The Universe in a Nutshell Study Guide

The Universe in a Nutshell by Stephen Hawking

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Plot Summary

Stephen Hawking is one of history's great physicists, and until October 1st, 2009 was the Lucasian Professor of Mathematics at the University of Cambridge for thirty years, the same chair held by Isaac Newton. Stephen Hawking is primarily known to the public not only for having a form of ALS that has left him almost completely paralyzed, leaving him able to speak only through an electronic device but that still allows him to write and communicate with others, but also for his brilliance.

Further, Hawking is known for contributing both to the theory of quantum gravity, which attempts to combine quantum mechanics and general relativity and for contributions to the study of black holes. His most popular work is A Brief History of Time, one of the great works of popular science in the twentieth century. It ranked in British best sellers for over four years.

The Universe in a Nutshell is an updated work of popular physics which informs the reader of advances in theoretical physics since his previous writings. Written in 2001, Hawking is able to take the reader through far more sophisticated attempts to unite science's two most successful theories, quantum mechanics and quantum gravity.

The book has seven chapters. The first two are the "trunk" of the book, to use Hawking's words. The rest of the chapters are built off of it. In chapter one, Hawking explains Einstein's two major breakthroughs regarded relativity, the theories of special and general relativity. It also explains how Einstein led to the creation of quantum mechanics. Thus, Einstein laid the foundations for the two most important scientific theories of the twentieth century. In chapter two, Hawking explains general relativity in more detail, which adds an analysis of gravity into special relativity. Einstein's work shows that space and time are one and that together they have a shape. Hawking also suggests ways that the theory can be united with quantum mechanics.

Chapter three, The Universe in a Nutshell, builds on the fundamental tension between these two theories and shows how one attempt to reconcile the two entails that the universe has multiple, simultaneous histories, all of them shaped by a "tiny nut." Chapter four discusses whether physics permits the future to be predicted and how such prediction is threatened by black holes, which absorb the information necessary to make such predictions.

Chapter five discusses whether the laws of physics permit time travel. A sufficiently advanced civilization, he argues, could in principle travel to the past, but it involves making use of probabilities that are infinitesimally small. Chapter six concerns the future of the human race and how advances in genetics and technology will continue at an accelerating rate, making the future radically different from the past and deeply dynamic. Chapter seven is perhaps the most complex, discussing p-brane theory, a proposed theory of quantum gravity. If p-brane theory is true, the present universe and all that is in it may simply be a "hologram".

Chapter 1, A Brief History of Relativity

Chapter 1, A Brief History of Relativity Summary and Analysis

Albert Einstein advanced the special and general theories of relativity, for which he is famous the world over. He was born in 1879. After a year, his family moved to Munich and his father, Hermann, and his uncle, Jakob, started a doomed-to-fail electrical business. Albert was not a child prodigy. In 1894, the business closed shop and the Einsteins immigrated to Milan except for Albert, who was to finish school.

Albert didn't care for the authoritarianism of the school and left after a few months, receiving his degree from the Federal Polytechnic School in Zurich in 1900. However, he had no professor who liked him enough to make him an assistant, so after two years he landed a job at the Swiss patent office in Bern. In 1905, at the patent office, Einstein penned three articles that rocketed him to the top of the scientific community. His papers changed humanity's conception of space, time and reality.

By the end of the nineteenth century, scientists thought they were only a few decades away from a final description of the laws of nature, believing that space was pervaded by "ether," a medium that generated waves of light and radio. All that was required were measurements of the ether's elasticity. But the ether theory started to fall apart. Light was predicted to travel at one speed through the either, but traveling different directions yielded different speeds, which was confirmed by a number of experiments. An Irish and Dutch physicist suggested that bodies in the ether were contracting, but Einstein's 1905 paper argued that without an ability to figure out whether one was moving through space, ether was redundant as an explanation.

In contrast, Einstein began assuming that scientific laws should remain constant in the view of all observers and that the speed of light is independent of motion. However, this required abandoning a universal notion of time. If people agreed on scientific laws, they would not agree on their space-time coordinates. Experiments have confirmed this.

The constancy of the laws of nature was the bedrock of relativity theory and implied that only relative motion matters. Many were convinced, but not all. Einstein simply did away with the key nineteenth century ideas of absolute rest and absolute time. Many found this unsettling. Did that mean everything was relative? The worries continued for decades, and the Nobel Prize, which Einstein received in 1921, did not mention relativity—it was still too controversial. However, the theory is not totally accepted and has proven through many experiments.

Relativity shows that the speed of light will appear constant to all and that nothing could go faster. Thus, if one employs energy to accelerate—applying to anything at all—the mass of the object increases, making it harder to accelerate. Going the speed of light would require infinite energy. And so mass and energy are equivalent, or E = mc2. The equation showed that if a uranium nucleus could be split, a huge amount of energy could be released.

When World War II came, Einstein was convinced by others to encourage President Roosevelt to begin the United States' nuclear research. The Manhattan Project follows and produced Fat Man and Little Boy, which were dropped on Hiroshima and Nagasaki in 1945. Some blamed A-Bombs on Einstein, but Einstein had no part in the Project and was horrified by their use.

By 1909, Einstein was famous and eventually accepted a position at the Prussian Academy of Science where he didn't have to teach; in 1914, he moved to Berlin with his family, though his marriage fell apart and his family went back to Zurich. Einstein later married his cousin Elsa.

Relativity contradicted Newton's law of gravity, which implied that one could send a signal faster than light, but this required a notion of absolute time and was replaced by personal time. Einstein understood this and started to worry about it in 1911, particularly about how it affected gravity. It turned out that the effects of gravity were relative as well, since one could see gravity as causing one object to draw another toward it or the latter object to accelerate toward the first. The equivalence would work so long as spacetime were curved, not flat. Mass and energy could therefore shape spacetime.

