are about to be executed. Your eyes are bandaged and you are tied to the stake. Twelve highly-trained sharpshooters have their rifles leveled at your heart. They pull the trigger, the shots ring out—you've survived! What do you do? Do you shrug your shoulders and say, "Well, that's the way it is. No need to seek an explanation of this. That's just the way it is." Leslie rightly says that's surely not a rational response to what's going on. He suggests that there are only two rational explanations of that amazing incident. One is that many, many, many executions are taking place today and just by luck you happen to be the one in which they all miss. That's a rational explanation. The other explanation is, of course, that the sharpshooters are on your side and they missed by choice. In other words there was a purpose at work of which you were unaware.

That parable translates well into thinking about a finely tuned and fruitful universe. One possibility is that maybe there are lots and lots of different universes, all with different given physical laws and circumstances. If there are lots and lots of them (and there would really have to be rather a lot) then just by chance, in one of them, the laws and circumstances will be such as to permit the development of carbon-based life. But, of course, that's the one in which we live, because we couldn't appear anywhere else. It's a possible explanation and in fact it's called the "many-universes" interpretation. The other possibility is that there is more going on than has met the eye and the sharpshooters are on
our side. That translates into the idea that this is not just any old universe. Rather it is a universe which is a creation which has been endowed by its creator with just those finely tuned given laws and circumstances that will make its history fruitful. Our world and our lives are the fulfillment of a purpose.

Leslie says in relation to the anthropic principle that there is an even-handed choice between the many universes and the anthropic theories. By itself, I think that is correct. Let me emphasize that both are metaphysical explanations. We have no adequate, scientific motivation for thinking of any other universe but the universe of our direct experience. So the speculation that there are many, many, other universes is a metaphysical speculation. I'm not against metaphysics. In fact, you can't live without it. But the many-universes interpretation is a metaphysical speculation just as positing the existence of a creator is a metaphysical speculation. Of course, if you think there are other reasons, as indeed I do, for believing that there is a God whose will and purpose lie behind the universe, then that second explanation, that the world is fruitful because it is a creation, becomes the more economic and persuasive explanation.

In both the intelligibility of the world and the finely tuned fruitfulness of the world, we see insights arising from science, but calling for some explanation and understanding which, by its very nature, will go beyond what science itself can provide. I think that suggests the insufficiency

of a merely scientific view of the world. In fact, I think we're living in an age where there is a great revival of natural theology taking place. That revival of natural theology is taking place, not on the whole among the theologians, who have rather lost their nerve in that area, but among the scientists. And not just among pious scientists like myself, but among scientists who have no particular time for, or understanding of, conventional religion. Nevertheless, many agnostic scientists feel that the rational beauty and the finely tuned fruitfulness of the world suggest that there is some intelligence or purpose behind the universe.

That revived natural theology is also revised in the sense that it is more modest in its ambitions. Unlike either the natural theology of the late Middle Ages or the eighteenth century, it doesn't claim to talk about proofs of God. We're in an area of discourse where knock-down argument or proof is not available. Rather, we're looking for insights which are intellectually satisfying.

Theology offers science a deeper, more comprehensive understanding than would be obtained from itself alone. But there is traffic across the border in both directions. The gift that science gives to theology is rather different—for it is to tell theology what the physical world is actually like in its structure and in its history. That raises issues to which theology has to address itself.

The classic interaction between science and theology concerns the question of origins. How did things begin? Actually I don't think that's a very important subject. People wrongly think that the theological doctrine of Creation is concerned with how things began. Who lit the blue touch paper of the big bang? The biblical doctrine of Creation isn't about that. It's not concerned with temporal origin, but with ontological origin. It answers the question, why do things exist at all? God is as much the Creator today as he was 15 billion years ago. Thus, though big-bang cosmology is very interesting scientifically, theologically it is insignificant. In *A Brief History of Time*, my friend and former colleague, Steve Hawking, says that if you think about quantum cosmology and how quantum mechanics fuzzed out the very early universe, then, though the universe has a finite age, it has no dateable beginning. Now that's a very interesting scientific speculation, but there's no particular theological mileage in it. Hawking says, "If there is no beginning, what place then for a Creator?" It is theologically naive to answer other than by, "Every place, as the Sustainer of the universe in Being." God is not a God of the edges, with a vested interest in beginnings. God is the God of all times and all places.

