CHAPTER 12

CONCLUSION

We find ourselves in a bewildering world. We want to make sense of what we see around us and to ask: What is the nature of the universe? What is our place in it and where did it and we come from? Why is it the way it is?

To try to answer these questions we adopt some “world picture.” Just as an infinite tower of tortoises supporting the fiat earth is such a picture, so is the theory of superstrings. Both are theories of the universe, though the latter is much more mathematical and precise than the former. Both theories lack observational evidence: no one has ever seen a giant tortoise with the earth on its back, but then, no one has seen a superstring either. However, the tortoise theory fails to be a good scientific theory because it predicts that people should be able to fall off the edge of the world. This has not been found to agree with experience, unless that turns out to be the explanation for the people who are supposed to have disappeared in the Bermuda Triangle!

The earliest theoretical attempts to describe and explain the universe involved the idea that events and natural phenomena were controlled by spirits with human emotions who acted in a very humanlike and unpredictable manner. These spirits inhabited natural objects, like rivers and mountains, including celestial bodies, like the sun and moon. They had to be placated and their favor sought in order to ensure the fertility of the soil and the rotation of the seasons. Gradually, however, it must have been noticed that there were certain regularities: the sun always rose in the east and set in the west, whether or not a sacrifice had been made to the sun god. Further, the sun, the moon, and the planets followed precise paths across the sky that could be predicted in advance with considerable accuracy. The sun and the moon might still be gods, but they were gods who obeyed strict laws, apparently without any exceptions, if one discounts stories like that of the sun stopping for Joshua.

At first, these regularities and laws were obvious only in astronomy and a few other situations. However, as civilization developed, and particularly in the last 300 years, more and more regularities and laws were discovered. The success of these laws led Laplace at the beginning of the nineteenth century to postulate scientific determinism; that is, he suggested that there would be a set of laws that would determine the evolution of the universe precisely, given its configuration at one time.

Laplace’s determinism was incomplete in two ways. It did not say how the laws should be chosen and it did not specify the initial configuration of the universe. These were left to God. God would choose how the universe began and what laws it obeyed, but he would not intervene in the universe once it had started. In effect, God was confined to the areas that nineteenth-century science did not understand.

We now know that Laplace’s hopes of determinism cannot be realized, at least in the terms he had in mind. The uncertainty principle of quantum mechanics implies that certain pairs of quantities, such as the position and velocity of a particle, cannot both be predicted with complete accuracy. Quantum mechanics deals with this situation via a class of quantum theories in which particles don’t have well-defined positions and velocities but are represented by a wave. These quantum theories are deterministic in the sense that they give laws for the evolution of the wave with time. Thus if one knows the wave at one time, one can calculate it at any other time. The unpredictable, random element comes in only when we try to interpret the wave in terms of the positions and velocities of particles. But maybe that is our mistake: maybe there are no particle positions and velocities, but only waves. It is just that we try to fit the waves to our preconceived ideas of positions and velocities. The resulting mismatch is the cause of the apparent unpredictability.

In effect, we have redefined the task of science to be the discovery of laws that will enable us to predict events up to the limits set by the uncertainty principle. The question remains, however: how or why were the laws and the initial state of the universe chosen?

In this book I have given special prominence to the laws that govern gravity, because it is gravity that shapes the large-scale structure of the universe, even though it is the weakest of the four categories of forces. The laws of gravity were incompatible with the view held until quite recently that the universe is unchanging in time:

the fact that gravity is always attractive implies that the universe must be either expanding or contracting. According to the general theory of relativity, there must have been a state of infinite density in the past, the big bang, which would have been an effective beginning of time. Similarly, if the whole universe recollapsed, there must be another state of infinite density in the future, the big crunch, which would be an end of time. Even if the whole universe did not recollapse, there would be singularities in any localized regions that collapsed to form black holes. These singularities would be an end of time for anyone who fell into the black hole. At the big bang and other singularities, all the laws would have broken down, so God would still have had complete freedom to choose what happened and how the universe began.

When we combine quantum mechanics with general relativity, there seems to be a new possibility that did not arise before: that space and time together might form a finite, four-dimensional space without singularities or boundaries, like the surface of the earth but with more dimensions. It seems that this idea could explain many of the observed features of the universe, such as its large-scale uniformity and also the smaller-scale departures from homogeneity, like galaxies, stars, and even human beings. It could even account for the arrow of time that we observe. But if the universe is completely self-contained, with no singularities or boundaries, and completely described by a unified theory, that has profound implications for the role of God as Creator.