A theory of curved spaces produced by Georg Reimann aided Einstein and his friend Marcel Grossman to build his theory, though Reimann believed only space was curved. In 1913, Einstein and Grossman wrote a paper that argued gravity could be analyzed as curved spacetime. However, one of Einstein's mathematical errors prevented them from formulating the appropriate equations. Einstein found the right equations in 1915, talking to mathematician David Hilbert about it. The name for the new theory was general relativity, the earlier theory special relativity.

In 1919, the theory was spectacularly confirmed. Spacetime was changed forever from a passive feature of the universe to a dynamic one. Though, Einstein's equations show no solution that could generate a static universe that did not change in time. To solve the problem, Einstein added a cosmological constant to the equation; this constant, which was later dropped, prevented Einstein from arguing that the universe was expanding or contracted; it later turned out that the universe is expanding. However, while Einstein considered the cosmological constant an error, he may have been right.

If galaxies are not far apart, they must have once been closer together, showing that fifteen billion years ago a "Big Bang" had occurred, though Einstein never took the idea seriously. Stephen Hawking and Roger Penrose were later able to show that general relativity implied the Big Bang. Einstein also resisted admitted that general relativity implied that the universe would come to an end when all stars died. Penrose and Hawking showed that time would end in a black hole; the theory of general relativity could not be defined inside of them.

General relativity broke down at the Big Bang because it was incompatible with quantum theory, the twentieth century's other complete conceptual revolution. Max Planck had unleashed the theory in 1900, when he postulated that radiation could be understand as the movement of discrete energy packets known as quanta. Einstein showed that quantum mechanics could explain the photoelectric effect and this demonstration was why Einstein won the Nobel.

Einstein worked on quantum theory until the 1920s, but Werner Heisenberg, Paul Dirac and Erwin Schrodinger's work generated a new picture of reality, known as quantum mechanics. Tiny particles no longer had definite positions. In contrast, there was an inverse relationship between fixing the position of a particle and its speed. Einstein thought this made the universe random, and said famously, "God does not play dice." But most scientists accepted the theory because of its extraordinary explanations.

The world has changed more in the twentieth century than any other. Technology made most of it possible and Einstein, more than almost any other, allowed this to happen.

Chapter 2, The Shape of Time

Chapter 2, The Shape of Time Summary and Analysis

Hawking believes that any good scientific theory should be rooted in the philosophy of science advanced by Karl Popper. On his view, mathematical models describe and unify observation and can make predictions and be falsifiable. If positivism is true, we cannot say what time it is; we can only describe what makes good predictions. Newton's model suggested that time and space were not affected by events around them; philosopher Immanuel Kant worried that this implied time was infinite; but then why would the universe be created now rather than at some other point?

This was only a problem for Newton, not Einstein. General relativity combined time with space to form four-dimensional spacetime. Objects in spacetime attempt to move in straight lines, but because of the curvature of spacetime, paths appear bent as if moved by a field. Further, one can't curve space without curving time; time has a shape. For Einstein, time and space are defined only by measurements in the universe. Accordingly, one cannot not sensibly ask what occurred before the universe was created.

However, in 1963, two Russian scientists, Lifshitz and Khalatnikov believed they could interpret General Relativity such that time had an infinite past and infinite future. But Penrose and Hawking were unconvinced. For them, spacetime is curved not just by massive objects but by the energy in it. Since energy is always positive, spacetime must be curved on the whole. It looks like Penrose and Hawking were right, since their theory predicted that as we peered further back into the universe's history by looking further into the night sky, we would find greater mass density. And this is what occurred. Further, the background radiation of the universe suggested a similar conclusion. Time has no independent meaning from the universe.

Reactions to Hawking and Penrose's work varied but it delighted religious leaders. Most physicists still dislike the idea. But to know the true answer to the question, general relativity and quantum mechanics must be integrated into a theory of quantum gravity. No one knows how to do this and it is the subject of most of the rest of the book.

While Dirac's initial discoveries in quantum mechanics made sense in a world of just atoms, it was difficult to reconcile with Maxwell's unification of magnetism, energy, and electricity. It turned out that while it is intuitive to think that the "ground state" or stationary state of an object would have zero energy, it does not. These are called "zero point fluctuations." In the 1940s, physicists Richard Feynman, Julian Schwinger and Shin'ichiro Tomonaga found a way to generate these zero point fluctuations rather than accept infinite energy hypotheses that seemed absurd.

But ground state fluctuations had serious effects on a quantum theory of gravity. It seemed to imply that an infinite number of wavelengths were possible in any region of spacetime and an infinite amount of ground state energy. If this were true, infinite energy should have collapsed the universe. However, Einstein's cosmological constant might solve the problem.

But a new sort of symmetry was discovered in the 1970s that revealed a natural physical mechanism to unravel these infinities. It is known as supersymmetry and implies that spacetime has dimensions beyond what we experience. They are measured by "Grassmann" variables rather than the real numbers we all know. A number of theories of "supergravity" came out of this view, which implied that supersymmetric field particles should have "superpartners." Supersymmetry also implied that particles had an odd property known as spin.

Fashioned changed, however. While infinities couldn't be detected in supersymmetry theories, they could not be ruled out. Many started to believe this indicated a flaw in these theories. And so a "supersymmetric string theory" was developed. Ripples on these strings are interpreted as particles. People thought superstrings were the foundation of a TOE, or Theory of Everything. For several years, strings reigned supreme. It yielded a set of five possible theories, but they all had problems. After 1985, strings were regarded as insufficient.