It is in sustaining the fruitful process of the world that God is at work as the Creator. Two insights about the process of the world come to us from science. The first is the very fertile process which turned a ball of energy into a world containing you and me. The second question is: Given we've got a universe with fine-tuning (given we've got the right ground rules), how does it actually come about that the world makes itself? How does it realize its in-built fruitfulness, its in-built potentiality? We understand many bits of that process quite well. All those bits we do understand seem to realize that fruitfulness through an interplay between two opposing tendencies which we could describe as "chance" and "necessity." Those are slippery words. By "chance," I mean simply happenstance—just the way things happen to be. When the universe was about a billion years old, there just happened to be a little bit more matter here than there. That was chance—happenstance—getting things going. That happenstance produced something lasting through the operation of "necessity," or lawful regularity. Because there was a little bit more matter here than there that matter exerted a little bit stronger gravitational pull, and draws more matter to itself in a sort of snowballing process. That's how scientists picture the universe: it started so uniform and began to get a bit grainy and lumpy. You've got to have the stars and you've got to have the galaxies that contain the stars. A fruitful universe has to become lumpy at some stage. That begins through chance, happenstance, and develops through necessity, snowballing through the attractive force of gravity. And, it seems that the interplay between those two tendencies, chance

as the origin of novelty, and necessity as the sifter and preserver of the novelty thus produced, is the prime way in which the fruitfulness of the universe is realized.

A more familiar example of this process is provided by biological evolution. Mutations occur through happenstance. That produces some new possibility for life, which is then sifted and preserved in the lawfully regular environment which is necessary for the operation of natural selection. In every stage of the fruitful history of the universe there is a interplay between chance and necessity. What do we make of that?

Jacques Monod, a great French biochemist, wrote a famous book in the early 1970s called *Chance and Necessity*. Monod argued that "Pure chance, absolutely free, but blind lies at the basis of this stupendous edifice of evolution." Of course the point where Monod puts in the knife is the word "blind." For Monod, the role of chance, of happenstance, in the evolving history of the universe subverts the religious claim that
there is a purpose at work in the world. For Monod, the role of chance means that ultimately the universe is a tale told by an idiot.

Monod's is a serious challenge. Nonetheless, we can take the same scientific picture of the interplay between happenstance and regularity, but offer an alternative interpretation, a more evenhanded interpretation, which lays as much emphasis on the necessary half as upon the chance half of the process. I respectfully suggest that when God came to create the world he was faced with a dilemma. The Christian God is a God of love and the gift of love is always the gift of independence, the genuine otherness of the beloved. Parents know that. There comes a time when Johnny has to be allowed to ride his bicycle into dangerous traffic on his own. The gift of love is a gift of a true independence. A God who is loving will endow his creation with its own due freedom, its own due independence. But independence by itself can easily degenerate into license and chaos. However, God is not only loving, he is faithful. And the God who is faithful will surely endow his creation also with the gift of reliability. Yet reliability by itself can easily rigidify into a merely mechanical world. I believe that the Christian God, who is both loving and faithful, has given to his creation the twin gifts of independence and reliability, which find their reflection in the fruitful process of the universe through the interplay between happenstance and regularity, between chance and necessity.

Moreover, many people have an outdated picture of the physical world. The great triumphs of the science in the eighteenth century, and the further discoveries of the nineteenth century, encouraged a mechanical, rather deterministic view of the physical world. We've always known that can't be right because we've always known that human beings have the experience of choice and responsibility. Twentieth-century science has seen the death of a merely mechanical view of the world. In part, that is due to the cloudy fitfulness of quantum theory. But more important still, it is also due to another unexpected insight of science gained in the last thirty-four years.