Einstein once asked the question: "How much choice did God have in constructing the universe?" If the no boundary proposal is correct, he had no freedom at all to choose initial conditions. He would, of course, still have had the freedom to choose the laws that the universe obeyed. This, however, may not really have been all that much of a choice; there may well be only one, or a small number, of complete unified theories, such as the heterotic string theory, that are self-consistent and allow the existence of structures as complicated as human beings who can investigate the laws of the universe and ask about the nature of God.

Even if there is only one possible unified theory, it is just a set of rules and equations. What is it that breathes fire into the equations and makes a universe for them to describe? The usual approach of science of constructing a mathematical model cannot answer the questions of why there should be a universe for the model to describe. Why does the universe go to all the bother of existing? Is the unified theory so compelling that it brings about its own existence? Or does it need a creator, and, if so, does he have any other effect on the universe? And who created him?

Up to now, most scientists have been too occupied with the development of new theories that describe *what* the universe is to ask the question *why.* On the other hand, the people whose business it is to ask *why,* the philosophers, have not been able to keep up with the advance of scientific theories. In the eighteenth century, philosophers considered the whole of human knowledge, including science, to be their field and discussed questions such as: did the universe have a beginning? However, in the nineteenth and twentieth centuries, science became too technical and mathematical for the philosophers, or anyone else except a few specialists. Philosophers reduced the scope of their inquiries so much that Wittgenstein, the most famous philosopher of this century, said, "The sole remaining task for philosophy is the analysis of language." What a comedown from the great tradition of philosophy from Aristotle to Kant!

However, if we do discover a complete theory, it should in time be understandable in broad principle by everyone, not just a few scientists. Then we shall all, philosophers, scientists, and just ordinary people, be able to take part in the discussion of the question of why it is that we and the universe exist. If we find the answer to that, it would be the ultimate triumph of human reason – for then we would know the mind of God.

ALBERT EINSTEIN

Einstein's connection with the politics of the nuclear bomb is well known: he signed the famous letter to President Franklin Roosevelt that persuaded the United States to take the idea seriously, and he engaged in postwar efforts to prevent nuclear war. But these were not just the isolated actions of a scientist dragged into the world of politics. Einstein's life was, in fact, to use his own words, "divided between politics and equations."

Einstein's earliest political activity came during the First World War, when he was a professor in Berlin. Sickened by what he saw as the waste of human lives, he became involved in antiwar demonstrations. His advocacy of civil disobedience and public encouragement of people to refuse conscription did little to endear him to his colleagues. Then, following the war, he directed his efforts toward reconciliation and improving international relations. This too did not make him popular, and soon his politics were making it difficult for him to visit the United States, even to give lectures.

Einstein's second great cause was Zionism. Although he was Jewish by descent, Einstein rejected the biblical idea of God. However, a growing awareness of anti-Semitism, both before and during the First World War, led him gradually to identify with the Jewish community, and later to become an outspoken supporter of Zionism. Once more unpopularity did not stop him from speaking his mind. His theories came under attack; an anti-Einstein organization was even set up. One man was convicted of inciting others to murder Einstein (and fined a mere six dollars). But Einstein was phlegmatic. When a book was published entitled *100 Authors Against Einstein,* he retorted, "If I were wrong, then one would have been enough!"

In 1933, Hitler came to power. Einstein was in America, and declared he would not return to Germany. Then, while Nazi militia raided his house and confiscated his bank account, a Berlin newspaper displayed the headline "Good News from Einstein – He's Not Coming Back." In the face of the Nazi threat, Einstein renounced pacifism, and eventually, fearing that German scientists would build a nuclear bomb, proposed that the United States should develop its own. But even before the first atomic bomb had been detonated, he was publicly warning of the dangers of nuclear war and proposing international control of nuclear weaponry.

Throughout his life, Einstein's efforts toward peace probably achieved little that would last – and certainly won him few friends. His vocal support of the Zionist cause, however, was duly recognized in 1952, when he was offered the presidency of Israel. He declined, saying he thought he was too naive in politics. But perhaps his real reason was different: to quote him again, "Equations are more important to me, because politics is for the present, but an equation is something for eternity."