Strings came to be thought of as a simple version of what came to be called "p-branes." P-branes have directional lengths and a p = 1 brane is a string, while a p = 2 brane is a surface and so on. P = 1 branes were no longer seen as the best interpretation. Instead, p-branes could make sense of supersymmetry at 10 or 11 dimensions, where 6 or 7 are rolled up infinitely small.

Hawking resists believing in extra dimensions. He worries that they cannot be made sense of, though we may observe them in the Large Hadron Collider to be built in the future. One reason Hawking and others take multiple dimensions seriously is that a web of unexpected relationships is produced between the various string models which show that they are basically equivalent, generating a theory known as M-theory. It also implies that we cannot say whether supergravity or superstrings is more fundamental but are distinct expressions of the same theory. And string theories lack infinities.

Quantum theory can represent the shaping of space and time if imaginary time exists, which is a valid mathematical concept that Hawking goes on to explain. Models based on imaginary time makes good predictions. Imaginary time behaves like a four spatial dimension because it is at "right angles" to regular time. Hawking then goes onto explain the notion of imaginary time in more detail. It also shows that black holes will decay, a theory Hawking discovered in 1974. Thus, quantum gravity should also make sense of thermodynamics.

Quantum gravity also suggests that it may manifest itself in terms of holograms, which generate three-dimensional images out of two dimensional information. This may mean that we can make sense of what is going on in black holes. It will also suggest that we live on a 3-brane, a four-dimensional surface that bounds a five-dimensional region, with the extra dimension curled up. But the state of the world is a four-dimensional "hologram" that encodes the five-dimensional information of the other part of the universe.

Chapter 3, The Universe in a Nutshell

Chapter 3, The Universe in a Nutshell Summary and Analysis

Hawking believes that we should try to understand the universe, particularly given how much progress we have made. There are billions and billions of galaxies with uncounted billions of stars, many of which have planets. They are distributed roughly uniformly through space. However, the universe is certainly changing in time. For evidence, it is important that the sky is dark because it shows that light hasn't reached every point in the universe.

But why did the stars light up? The story begins with Edward Hubble, who found that collections of stars are sometimes "red-shifted" and "blue-shifted," meaning that the light they emit is either shifted towards the red end of the light spectrum or the blue end. It was later discovered that this meant stars were either moving further away from us (red) or closer (blue). Almost all stars are red shifted and the farther they are, the faster they are moving. The universe is expanding; this was on of the twentieth century's great discoveries.

Penrose and Hawking have shown that General Relativity proves that the universe started with a tremendous explosion, around fifteen billion years ago. The chain of events had a beginning and we should try to understand it in terms of scientific laws. Despite knowing that there was a beginning, we know little about it because General Relativity breaks down, but this is because it didn't incorporate Heisenberg uncertainty. When the universe is very small, quantum effects are everywhere. And so the universe, given quantum mechanics, may not have a single history and may have every possible history. This is now accepted as scientific fact.

Einstein's General Relativity can be combined with multiple histories, or at least physicists are moving in that direction now. We need boundary conditions that describe what happens on the edges of the universe. You cannot go beyond the universe, so what happens when you reach it? Hawking and Hartle thought that the universe may have no boundary, that is, the universe's real-time history determines its imaginary time history and vice verse. And so the universe doesn't have to end or begin in imaginary time. Imaginary time surfaces might be closed surfaces like the Earth's surface. No one falls of the Earth.

The no boundary condition may imply that the universe is self-contained and would not need anything outside of it to wind it up. This is what many scientists believe. The rolls of the dice and multiple histories are enough. We cannot coherently ask why the universe is the way it is because it is the way it is because we exist. If the universe has multiple histories, then we are simply in whatever universe we are in, and there is no ultimate explanation of why we are in this one rather than another. The question is similar to asking why we don't live in a different-dimensioned universe. There couldn't be a universe otherwise.

It is also thought that in our universe, matter is expanding at an accelerating rate, which Hawking thinks is beneficial because energy is converted into matter from gravitational fields. Inflation may be a law of nature. However, initially the universe expanded incredibly rapidly and slowed down.

Hawking next returns to discuss the future behavior of the probably histories of the universe that contain the possibility of intelligent beings. The answer depends on the amount of matter in the universe. If the amount of matter is high enough, the universe will eventually contract, but if it is low enough, the universe will expand forever. Something called "vacuum energy", whose force is inverse to mass, will also have effects and is like Einstein's cosmological constant.

In some, the behavior of the vast universe can be seen as a history in imaginary time, which is a little sphere, like Hamlet's nutshell.

Chapter 4, Predicting the Future

Chapter 4, Predicting the Future Summary and Analysis

Hawking begins chapter four by discussing the previous view of physicists that the universe was deterministic, meaning that any one state of the world plus the laws of nature would entail every future state. It looks like determinism is threatened by Heisenberg uncertainty. The problem is that uncertainty prevents us from even testing whether determinism is true. We can't get the data so we can't get an answer. Garbage in, garbage out.

Quantum mechanics partially restores determinism because we can accurately predict about half of what we could with full determinism. Particles don't have well-defined positions or velocities, but their states can be represented with wave functions, numbers at each point of space that list the probability that a particle can be found in that position. The Schrodinger equation specifies the rate at which the wave function changes with time, in the past or the future. We can only predict wave functions.

However, the Schrodinger equations assume that time runs smoothly everywhere, forever. But absolute time was overthrown over one hundred years ago. In fact, time may not go on forever for every observer due to black holes. Black holes have an escape philosophy that cannot even be breached by light. It looks impossible to escape it. Once very few people believed in black holes, including Einstein, but Hawking not only believes in them but thinks that they radiate energy in a certain sense. Black holes appear to have singularities, centers that are infinitely small and infinitely dense. Hawking then explains how black holes can be detected; basically, one must look for matter that orbits around a seemingly invisible object.