Even the physics of the everyday world, even the physics of Newton, is not as mechanical as Sir Isaac and his followers thought it to be. That's a very surprising discovery. Those of us who learned classical physics, learned that subject by thinking about certain tame, predictable systems, like a steadily ticking pendulum. That's a very simple robust system. If you take a pendulum and slightly disturb it, or you are slightly ignorant about how it is moving, the slight disturbance only produces slight consequences, the slight ignorance produces only slight errors in your estimation of how it will behave. We thought the everyday physical world was all like that. It was tame, it was predictable, it was controllable. Now, we've discovered that, in fact, almost all the everyday physical world is not like that at all.

Almost all of the everyday physical world is so exquisitely sensitive that the smallest disturbance produces quite uncontrollable and unpredictable consequences. This is the insight that is rather ineptly named chaotic dynamics. The discovery was first made in relation to attempts to make models of the earth's weather systems. In the trade it is sometimes called the butterfly effect: that the great weather systems of the earth are so sensitive to individual circumstance that a butterfly stirring the air with its wings in Beijing today will have consequences for the storm systems over New England in a month's time! Now, the world—that exquisitely sensitive world—is an intrinsically unpredictable world. We can't know about all those butterflies in Beijing. We've learned that the physical world, whatever it is, it isn't mechanical, even at the everyday level. It is something more subtle and more supple. Modern science already presents us with a picture of the physical world that is unpredictable in detail and open to the future. That is a gain for science. Science begins to describe a world which is sufficiently flexible in its development, a world of true becoming, of which we can consider ourselves as inhabitants. The future is genuinely new, not just rearrangement of what was there in the past. In such a world of true becoming, with its open future, we can begin to understand our own powers of agency, our own powers to act and bring things about. Such a physical world is capable also of being open to God's providential interaction and his agency. Our whole picture of the physical world is much more hospitable to the presence of both humanity and divine providence than would have seemed conceivable a hundred years ago.

I'd like to conclude with a quotation which in many ways summarizes what I'm trying to do as a physicist and as a priest. I want to hold these two parts of me together, and to enjoy their friendly relationship. I believe I can do so, not without puzzles, of course, but I hope without dishonesty and without compartmentalism. I've tried to show how science and theology interact positively, how their mutual relationship is one of friendship in the search for truth and not warfare with each other. Bernard Lonergan once said, "God is the all-sufficient explanation, the eternal rapture glimpsed in every Archimedean cry of Eureka." I like that very much. The search for understanding, which is so natural to a scientist, is, in the end, the search for God. That is why science and religion must be friends.

Questions for Reading

1. What does Polkinghorne say about his understanding of the relationship between science and religion? How do science and religion compare in terms of the methods they use and the questions they ask?

2. What does Polkinghorne mean when he says that both religious belief and scientific belief are *motivated* understandings of the way things are?

3. What is a GUT? How does Polkinghorne relate the GUT to theology?

4. What does Polkinghorne suggest are two possible starting points for a theory of the world? On what basis does he reject one and favor the other?

5. Polkinghorne uses the example of mathematical understandings of the structure of the world to show that mathematics does allow a place for belief in God. Explain.

6. In this essay, Polkinghorne provides a lengthy scientific explanation of how this universe became a *fruitful* universe. What does he want us to conclude about the process?

7. Briefly explain John Leslie's parable about the man who is about to be executed. What conclusion does Polkinghorne draw from it regarding our "finely tuned and fruitful" universe?

8. Instead of a theology of creation that concerns itself with *how things began*, with what kind of theology of creation does Polkinghorne think we should be engaged? Why?

9. What is Polkinghorne's criticism of Jacques Monod's theory about chance and necessity in evolution? What alternative interpretation does Polkinghorne offer as a corrective to his theory?

10. What is Polkinghorne's criticism of the 19th century mechanical view of the world?

11. What is "chaotic dynamics," also known as the butterfly effect, as it applies to the study of weather? What does Polkinghorne see as the implications of chaotic dynamics for understanding the possibility of God's interaction in the physical world?

12. To conclude his essay, Polkinghorne quotes the philosophical theologian, Bernard Lonergan: "God is the all-efficient explanation, the eternal rapture glimpsed in every Archimedean cry of Eureka." What point is Polkinghorne trying to make?