GALILEO GALILEI

Galileo, perhaps more than any other single person, was responsible for the birth of modern science. His renowned conflict with the Catholic Church was central to his philosophy, for Galileo was one of the first to argue that man could hope to understand how the world works, and, moreover, that we could do this by observing the real world.

Galileo had believed Copernican theory (that the planets orbited the sun) since early on, but it was only when he found the evidence needed to support the idea that he started to publicly support it. He wrote about Copernicus's theory in Italian (not the usual academic Latin), and soon his views became widely supported outside the universities. This annoyed the Aristotelian professors, who united against him seeking to persuade the Catholic Church to ban Copernicanism.

Galileo, worried by this, traveled to Rome to speak to the ecclesiastical authorities. He argued that the Bible was not intended to tell us anything about scientific theories, and that it was usual to assume that, where the Bible conflicted with common sense, it was being allegorical. But the Church was afraid of a scandal that might undermine its fight against Protestantism, and so took repressive measures. It declared Copernicanism "false and erroneous" in 1616, and commanded Galileo never again to "defend or hold" the doctrine. Galileo acquiesced.

In 1623, a longtime friend of Galileo's became the Pope. Immediately Galileo tried to get the 1616 decree revoked. He failed, but he did manage to get permission to write a book discussing both Aristotelian and Copernican theories, on two conditions: he would not take sides and would come to the conclusion that man could in any case not determine how the world worked because God could bring about the same effects in ways unimagined by man, who could not place restrictions on God's omnipotence.

The book, *Dialogue Concerning the Two Chief World Systems,* was completed and published in 1632, with the full backing of the censors – and was immediately greeted throughout Europe as a literary and philosophical masterpiece. Soon the Pope, realizing that people were seeing the book as a convincing argument in favor of

Copernicanism, regretted having allowed its publication. The Pope argued that although the book had the official blessing of the censors, Galileo had nevertheless contravened the 1616 decree. He brought Galileo before the Inquisition, who sentenced him to house arrest for life and commanded him to publicly renounce Copernicanism. For a second time, Galileo acquiesced.

Galileo remained a faithful Catholic, but his belief in the independence of science had not been crushed. Four years before his death in 1642, while he was still under house arrest, the manuscript of his second major book was smuggled to a publisher in Holland. It was this work, referred to as *Two New Sciences,* even more than his support for Copernicus, that was to be the genesis of modern physics.

ISAAC NEWTON

Isaac Newton was not a pleasant man. His relations with other academics were notorious, with most of his later life spent embroiled in heated disputes. Following publication of *Principia Mathematica* – surely the most influential book ever written in physics – Newton had risen rapidly into public prominence. He was appointed president of the Royal Society and became the first scientist ever to be knighted.

Newton soon clashed with the Astronomer Royal, John Flamsteed, who had earlier provided Newton with much-needed data for *Principia,* but was now withholding information that Newton wanted. Newton would not take no for an answer: he had himself appointed to the governing body of the Royal Observatory and then tried to force immediate publication of the data. Eventually he arranged for Flamsteed's work to be seized and prepared for publication by Flamsteed's mortal enemy, Edmond Halley. But Flamsteed took the case to court and, in the nick of time, won a court order preventing distribution of the stolen work. Newton was incensed and sought his revenge by systematically deleting all references to Flamsteed in later editions of *Principia.*

A more serious dispute arose with the German philosopher Gottfried Leibniz. Both Leibniz and Newton had independently developed a branch of mathematics called calculus, which underlies most of modern physics. Although we now know that Newton discovered calculus years before Leibniz, he published his work much later. A major row ensued over who had been first, with scientists vigorously defending both contenders. It is remarkable, however, that most of the articles appearing in defense of Newton were originally written by his own hand – and only published in the name of friends! As the row grew, Leibniz made the mistake of appealing to the Royal Society to resolve the dispute. Newton, as president, appointed an "impartial" committee to investigate, coincidentally consisting entirely of Newton's friends! But that was not all: Newton then wrote the committee's report himself and had the Royal Society publish it, officially accusing Leibniz of plagiarism. Still unsatisfied, he then wrote an anonymous review of the report in the Royal Society's own periodical. Following the death of Leibniz, Newton is reported to have declared that he had taken great satisfaction in "breaking Leibniz's heart."