Black holes absorb energy and appear to keep it forever, and so information in the universe is actually lost. This is what physicist John Wheeler meant when he said "a black hole has no hair." But Hawking discovered that black holes aren't completely black. Singularities can't be infinitely small and dense or uncertainty would be violated - speed and velocity could be determined. Hawking then explains that black holes can absorb particle pairs, sucking in one and releasing the other, which would release radiation and thus information; therefore, thermal radiation can escape a black hole. However, black hole radiation has never been observed.

If black hole radiation occurs, energy will escape the black hole over time, which means its temperature will rise and its radiation rate will increase. Thus, black holes will shrink. Physicists don't know how to make sense of this, but it looks like they disappear altogether. Then the information is released in full, although it probably emerges continuously with the radiation rather than escaping all at once in the end. But, some information may well get lost, depending on the answer. If information is lost, anything could have happened in the past. We can't infer anything because we don't have all the data. We also cannot predict which of the particle pairs will be released when the other goes in the black hole, so the information we get may be random.

Some physicists resisted the idea that information was lost. Strominger and Vafa postulated in 1996 that black holes are composed of p-branes. When particles hit them, extra, multi-dimensional branes are produced. Branes can therefore absorb and emit particles much like black holes. In this way, p-branes can predict the rates of emission that the virtual-particle pair indicates, though the p-brane model shows that information will be captured in the p-brane waves' wave functions. If this theory is true, the Schrodinger equation will be able to determine the wave function for information and particles released from black holes at a later time. Half-determinism will be preserved.

Whether the view is true is one of the important questions in contemporary theoretical physics.

Chapter 5, Protecting the Past

Chapter 5, Protecting the Past Summary and Analysis

Hawking thinks it is hard to speculate on time travel. All discussions begin with General Relativity. Time travel might be possible with wormholes, tubes of spacetime that connect different regions of space and time. Wormholes could break the light barrier because no thing would go faster than light, though moving along spacetime would appear that way from some perspectives. However, time travel generates the grandfather paradox: what if you went back and killed your grandfather before he was conceived.

Avoiding philosophy, the main question is whether the laws of physics allow spacetime to warp to such a degree to allow a spaceship to return to its own past. There are three types of answers to the question. General Relativity seems to rule it out. On "semiclassical" theory, matter behaves according to quantum theory, but spacetime would be well-defined and classical. This picture is well-defined and helps us move forward. We would start in regions of spacetime that are ordinary.

Cosmic strings, not to be confused with string theory, are objects with length but tiny cross sections. The spacetime outline of such a string is flat. Cosmic strings allow spacetime to be curved around it, avoiding time loops and preventing travel to the past, but if a second string moves relative to the first, then moving backward in time is possible. This case is consistent with the physics we know. But the warping will produce time loops in infinite directions in space and backward in time.

This would be a bizarre universe and we have no evidence of it. But could some advanced civilization build a time machine? First, they would have to be able to surpass a time travel "horizon," the separate time loops from regions that lack them. These are a bit like black hole horizons. Penrose and Hawking's machinery for studying singularities and black holes can be employed to analyze such a case. Hawking thinks he can prove that spacetime paths might have finite duration but allow going faster than light, accelerating a person within such a past faster and faster until they exceed the boundary condition.

Much of the possibility of time travel depends on finding local spaces of negative energy, which is impossible on standard quantum mechanics. However, on semiclassical theory, Hawking thinks that one can "move" positive vacuum energy such that a local area has negative energy but the energy of the larger area is still possible. If possible, time travel is possible. So an advanced civilization might be able to created an energy density finite on a time boundary by taking the virtual particles in a closed loop out of the system. But such a system might not be stable.

Hawking thinks that we must consider whether time travel is possible at least in order to figure out that it is impossible. Getting the answer will teach us a lot about the universe.

To answer the question, we have to consider quantum fluctuations of matter fields and spacetime. But we don't have a quantum gravity theory yet, so the answer is hard to give.

With Feynman's multiple history idea, we will find that histories have curved spacetime that contain matter fields. Some spacetimes will be warped enough to go back to the past. It may occur on a microscopic scale and we not notice it. Time travel would go back in time in incredibly small intervals. However, there is even some arbitrariness in the definition of this idea, such that rendering it sensible is difficult.

So, Hawking thinks that quantum theory probably permits time travel, but on an incredibly small scale. Sci-fi writers won't have much use for this. This begs the question of whether macroscopic time loops can exist.

Hawking then gives a complex explanation of how it might be possible by considering a hypothetical rotating Einstein universe that would generate a high enough probability of a macroscopic time loop to eventually produce one. The Einstein universe only produces space loops, but Hawking points out that the math is equivalent to the math needed for time travel, so it also shows the possibility of time travel. However, the probability of producing a black hole might go to zero when we approach the degree of warp time loops require.

Hawking calls this the Chronology Protection Conjecture, which holds that the laws of physics work together to bar macroscopic time travel. The probabilities of such travel are extremely small. The probability that you could go back and kill your grandfather is less than one in ten with a trillion trillion trillion trillion trillion zeroes after it.

Chapter 6, Our Future?, Star Trek or Not?

Chapter 6, Our Future?, Star Trek or Not? Summary and Analysis

Hawking wonders if humanity will ever reach a final state of science and technology. For nearly all of history, humanity has moved forward but at an ever increasing rate. Population, technological development, electricity consumption and the number of scientific articles are increasing exponentially, all doubling every forty years or less. But these patterns cannot continue forever, so what can we expect? We might wipe ourselves out, but Hawking is an optimist.

We might discover a final theory in the not-too-distant future. It will determine what is possible, such as Star Trek style warp drive. Right now, it looks like exploring the galaxy will be slow and tedious. And yet, we don't yet know how we can make use of the laws of physics as we know them, so many possibilities lie open. One set of possible changes lies in DNA, though biological evolution on its own is random. Once DNA contained all the information about us that there was, but once language became possible, this was changed forever. While two hundred thousand books a year are published and most of them are garbage, even if one bit in a million is useful, the increase in information is one hundred thousand times faster than evolution.

This means that in the absence of natural or man-made disaster, improving human genetics lies in the future. Genetic engineering will create great problems for unimproved humans, but it is going to happen. But "the human race needs to improve its mental and physical qualities to deal with an increasingly complex world." Computers are also doubling their computational power every eighteen months. If continued, the possibilities are endless and they may develop the level of complexity of the human brain. Right now, the size of biological brains is limited by the womb, but if children can gestate outside of the womb, it is not clear how large they can become.

However, as brains increase in size, computation may become more complex but it will be slower. Thus, we will trade off quick-wittedness for intelligence. Electronic circuits have the same complexity-versus-speed trade-off. But the speed of light is a practical limit on the design of faster computers. Computers might also come to have parallel processing, like human brains.

If we do not destroy ourselves, we will probably spread to other planets in the solar system and nearby stars. We may find extraterrestrials, but they are almost certainly not at a technological level similar to ours. They will either be far more primitive or far more advanced, given the probability that they evolved at some point in the past or after we did. But if they were advanced, why haven't they spread across the galaxy?

Hawking believes that humanity will be on its own but with increasingly fast biological and electronic development. The differences between humanity in a millennium and Star Trek will be fundamental.

Chapter 7, Brane New World

Chapter 7, Brane New World Summary and Analysis

Today, the Theory of Everything, or M-Theory, has no single formulation as far as we know. What we have appears to be only an approximation of what there is. The true story may be utterly different than we think, just as Einstein was utterly different from Newton. Our current scientific theories continue to penetrate to small and smaller distances, and if this trend continues, science will discover new levels of particles, just as we discoverer quarks. But there is a limit to this series.

The smallest length in physics is the Planck length. Examining smaller distances requires more energy than exists in black holes. We are not sure what the Planck length is, given M-theory, but it may be as small as a millimeter divided by a hundred thousand billion billion billion. Yet mathematical models may help us. They have shown that the universe may in fact be composed of more than four dimensions. We may be able to probe the others with extremely high energy particles.

If the other dimensions are large enough—and while most think they are very small, some think they might be very large or infinite—then it should be able to be mapped. The next generation of particle accelerators may be able to probe them. And so we might live in a "brane world." Matter and nongravitational forces like electromagnetism will be limited to the brane, but gravity might permeate all of spacetime even at higher dimensions. And it might then fall off faster with distance than we think.

The fall off will not occur in our own brane because we would have observed it already, but it may occur in the other dimensions if they end on another brane not far away from our own. Now for distances smaller than the separation of brane, gravity should vary more, and they may be separated by less than a few millimeters. A shadow brane may exist nearby and we could feel its gravitational influence. There is more matter than we observe in the universe; maybe it is in a nearby brane.

Missing matter might come from exotic particles known as WIMPs—weakly interacting massive particles—or axions—light elementary particles—but it could be in a shadow world as well with shadow humans. Another possibility is that the branes are infinitely but highly curved like a saddle. Curvature of this sort would behave like a second brane, and this shape could explain odd planetary orbits. If branes go on forever, gravitational energy may be being siphoned off of our universe.

Such loss of energy could explain why we don't see the gamma radiation that is supposed to come from evaporating black holes. This radiation from brane-world black holes comes about through the quantum fluctuations of brane particles. These branes may flicker in and out of being as a result. Heisenberg uncertainty predicts in this case that brane worlds could appear as bubbles with branes forming on their surface, producing higher-dimensional space. If a brane was small, it would collapse in on itself, but if it reached a critical size, it would stay in existence and appear to those living in it like the universe was expanding.

The no boundary proposal suggests that spontaneously created brane worlds will have histories like nutshells. They would be four-dimensional spheres with two more dimensions. These nutshells will not be hollow, but will contain curled up dimensions. The brane history in imaginary time would generate its real history and may expand—in real time—in an inflationary fashion. A smooth, round nutshell is the most probable shape of such a world.

Imaginary time histories without perfect smoothness and roundness may have real time behavior that expanded in an inflationary way and then slowed down. In these worlds, like could have developed. Only the "slightly hairy" nutshells would have intelligence. Once these branes expanded, higher-dimensional space in the brane would increase. And an enormous bubble would surround the brane we live in.

But do humans live on a brane? Perhaps, and so we could be shadows branes cast from what goes on within the bubble. Yet which is reality? Hawking's positivist viewpoint suggests that the answer is arbitrary. Another question is what lies outside the brane. There may be nothing outside or the outside of a bubble may be glued to another one or the bubble might reach into space, not its mirror image. Branes might even collide, creating catastrophic explosions—the big bang might be one.

Hawking claims that brane worlds are hot research topics. While speculative, such models make predictions and could explain the weakness of gravity relative to other forces. The Planck length might therefore be very large. With sufficiently powerful particle accelerators, we might be able to probe it. If so, we may be able to figure out if we live on a brane.

Characters

Stephen Hawking

Of the important physicists in history, Stephen Hawking is among the most important alive. For thirty years Hawking taught mathematics and physics at Cambridge, holding the prestigious Lucasian Chair of Mathematics, which he shares with Isaac Newton. Hawking also has ALS, or a type of Lou Gehrig's disease, that progresses particularly slowly and has allowed him to live for decades despite being largely immobile and unable to speak.

Hawking's accomplishments in theoretical physics are quite important. Much of Hawking's work has concerned black holes, interstellar phenomena produced by incredible concentrations of gravity so powerful that they prevent light from escaping their event horizons. It is often thought that the center of a black hole contains a singularity, an infinitely dense and infinitely small concentration of matter and energy. Hawking is the world's foremost singularity theorist.