During the period of these two disputes, Newton had already left Cambridge and academe. He had been active in anti-Catholic politics at Cambridge, and later in Parliament, and was rewarded eventually with the lucrative post of Warden of the Royal Mint. Here he used his talents for deviousness and vitriol in a more socially acceptable way, successfully conducting a major campaign against counterfeiting, even sending several men to their death on the gallows.

PREVIOUS NEXT

GLOSSARY

Absolute zero: The lowest possible temperature, at which substances contain no heat energy.

Acceleration: The rate at which the speed of an object is changing.

Anthropic principle: We see the universe the way it is because if it were different we would not be here to observe it.

Antiparticle: Each type of matter particle has a corresponding antiparticle. When a particle collides with its antiparticle, they annihilate, leaving only energy.

Atom: The basic unit of ordinary matter, made up of a tiny nucleus (consisting of protons and neutrons) surrounded by orbiting electrons.

Big bang: The singularity at the beginning of the universe.

Big crunch: The singularity at the end of the universe.

Black hole: A region of space-time from which nothing, not even light, can escape, because gravity is so strong.

Casimir effect: The attractive pressure between two flat, parallel metal plates placed very near to each other in a vacuum. The pressure is due to a reduction in the usual number of virtual particles in the space between the plates.

Chandrasekhar limit: The maximum possible mass of a stable cold star, above which it must collapse into a black hole.

Conservation of energy: The law of science that states that energy (or its equivalent in mass) can neither be created nor destroyed.

Coordinates: Numbers that specify the position of a point in space and time.

Cosmological constant: A mathematical device used by Einstein to give space-time an inbuilt tendency to expand.

Cosmology: The study of the universe as a whole.

Dark matter: Matter in galaxies, clusters, and possibly between clusters, that can not be observed directly but can be detected by its gravitational effect. As much as 90 percent of the mass of the universe may be in the form of dark matter.

Duality: A correspondence between apparently different theories that lead to the same physical results.

Einstein-Rosen bridge: A thin tube of space-time linking two black holes. *Also see* Wormhole.

Electric charge: A property of a particle by which it may repel (or attract) other particles that have a charge of similar (or opposite) sign.

Electromagnetic force: The force that arises between particles with electric charge; the second strongest of the four fundamental forces.

Electron: A particle with negative electric charge that orbits the nucleus of an atom.

Electroweak unification energy: The energy (around 100 GeV) above which the distinction between the electromagnetic force and the weak force disappears.

Elementary particle: A particle that, it is believed, cannot be subdivided.

Event: A point in space-time, specified by its time and place.

Event horizon: The boundary of a black hole.

Exclusion principle: The idea that two identical spin-1/2 particles cannot have (within the limits set by the uncertainty principle) both the same position and the same velocity.

Field: Something that exists throughout space and time, as opposed to a particle that exists at only one point at a time.

Frequency: For a wave, the number of complete cycles per second.

Gamma rays: Electromagnetic rays of very short wavelength, produced in radio-active decay or by collisions of elementary particles.

General relativity: Einstein's theory based on the idea that the laws of science should be the same for all observers, no matter how they are moving. It explains the force of gravity in terms of the curvature of a four-dimensional space-time.

Geodesic: The shortest (or longest) path between two points.

Grand unification energy: The energy above which, it is believed, the electro-magnetic force, weak force, and strong force become indistinguishable from each other.

Grand unified theory (GUT): A theory which unifies the electromagnetic, strong, and weak forces.

Imaginary time: Time measured using imaginary numbers.

Light cone: A surface in space-time that marks out the possible directions for light rays passing through a given event.

Light-second (light-year): The distance traveled by light in one second (year).

Magnetic field: The field responsible for magnetic forces, now incorporated along with the electric field, into the electromagnetic field.

Mass: The quantity of matter in a body; its inertia, or resistance to acceleration.

Microwave background radiation: The radiation from the glowing of the hot early universe, now so greatly red-shifted that it appears not as light but as microwaves (radio waves with a wavelength of a few centimeters). Also see COBE, on page 145.

Naked singularity: A space-time singularity not surrounded by a black hole.

Neutrino: An extremely light (possibly massless) particle that is affected only by the weak force and gravity.

Neutron: An uncharged particle, very similar to the proton, which accounts for roughly half the particles in an atomic nucleus.