Hawking has also helped lay the foundation for the theory of quantum gravity that tries to integrate physics' most important theories, quantum mechanics and general relativity. He is widely known due to his popular science writing, among which is A Brief History of Time. The Universe in a Nutshell is his third popular physics work.

Hawking is the book's author but he also features as a character because his discoveries are relevant to the history of physics. He also displays a great deal of humor, favoring puns and some self-deprecating humor. Hawking often works in conjunction with his students, and so mentions papers he has written with them.

Albert Einstein

Albert Einstein is perhaps the most famous scientist in history to the minds of most of those living today. He was a theoretical physicist who made completely revolutionary contributions to physics, contributions that not only laid the groundwork for general relativity and quantum mechanics but that changed humanity's way of looking at the universe. Hawking discusses Einstein at the beginning of the first chapter and spends the rest of the chapter giving a history of Einstein's ideas because they raised the questions that physics has been trying to answer every since his early work.

Einstein argued that space and time were relative, meaning that there is no such thing as an absolute position in space and time. Instead, perspectives can be harmonized by holding the speed of light constant across them. This is the theory of special relativity. Einstein next added an analysis of gravity to special relativity generated the theory of general relativity which proved that space and time were a single fabric that could explain gravity in terms of its curvature. Finally, Einstein helped lay the groundwork for quantum mechanics by using mathematical models to explain the photoelectric effect.

It is these two theories, general relativity and quantum mechanics that rank as the two most successful scientific theories in the history of man. However, the two theories appear completely incompatible. Since Einstein's time, the problem of how to reconcile the theories has become increasingly acute, generating more and more complicated theories and models along with requiring entire fields of mathematics to be constructed in order to solve the problems the models and theories raise.

Roger Penrose

A mathematical physicist and close friend of Hawking's. The two men have co-authored a number of important papers about black holes.

Kip Thorne

An American theoretical physicist who has added a great deal to humanity's understanding of gravitational physics and astrophysics. He is a great friend of Stephen Hawking and the two often make bets on scientific phenomena and the truth of scientific theories.

Isaac Newton

The seventeenth and eighteenth century physicist and mathematician who not only discovered the classical laws of gravity but also invented calculus. His Principia is one of the most important books in the history of science and he ranks among history's greatest geniuses.

Hawking's Students

Hawking often co-authors papers with his students and mentions their work in the book.

Werner Heisenberg

A theoretical physicist who made foundational discovers in quantum mechanics. He is most famous for the Heisenberg Uncertainty Principle, which holds that there is an inverse relation between how finely one can calculate the velocity and position of a particle.

Richard Feynman

A famous American physicist who created a new formulation of quantum mechanics and the theory of quantum electrodynamics along with the physics of superfluidity. Hawking mentions him in various parts of the book.

God

The God of the Judeo-Christian tradition is rarely mentioned in the book but Hawking often mentions God figuratively as the creator of the laws of physics. He also believes that his no-boundary condition shows that God's existence is unnecessary.

Future Humans

Hawking often speculates on the nature of future humans which he believes will be increasingly intelligent as time goes on.

Aliens

Hawking thinks that aliens may exist but that they are either dramatically more primitive or dramatically more advanced than we are.

The Founders of Quantum Mechanics

Throughout the book, Hawking mentions the various founders of quantum mechanics and explains their scientific contributions.

Objects/Places

Cambridge

The English university where Hawking teaches.

Special Relativity

The theory of physics that holds that no absolute well-defined state of rest exists.

General Relativity

The theory that brings together special relativity and Newton's laws of gravity and understands gravity as a function of a single fabric of space and time known as spacetime.

Quantum Mechanics

The principles which describe reality at the smallest levels of nature. It has also had a revolutionary impact on how scientists understand reality.

Quantum Gravity

That part of theoretical physics which tries to combine quantum mechanics and general relativity into one theory.

P-Branes

A p-brane is a mathematical idea that is extended into space and that represents a precise number of dimensions. Superstrings are 1-branes, having only length, but 2-branes are membranes. These branes extend throughout spacetime.

The No-Boundary Condition

Hawking and Hartle has suggested that spacetime curves back in on itself and therefore has no boundary. Hawking suggests that this means the universe did not need to be created and so God becomes superfluous.

The Universe

The region of spacetime and the matter and energy it contains. Hawking believes that our universe has multiple histories and is probably a "holographic" shadow of a five-dimensional p-brane.

Time Travel

Hawking discusses time travel at length, arguing that it is possible given the laws of physics but is incomprehensibly improbable.

Star Trek

Star Trek is a famous science fiction television show which depicts the future. Hawking thinks the future will be very different from how Star Trek conceives of it.

Holograms

In the book, "holograms" are representations of information in smaller numbers of dimensions that represent larger numbers of dimensions. Hawking thinks the universe we know may be a hologram reflecting a five-dimensional p-brane.

Black Holes

General Relativity suggests that gravity can become so intense in a region of matter that a phenomenon known as a black hole is produced. The black hole is so powerful that end light cannot escape it. Hawking is perhaps the world's greatest black hole theorist and has suggested that black holes radiate particles.

Nutshell

A nutshell is a representation of a compact beginning state of a universe that Hawking uses as a conceptual focal point for the book.

Themes

The Theory of Quantum Gravity

The Universe in a Nutshell is a work of largely speculative science. Stephen Hawking first explains how the - in some sense - last major problem for physics was set up and how some propose to solve it. The problem is developing a theory of quantum gravity. The theory of quantum gravity would be a theory of everything. It would describe all physical phenomena at every level of nature. It would thus be a final theory, a theory that described the ultimate nature of the universe.