Neutron star: A cold star, supported by the exclusion principle repulsion between neutrons.

No boundary condition: The idea that the universe is finite but has no boundary (in imaginary time).

Nuclear fusion: The process by which two nuclei collide and coalesce to form a single, heavier nucleus.

Nucleus: The central part of an atom, consisting only of protons and neutrons, held together by the strong force.

Particle accelerator: A machine that, using electromagnets, can accelerate moving charged particles, giving them more energy.

Phase: For a wave, the position in its cycle at a specified time: a measure of whether it is at a crest, a trough, or somewhere in between.

Photon: A quantum of light.

Planck's quantum principle: The idea that light (or any other classical waves) can be emitted or absorbed only in discrete quanta, whose energy is proportional to their wavelength.

Positron: The (positively charged) antiparticle of the electron.

Primordial black hole: A black hole created in the very early universe.

Proportional: 'X is proportional to Y' means that when Y is multiplied by any number, so is X. 'X is inversely proportional to Y' means that when Y is multiplied by any number, X is divided by that number.

Proton: A positively charged particle, very similar to the neutron, that accounts for roughly half the particles in the nucleus of most atoms.

Pulsar: A rotating neutron star that emits regular pulses of radio waves.

Quantum: The indivisible unit in which waves may be emitted or absorbed.

Quantum chromodynamics (QCD): The theory that describes the interactions of quarks and gluons.

Quantum mechanics: The theory developed from Planck's quantum principle and Heisenberg's uncertainty principle.

Quark: A (charged) elementary particle that feels the strong force. Protons and neutrons are each composed of three quarks.

Radar: A system using pulsed radio waves to detect the position of objects by measuring the time it takes a single pulse to reach the object and be reflected back.

Radioactivity: The spontaneous breakdown of one type of atomic nucleus into another.

Red shift: The reddening of light from a star that is moving away from us, due to the Doppler effect.

Singularity: A point in space-time at which the space-time curvature becomes infinite.

Singularity theorem: A theorem that shows that a singularity must exist under certain circumstances – in particular, that the universe must have started with a singularity.

Space-time: The four-dimensional space whose points are events.

Spatial dimension: Any of the three dimensions that are spacelike – that is, any except the time dimension.

Special relativity: Einstein's theory based on the idea that the laws of science should be the same for all observers, no matter how they are moving, in the absence of gravitational phenomena.

Spectrum: The component frequencies that make up a wave. The visible part of the sun's spectrum can be seen in a rainbow.

Spin: An internal property of elementary particles, related to, but not identical to, the everyday concept of spin.

Stationary state: One that is not changing with time: a sphere spinning at a constant rate is stationary because it looks identical at any given instant.

String theory: A theory of physics in which particles are described as waves on strings. Strings have length but no other dimension.

Strong force: The strongest of the four fundamental forces, with the shortest range of all. It holds the quarks together within protons and neutrons, and holds the protons and neutrons together to form atoms.

Uncertainty principle: The principle, formulated by Heisenberg, that one can never be exactly sure of both the position and the velocity of a particle; the more accurately one knows the one, the less accurately one can know the other.

Virtual particle: In quantum mechanics, a particle that can never be directly detected, but whose existence does have measurable effects.

Wave/particle duality: The concept in quantum mechanics that there is no distinction between waves and particles; particles may sometimes behave like waves, and waves like particles.

Wavelength: For a wave, the distance between two adjacent troughs or two adjacent crests.

Weak force: The second weakest of the four fundamental forces, with a very short range. It affects all matter particles, but not force-carrying particles.

Weight: The force exerted on a body by a gravitational field. It is proportional to, but not the same as, its mass.

White dwarf: A stable cold star, supported by the exclusion principle repulsion between electrons.

Wormhole: A thin tube of space-time connecting distant regions of the universe. Wormholes might also link to parallel or baby universes and could provide the possibility of time travel.

PREVIOUS NEXT

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Stephen Hawking

ABOUT THE AUTHOR

Stephen Hawking, who was born in 1942 on the anniversary of Galileo’s death, holds Isaac Newton’s chair as Lucasian Professor of Mathematics at the University of Cambridge. Widely regarded as the most brilliant theoretical physicist since Einstein, he is also the author of *Black Holes and Baby Universes,* published in 1993, as well as numerous scientific papers and books.

PREVIOUS