The problem is that the theory of quantum gravity must be generated out of two radically different but incredibly successful theories: the theory of general relativity and the theory of quantum mechanics. General relativity is Einstein's famous theory that gravity can be represented as the curvature of spacetime. Rather than being a passive part of the universe, space and time are active and dynamic. However, general relativity only accurately describes the universe at large levels of nature where gravitational forces are relatively powerful.

In contrast, the theory of quantum mechanics is an incredibly successful theory for making sense of phenomena at smaller levels of nature, specifically at the atomic and subatomic level of nature. Just as there are few phenomena described by general relativity as the quantum level, there are few phenomena described by quantum mechanics at astronomical level. These two theories have proven incredibly difficult to bring together and have been around in somewhat developed form for over seventy years. Hawking spends much of the book discussing a proposed reconciliation of the theories known as p-brane theory.

Truth is Stranger than Fiction

The Universe in a Nutshell is very much a "Wow" kind of book. It is full of shocking views and ideas that will seem weird and novel to the reader. First, many people find that the theories of special and general relativity are difficult to understand, particularly with their rejection of the commonsense notion of absolute space and absolute time and the merging of space and time, which seem rather different. Second, many people find quantum mechanics bizarre, particularly because quantum mechanics understands the fundamental elements of nature not as discrete particles but as probability fields that are, within limits, deeply indeterminate.

But the craziest ideas arise when Hawking explains to the reader how physicists are proposing to reconcile these two, already bizarre, theories. P-brane theory is full of new concepts and is, in fact, almost entirely composed of ideas that are so mathematically abstract that even Hawking has trouble explaining it. First, p-brane theory involves the existence of a 10 or 11 dimensional universe, something that is by definition incomprehensible to human minds. Second, p-brane theory tries to make sense of the idea that the universe has multiple histories, yet is one universe and has these histories simultaneously. Finally, p-brane theory suggests that all of this universe may simply be a "hologram" that is projected by a five-dimensional p-brane, an idea totally beyond our ken.

Hawking delights in explaining these ideas to the reader not only because they are scientifically plausible, but in fact because they are bizarre. The world is stranger than we could imagine without history's great physicists. Every once in awhile, some great physicist comes along and completely revolutionized physics and with it our conception of the world.

Science and Humanity

While much of Hawking's aim in writing The Universe in a Nutshell is to communicate new ideas in physics to other humans, humanity is also part of Hawking's subject matter. First, Hawking is interesting not only in philosophy of science but in a number of topics that concern how humans work and think about this. For instance, he is particularly impressed with how Einstein's theories of relativity revolutionized humanity's way of thinking about time and space, particularly when contrasted with the Newtonian idea. It made the notion of agent-relativity center stage and caused many to wonder if everything was relative.

But Hawking is particularly interested in how p-brane theory and related ideas will impact how humanity thinks about the universe and how technological progress that results from physics will change humanity and its future. For one thing, Hawking thinks that p-brane theory can show that the universe has no beginning or end in space or time and needs not have one. He tacitly suggests that this means that a role for God in the universe would be superfluous, that there would be no point in appealing to him as an explanation for where the universe came from.

Hawking also speculates that human genetic and computational complexity will increase with time. He treated genetic engineering as a certainty. No matter how hard we try to resist it, it will become a fact of life. He is most interested in how we will deal with it.

Style

Perspective

Stephen Hawking may be the most famous living scientist next to, perhaps, Richard Dawkins. Hawking is widely known not only as the genius physics professor in the wheelchair and that talks through a computer-generated voice program. He is also famous for his popular science writing, in particular, A Brief History of Time. Hawking is well-known within the physics community for his contribution to black hole theory and for helping to lay the groundwork for a theory of quantum gravity.

As someone so intelligent, theoretical and bound to the world of ideas of necessity, Hawking is surprisingly down to earth in the book. While he understands physics at an unparalleled level, he has a passion for communicating its ideas to the public. He also has wit and charm, often using puns and poking fun at himself. Hawking is rarely political and seems to have no particular ax to grind, save his philosophy of science and the theological implications of his no boundary condition.

First, Hawking is a positivist in the philosophy of science, meaning that the only meaningful scientific models are those that make predictions and that can be falsified. Models and theories do not describe reality but are simply attempts to explain physical phenomena. Second, Hawking thinks that space and time have no boundary, meaning that they have no beginning or end. Consequently, there is no need for a creator God.

All in all, however, Hawking seems to adhere to the "scientific world view", with all that exists in the world being describable by physics and a spirit of optimism about humanity's future so long as he slows down and reasons carefully. If so, the sky is the limit.

Tone

The tone of The Universe in a Nutshell is innocent, light-hearted, fanciful and often abstract. The book is littered with charts, illustrations, and small boxes illustrating famous scientific experiments or further explaining scientific concepts. The book thus also has a light feel because it is full of pictures, cute illustrations and often humorous images of aliens, contractual bets Hawking has with other physicists or even photos of Hawking in his wheelchair engaged in a hypothetical physics experiment, like falling into a black hole.

The book is innocent because of its optimism. While Hawking realizes that physicists have from time to time been co-opted by governments for their purposes, particularly with the theory of special relativity being used to create the atom bomb, he passes over these controversial issues silently. He worries little about the potential of science for harm and almost exclusively focuses on its potential for gain. He demonstrates no hesitance about genetic engineering, cloning and the like.

The book has a light-hearted tone as it is comprised of a variety of cute stories, jokes and amusing pictures. It is not that Hawking doesn't take his subject matter seriously—he is incredibly serious about his work, to be sure. But he thinks that science is wonderful and he also approaches the subject with a child-like sense of wonder and awe. A fanciful element is also included in the tone because Hawking is talking about deeply abstract matters and engaging in wild speculations about eleven-dimensional universes, the insides of black holes, multi-dimensional p-branes and the nature of alien species. Finally, for similar reasons, the tone often becomes abstract when Hawking is explaining the scientific details of a theory.

Structure

The Universe in a Nutshell is composed of seven short chapters. Hawking describes the first two chapters as the core or "trunk" of the book which lays out its major concepts, questions and answers. Chapter one, "A Brief History of Relativity," begins with a brief history of Einstein and moves to his two major breakthroughs that led to the development of the theory of special relativity and the theory of general relativity. Hawking also explains how Einstein was instrumental in the creation of quantum mechanics. The point of the chapter is to show how Einstein built the scaffold for the two most successful scientific theories in history.

Chapter two, "The Shape of Time," expands the explanation of Einstein's theory of general relativity, which combines special relativity with the mechanics of gravity. Einstein showed that space and time can be treated as a single substance that curves around matter and energy. Hawking also starts speculating about how general relativity might be merged with quantum mechanics to create a theory of quantum gravity.

Chapter three, "The Universe in a Nutshell," emphasizes how incompatible quantum mechanics and general relativity are. Any hope to combine the two theories requires postulating multiple simultaneous histories of the universe, each of which is shaped by a "tiny nut." Chapter four, "Predicting the Future," examines how the laws of physics might allow the prediction of the future and asks whether prediction is threatened by black holes. Chapter five, "Protecting the Past," asks the opposition question: do the laws of physics prevent the possibility of time travel? Hawking thinks that the laws don't forbid time travel but instead render it extremely and unimaginably improbable.

Chapter six, "Our Future? Star Trek or Not?," asks what the future of humanity might look like given current science and expected future discoveries with respect to human genetics and computing. Hawking thinks that discoveries will continue but the rate will increase and thus generate a future that is unimaginably different from our own. Chapter seven, "Brane New World," is the most complicated because it focuses primarily on the proposed theory of quantum gravity, p-brane theory. If the theory is true, it may show that our universe is a four-dimensional "holographic image" that is a projection of a five-dimensional p-brane.

Quotes

"This required abandoning the idea that there is a universal quantity called time that all clocks would measure." Chap. 1, p. 9

"Some people have blamed the atomic bomb on Einstein because he discovered the relationship between mass and energy; but that is like blaming Newton for causing airplanes to crash because he discovered gravity. Einstein himself took no part in the Manhattan Project and was horrified by the dropping of the bomb." Chap. 1, p. 13

"The reason general relativity broke down at the big band was that it was not compatible with quantum theory, the other great conceptual revolution of the early twentieth century." Chap. 1, p. 24

"God does not play dice." Chap. 1, p. 26

"If one takes the positivist position, as I do, one cannot say what time actually is. All one can do is describe what has been found to be a very good mathematical model for time and say what predictions it makes." Chap. 3, p. 31

"Thus time has a shape." Chap. 2, p. 35

"To understand the origin and fate of the universe, we need a quantum theory of gravity, and this will be the subject of most of this book." Chap. 2, p. 43

"The universe has multiple histories, each of which is determined by a tiny nut." Chap. 3, p. 67

"We must try to understand the beginning of the universe on the basis of science. It may be a task beyond our powers, but we should at least make the attempt." Chap. 3, p. 79

"If the histories of the universe in imaginary time are indeed closed surfaces ... it would have fundamental implications for philosophy and our picture of where we came from. The universe would be entirely self-contained; it wouldn't need anything outside to wind up the clockwork and set it going. ... This may sound presumptuous, but it is what I and many other scientists believe." Chap. 3, p. 85

"In this chapter we have seen how the behavior of the vast universe can be understood in terms of its history in imaginary time, which is a tiny, slightly flattened sphere. It is like Hamlet's nutshell, yet this nut encodes everything that happens in real time. So Hamlet was quite right. We could be bounded in a nutshell and still count ourselves kings of infinite space." Chap. 3, p. 99

"A black hole has no hair." Chap. 4, p. 118

"Even if it turns out that time travel is impossible, it is important that we understand why it is impossible." Chap. 5, p. 147

"I estimate the probability that Kip Thorne could go back and kill his grandfather as less then one in ten with a trillion trillion trillion trillion trillion zeroes after it." Chap. 5, p. 153

"The future of science won't be like the comforting picture painted in Star Trek: a universe populated by many humanoid races, with an advanced but essentially static science and technology. Instead, I think we will be on our own, but rapidly developing in biological and electronic complexity. Not much of this will happen in the next hundred years .... But by the end of the next millennium ... the difference from Star Trek will be fundamental." Chap. 6, p. 171

"Do we live on a brane or are we just holograms?" Chap. 7, p. 173

"Which is reality, brane or bubble? They are both mathematical models that describe the observations. One is free to use whichever model is most convenient." Chap. 7, p. 198

"O Brane new world; That has such creatures in't." Chap. 7, p. 200

"That is the universe in a nutshell." Chap. 7, p. 200

Topics for Discussion

Explain in brief, the theory of general relativity and why it shows (a) that space and time are unified and (b) that spacetime has a shape.

Explain in brief what the theory of quantum mechanics is and how Einstein laid its foundations.

What does Hawking mean when he says that the universe has multiple histories?

Does Hawking think that the laws of physics allow prediction the future? What might threaten such prediction? How might this threat be blocked?

Does Hawking think time travel is possible? How would it work? What is the probability of the possibility? Why?

What is Hawking's no-boundary condition? Hawking mentions it could have profound theological implications. What might they be?

What is the anthropic principle? How does Hawking use it in the book?

What is a "brane new world" and what does it suggest about our universe?

What does Hawking think the future will be like? How does it differ from Star Trek's vision of the future?